EFFECTS OF SUN-DRIED *Opuntia ficus-indica* CLADODES ON DIGESTIVE PROCESSES IN SHEEP

by

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Dedication

This degree and my dissertation are dedicated to my beloved husband, Horacio Jussub and our children; Sumaya and Yanick for their constant support, love, encouragement and prayers. Thank you (OBRIGADO).

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Declaration

I declare that the dissertation hereby submitted by me for the **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 for a degree at another university/faculty. I furthermore cede copyright of the dissertation in favour of the University of the Free State.

Carla Menezes

Bloemfontein

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List of Abbreviations

CO_2	carbon dioxide
ha	hectare
DM	dry matter
CP	crude protein
CF	crude fibre
NFE	nitrogen-free-extract
OM	organic matter
NPN	non-protein nitrogen
NDF	neutral-detergent fibre
ADF	acid-detergent fibre
Fat/lipid	lipid content
EE	ether extract
GE	gross energy
P	phosphorus
Ca	calcium
K	potassium
Mg	magnesium
N	nitrogen
O.	*Opuntia*
GIT	gastrointestinal tract
ad lib.	*ad libitum*
TLM	treatment lucerne hay and yellow maize meal
T0	treatment with 0% of sun-dried and coarsely ground *Opuntia* cladodes
T24	treatment with 24% of sun-dried and coarsely ground *Opuntia* cladodes
T36	treatment with 36% of sun-dried and coarsely ground *Opuntia* cladodes
var.	variety
MJ	megajoule
g	gram
kg	kilogram

Abstract

Effects of sun-dried *Opuntia ficus-indica* cladodes on digestive processes in sheep

by

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The effects of incremental inclusion levels (0, 24, and 36%) of sun-dried and coarsely ground *Opuntia* cladodes in balanced sheep diets on certain aspects of the digestive processes were investigated in sheep. The treatment diets (T0, T24 and T36) comprised respectively (air dry basis) 0, 240 and 360 g/kg sun-dried, coarsely ground *Opuntia*; 660, 410 and 285 g/kg coarsely ground lucerne hay; 300 g/kg yellow maize meal; 0, 10 and 15 g/kg feed grade urea; and 40 g/kg molasses meal. Eighteen seven month old Dorper wethers were randomly divided and allocated according to body weight into three groups of six animals each. The three groups were each fed one of the three treatment diets (T0, T24, or T36). The experimental animals were housed indoors in individual metabolism crates and fed *ad libitum* during the 7-day or 14-day trial periods. The feed and water intake, urine and faeces excretion, as well as the apparent digestibility of the diets and specific nutrients were evaluated and compared. At the end of the 7-day trial period a random selection of nine animals, three wethers from each treatment diet, were slaughtered. The other nine animals were slaughtered at the end of the 14-day trial period. The GIT (gastrointestinal tract) of each wether was carefully removed and dissected. Samples of digesta contents and also intestinal tissue from different sections of the GIT were collected and analyzed.

In general, incremental inclusion of *Opuntia* cladodes to a level of 36% in the diets for Dorper wethers resulted in small decreases of OM, CP and GE of the diets and a considerable drop in the ADF and NDF fractions of the feed. Although the EE content of diets was small, inclusion of sun-dried and coarsely ground *Opuntia* cladodes at these levels increased the lipid content. The results obtained in this present study concur with the general recommendation to add protein (including NPN) and energy sources to sheep diets with high inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes.

The inclusion of sun-dried and coarsely ground *Opuntia* cladodes at 24 and 36% levels as partial substitution of lucerne hay in diets of Dorper wethers had no adverse effects on feed intake during the 14-day period of the feeding trial. The feed intake of the Dorper wethers tended to increase with incremental inclusion levels of *Opuntia* cladodes in the diets, especially during the 14-day trial period. This suggested that incremental levels of sun-dried and coarsely ground *Opuntia* cladodes up to a level of 36% did not affect the acceptability of the diets for Dorper wethers negatively and may even improve the acceptability of the diets.

The voluntary daily water intake and urine excretion of the Dorper wethers increased with the incremental inclusion of sun-dried and coarsely ground *Opuntia* cladodes up to a level of 36% in the diet. Although these differences were negligible during the first 7-day trial period, the differences were more evident during the 14-day trial period. The Dorper wethers fed on a diet with 36% sun-dried and coarsely ground *Opuntia* cladodes drank on average about 1 100 ml/day more water and produced 237 ml urine/day, than those fed the control diet (T0) without *Opuntia* cladodes. This suggested that a substantial part of the induced higher water intake was secreted via another route, namely through the faeces. The faeces excreted by Dorper wethers fed on diets containing *Opuntia* cladodes were softer in consistency and contained visibly more water than those produced by animals fed on the control diet without *Opuntia* cladodes.

The daily nutrient intake of DM, CP, GE, and OM was not affected by the inclusion of *Opuntia* cladodes in the diet, but the intake of ADF and NDF tended to decrease with incremental levels of *Opuntia* cladodes and the concomitant reduction of lucerne hay in the diet. It is important to note the increases in apparent digestibility of the DM, CP, and lipids of the diet as the inclusion levels of *Opuntia* cladodes increase to a 36% inclusion level.

The chemical composition of the digesta collected from different parts of the GIT of Dorper wethers fed on the three experimental diets appears not have been changed by the inclusion of sun-dried and coarsely ground *Opuntia* cladodes up to a level of 36% of the diet. Most changes that were observed at the end of the first 7-day trial period of the study occurred in the reticulo-rumen, omasum and in the lower GIT (colon and rectum). The inclusion of *Opuntia* cladodes to a level of 36% in the diet had a positive increasing effect on CP while the ADF content of the digesta was reduced. Very little changes were noted in the digesta contents of the small intestine.

The histological results showed no visible pathologic alterations in the mucosa of the GIT of Dorper wethers when ingesting sun-dried and coarsely ground *Opuntia* cladodes to a level of 36% in diets for a period of 14 days. Therefore, the reasons and mechanism whereby wet faeces are produced when sheep is fed diets containing considerable amounts of sun-dried and coarsely ground *Opuntia* cladodes were not histological demonstrable.

Based on the results of this study, it is concluded that inclusion of sun-dried and coarsely ground *Opuntia* cladodes as partial substitution of lucerne in balanced sheep diets has no detrimental effects at a 36% inclusion level. No detrimental effects were observed in feed intake, apparent digestibility, and histological characteristics of the GIT mucosa of young Dorper wethers.

Further research is needed to establish the optimum inclusion level of sun-dried and coarsely ground *Opuntia* cladodes in the diet of different ruminant species. It is also important to further investigate the effects of *Opuntia* cladodes in ruminant diets on the digestive processes and especially also on the renal functions. The physiological and/or biochemical mechanisms (enteric secretion and/or absorptive alterations) responsible for the production of wet faeces in ruminants ingesting considerable amounts of *Opuntia* cladodes require further investigation.

Opsomming

Effects of sun-dried *Opuntia ficus-indica* cladodes on digestive processes in sheep

deur

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Die invloed van toenemende insluitingspeile (0, 24, en 36%) van songedroogde en grofgemaalde *Opuntia* kladodes in gebalanseerde skaapdiëte op sekere aspekte van die verteringsprosesse is by skape ondersoek. Die behandelingsdiëte (T0, T24, en T36) het onderskeidelik bestaan uit (lugdroë basis) 0, 240 en 360 g/kg songedroogde en grofgemaalde *Opuntia* kladodes; 660, 410 en 285 g/kg grofgemaalde lusernhooi; 300 g/kg geel mieliemeel; 0, 10 en 15 g/kg voergraad ureum; en 40 g/kg molassemeel. Agtien sewe maande oud Dorper hamels is ewekansig verdeel en volgens liggaamsmassa toegeken aan drie groepe van ses diere elk. Die drie groepe is elk een van die drie behandelingsdiëte (T0, T24, of T36) gevoer. Die proefdiere is binnenshuis in indiwiduele metabolismekratte gehuisves en *ad libitum* gevoer tydens die 7-dag of 14-dag proefperiodes. Die voer- en waterinname, urine en misuitskeiding asook die skynbare verteerbaarheid van die diëte en spesifieke voedingstowwe is evalueer en vergelyk. Aan die einde van die 7-dag proefperiode is 'n ewekansige groep van nege diere, drie per behandelingsdieet, geslag. Die ander nege diere is aan die einde van die 14-dag proefperiode geslag. Die dermkanaal van elke hamel is versigtig verwyder en gedissekteer. Monsters van die derminhoud, asook weefselsnitte uit die verskillende dele van die dermkanaal, is versamel en ontleed.

In die algemeen het toenemende insluitingspeile van *Opuntia* kladodes tot 'n peil van 36% in die dieet van Dorperhamels klein afnames in OM, RP en BE tot gevolg gehad en 'n aansienlike afname in die ADF en NDF fraksies van die voer. Alhoewel die EE inhoud van die diëte klein was, het insluiting van songedroogde en grofgemaalde *Opuntia* kladodes die inhoud van lipiede verhoog. Die resultate van die studie stem ooreen met die algemene aanbeveling dat proteïen- (insluitend NPN) en energiebronne toegevoeg moet word in skaapdiëte met groot insluitingspeile van songedroogde en grofgemaalde *Opuntia* kladodes.

Die insluiting van songedroogde en grofgemaalde *Opuntia* kladodes teen peile van 24% en 36% as gedeeltelike vervanging van lusernhooi in diëte van Dorperhamels het geen nadelige effek gehad op voerinname gedurende die 14-dag periode van die voedingsproef. Die voerinname van die Dorperhamels het geneig om toe te neem met toenemende insluitingspeile van *Opuntia* kladodes in die diëte, veral gedurende die 14-dag proefperiode. Toenemende peile van songedroogde en grofgemaalde *Opuntia* kladodes tot 36% het nie die aanvaarbaarheid van die diëte vir Dorperhamels negatief beïnvloed nie en mag dit selfs verbeter.

Die daaglikse waterinname en uitskeiding van uriene deur die Dorperhamels het gestyg met toenemende insluiting van songedroogde en grofgemaalde *Opuntia* kladodes tot 'n peil van 36% in die dieet. Alhoewel die verskille klein was gedurende die eerste 7-dag proefperiode, was die verskille meer opvallend gedurende die 14-dag proefperiode. Die Dorperhamels wat 'n dieet met 36% songedroogde en grofgemaalde *Opuntia* kladodes gevreet het, het sowat 1 100 ml/dag meer water gedrink maar slegs 237 ml urine/dag meer gelewer as die hamels wat die kontrole dieet (T0) sonder *Opuntia* kladodes gevreet het. Dit dui daarop dat 'n aansienlike deel van die geinduseerde groter waterinname deur 'n ander weg as die urine uitgeskei is, naamlik deur die mis. Die mis wat deur die Dorperhamels uitgeskei is op die diëte wat *Opuntia* kladodes bevat het, was papper en het sigbaar meer water bevat as die van hamels wat nie *Opuntia* kladodes ingeneem het nie.

Die daaglikse inname van DM, RP, BE, en OM is nie verander deur die insluiting van *Opuntia* kladodes in die dieet nie, maar die inname van ADF en NDF het geneig om te daal met toenemende insluitingspeile van *Opuntia* kladodes in ooreenstemming met die vermindering van lusernhooi in die dieet. Dit is belangrik om te let op die verbetering in skynbare verteerbaarheid van die DM, RP, en lipiede in die dieet met toenemende insluiting van *Opuntia* kladodes tot op 36%.

Die chemiese samestelling van die derminhoud wat uit verskillende dele van die dermkanaal van die Dorperhamels op die drie proefdiëte versamel is, is skynbaar nie deur die insluiting van songedroogde en grofgemaalde *Opuntia* kladodes tot 36% van die dieet verander nie. Meeste van die verskille wat waargeneem is aan die einde van die eerste 7-dag proefperiode het voorgekom in die retikulo-rumen, omasum en die laer dermkanaal (kolon en rektum). Die insluiting van *Opuntia* kladodes tot 'n vlak van 36% in die dieet het 'n positiewe verhogende effek op die RP gehad, terwyl die ADF van die derminhoud gedaal het. Geringe veranderinge is waargeneem in die derminhoud van die dunderm.

Die histologiese evaluering het geen waarneembare patologiese veranderinge getoon in die slymvlies van die dermkanaal van Dorperhamels wat songedroogde en grofgemaalde *Opuntia* kladodes tot 36% van die dieet oor 'n periode van 14 dae gevreet het. Derhalwe kon die redes en meganismes hoe nat mis deur skape gelewer word wanneer aansienlike hoeveelhede songedroogde en grofgemaalde *Opuntia* kladodes vreet, nie histologies demonstreer word nie.

Volgens die resultate van die studie is afgelei dat die insluiting van songedroogde en grofgemaalde *Opuntia* kladodes tot op 36% ter gedeeltelike vervanging van lusernhooi in gebalanseerde skaapdiëte nie nadelige effekte gelewer het nie. Geen nadelige effek is op voerinname, skynbare verteerbaarheid, en histologiese eienskappe van die slymvliese in die dermkanaal van jong Dorperhamels waargeneem nie.

Verdere navorsing word benodig om die optimum insluitingsvlak van songedroogde en grofgemaalde *Opuntia* kladodes in diëte van verskillende herkouerspesies vas te stel. Dit is ook belangrik om verder ondersoek in te stel na die invloed van *Opuntia* kladodes in herkouerdiëte op verteringsprosesse en veral ook die nierfunksies. Die fisiologiese en/of biochemiese meganismes (enteriese sekresie en/of verandering in absorpsie) wat verantwoordelik is vir die produksie van nat mis in herkouers wat aansienlike hoeveelhede *Opuntia* kladodes inneem, moet verdere aandag verdien.

1. Introduction

Seasonal feed shortages and frequent droughts, particularly during dry seasons, are major constraints to livestock production in the tropical and subtropical arid regions of the world. As a result, ruminant livestock grazing on natural pastures (veld) loose weight during these periods. Therefore, it is important to evaluate alternative animal feeds that are more adapted to arid conditions and use water more efficiently.

Cacti in general and *Opuntia* in particular are plants very tolerant to high temperatures and considered to be able to provide green forage in most seasons (Nobel, 1995). The *Opuntia* have adapted well to arid zones characterized by drought conditions, poor and erratic rainfall and poor soils subjected to erosion (Ben Salem *et al.*, 1996). *Opuntia* adapts well to a range of soils and climates (Zeeman & Terblanche, 1979; Ben Salem *et al.*, 1996; Batista *et al.*, 2003; Zeeman, 2005; De Waal *et al.*, 2006). Some species of *Opuntia* are naturalized weeds in countries such as Australia, South Africa and neighboring countries where more favorable environmental conditions prevail (Barbera, 1995).

The cladodes of spiny and spineless cactus pear (*Opuntia* species) are utilized to feed livestock during frequent periods of food shortages or droughts in arid and semi-arid regions (Felker, 1995; Ben Salem *et al.*, 2002a; Tegegne, 2002a,b; Batista *et al.*, 2003; De Waal *et al.*, 2006). These plants are particularly attractive as animal feed because of their high biomass yields, palatability, tolerance to salinity and high digestible energy content (Nobel, 1995). In addition *Opuntia* also serves as a source of water for livestock in dry regions (Ben Salem *et al.*, 1996).

Overgrazing can destroy the young plants and older plants yield much less material during the following season (Steenkamp, 1973). If spineless cactus pear plants are heavily grazed, they should only be utilized every second year (De Kock, 1965). Ruminants can graze spineless cactus pear plantations while supplementary feed is provided separately in feeding troughs (Felker, 1995). It is preferable to commence grazing or harvesting only once the plants are three years old (De Kock, 1965). Grazing or browsing should be restricted to the removal of only the two most recently produced cladodes when the plants are grazed for the first time. Probably the best system at this stage would be a "cut and carry" system. In successive grazing cycles it is advisable that only the present season's growth be grazed and then the animals should be removed (De Kock, 1965).

Moreover, cacti are multi-use range species and used mainly to provide forage for livestock and fruit for humans (Nefzaoui & Ben Salem, 2002). It has been a successful food supplement to dairy and beef cattle, goats and sheep, but not to horses (Felker, 1995). In recent years there has been increased interest in *Opuntia* species for the important role it plays in the success of sustainable agricultural systems in marginal areas (Barbera, 1995; Nobel, 1995). Moreover, *Opuntia* is particularly attractive as a feed because of its high efficiency in converting water into digestible energy (Nobel, 1995).

Most plants open their stomata during the day, hence they begin taking up CO_2 from the atmosphere and uses solar energy to incorporate carbon dioxide (CO_2) through the complex process of photosynthesis in carbohydrates. The opening of the stomata during day leads to a much greater water loss than for the stomata opening at night, when temperatures are lower and humidity is higher. *Opuntia ficus-indica* opens its stomata at night which is a reflection of its adaptation to economise on CO_2 uptake and water loss (Nobel, 1995). This is the key to water conservation by crassulacean acid metabolism (CAM) plants such as *Opuntia* (Nobel, 1995; Nefzaoui & Ben Salem, 2002).

Opuntia has been introduced in North Africa early in the 1900s to reduce water and wind erosion and rangeland degradation (Nefzaoui & Ben Salem, 2001). It is estimated that in low rainfall areas, some 700 000 ha of planted areas are preventing erosion and desertification and also provide feed for livestock during dry season (Nefzaoui & Ben Salem, 2001). In Tunisia, *Opuntia* provides a large amount of fodder for livestock and also plays a role in soil conservation (Nefzaoui & Ben Salem, 2001).

In South Africa, cladodes of spiny and spineless cactus pears have been used by livestock farmers as drought fodder since the 18^{th} century when first introduced to the country (Brush & Zimmermann, 1995; Van Sittert, 2002). According Brush and Zimmermann (1995) *Opuntia ficus-indica* have invaded about 900 000 ha of natural pastures, mostly in the Eastern Cape. There is evidence to suggest that originally (at least 250 years ago) only spineless *Opuntia ficus-indica* was introduced into South Africa and they reverted back to the spiny form over a period of nearly 200 years (Brush & Zimmermann, 1995). The spiny forms are considerably more aggressive than the original spineless form and are consequently better adapted to multiply (Brush & Zimmermann, 1995).

In general, *Opuntias* are considered to be high in water content [about 150 g dry matter (DM)/kg fresh material], high *in vitro* digestibility (about 750 g/kg DM), ash (about 200 g ash/kg DM), calcium (14 g Ca/kg DM), soluble carbohydrate and vitamin A, but low in fibre (about 86 g CF/kg DM), phosphorus (range from 1-3 g P/kg DM) and crude protein content varying from about 50 to 120 g protein/kg DM (Nobel, 1994; Felker, 1995; Ben Salem *et al.*, 1996; Nefzaoui & Ben Salem, 2001; Ben Salem *et al.*, 2002a; Batista *et al.*, 2003; Verás *et al.*, 2005). The fibre comprises mostly of lignin and cellulose (Felker, 1995; Verás *et al.*, 2005). Lopéz-Garcia *et al.* (2001) showed significant differences in the chemical analysis (Table 1.1) associated with variation in species, physiological factors, and climate. In terms of digestibility Lopéz-Garcia *et al.* (2001) stated that feed intake by animals are influenced by species, variety and season (Table 1.2), cladode age and their relationship (Revuelta, 1963; Flores & Aguirre, 1992).

Table 1.1 Nutritional value (%) of *Opuntia* species on a DM basis (adapted from Lopéz-Garcia *et al.*, 2001)

Species	DM	OM	CP	Fat	Fibre	Ash	NFE
				%			
Nopalea spp.	10.69	73.79	8.92	1.51	17.21	26.21	50.7
O. lucens	17.45	69.59	3.67	0.57	5.58	30.43	62.75
O. robusta	10.38	81.41	4.43	1.73	17.63	18.59	57.61
O. duranguensi	10.34	82.94	4.51	1.29	8.23	17.06	68.91
O. ficus-indica cv. *Amarillo oro*	11.29	86.93	3.81	1.38	7.62	13.07	74.13
O. ficus-indica	13.36	81.55	3.66	1.76	9.18	18.45	69.95
O. imbricata	10.41		5.01	1.81	7.81	17.30	68.11

Key: DM= dry matter; OM= organic matter; CP= crude protein and NFE = nitrogen-free extractives

In Mexico, the consumption of fresh *Opuntia* cladodes for cattle has been estimated at 15 to 40 kg per cow/day (Lopéz-Garcia *et al.*, 2001). However, under drier conditions, if plant yield is abundant, the consumption was as high as 90 kg per cow/day. In the case of sheep and goats, consumption ranges from 3 to 9 kg per day, which may be less if other sources of food are also available (Lopéz-Garcia *et al.*, 2001).

Table 1.2 Variability in nutrient digestibility of spineless *Opuntia* (adapted from Lopéz-Garcia *et al.*, 2001)

Season	CP	Fat	NFE	Cellulose
Winter-Spring	0.2 – 0.3	0.08 – 0.12	3.0 - 5.5	0.4 – 1.0
Summer-Autumn	0.3 – 0.4	0.15 – 0.16	6.5 – 11.0	0.8 – 2.0

Key: CP= crude protein and NFE = nitrogen-free extractives

There is very limited information available in the literature regarding *in vitro* or *in vivo* digestibility and the metabolizable energy content of *Opuntia* cladodes to formulate animal diets. However, the *in vitro* digestibility of *Opuntia* is considered to be relatively high (about 750 g/kg DM; Felker, 1995). Retamal *et al.* (1987) concluded that the *Opuntia ficus-indica* has small variation in energy content.

The nutrient deficiencies or shortcomings of *Opuntia* can be rectified easily by appropriate supplementation. Nefzaoui and Ben Salem (2001) and Ben Salem *et al.* (2002 a,b) stated that the low crude protein (CP) content of *Opuntia* increases after applying nitrogen fertilizer. Considering the relative low levels of protein and fibre of *Opuntia*, chicken litter is considered a good CP as well as fibre source (Magalhães *et al.*, 2004). But, chicken litter contains mainly non-protein nitrogen (NPN) in the form of uric acid and may require supplementation with a true protein source such as cotton seed cake (Magalhães *et al.*, 2004).

Ruminants consume more of diets with higher protein content. Therefore, the low protein content may limit the ingestion of spineless cactus pear, resulting in a low intake of energy. Because of this, some form of protein supplementation is necessary for sheep to utilise the spineless cactus pear more efficiently (Steenkamp, 1973). Terblanche (1970) stated that lucerne is a good and economical way to supplement the low protein content of the spineless cactus pear cladodes.

About 30% lucerne meal or 6.5% fishmeal can be mixed with ground spineless cactus pear cladodes to constitute a good maintenance diet (Steenkamp & Hayward, 1981). The results of trials where spineless cactus pear cladodes have been supplemented only with NPN as a nitrogen source were unsatisfactory (Steenkamp & Hayward, 1981). Viana *et al.* (1966) compared *Opuntia* to maize silage for fattening steers; both were mixed with cassava roots, commercial concentrate, bone meal, and mineral salts and reported similar live weight gains during a period of 287 days.

Santos and Albuquerque (2001) compared three different varieties of *Opuntia* (*miúda, redonda and gigante*) on dairy production and DM production and concluded that *Opuntia* var. *miúda* was better ($P<0.05$) for dairy production. Moreover, the DM content of *Opuntia* var. *miúda* was higher than *Opuntia* var. *redonda* and var. *gigante* ($P<0.05$). In contrast, the protein, fibre, and mineral contents were lower than for the other two varieties. Moreover, Santana *et al.* (1972) fed lactating Holstein cows with maize silage compared to *Opuntia var. gigante* and found no differences between treatment for milk fat and milk production.

Mature sheep need about two weeks to adapt to a diet of fresh, chopped spineless cactus pear cladodes. Once they have adapted, sheep will consume about 2.3 to 6.8 kg chopped fresh material every day but the intake will only provide about 80% of their energy requirements, about 32% of the P requirements and 36% of the protein needs, while the total Ca requirement will be provided (Terblanche, 1970).

Wanderley *et al.* (2002) evaluated the performance of lactating Holstein cows fed a diet with different levels (0, 12, 24 and 36%) of *Opuntia ficus-indica* substituting sorghum silage and concluded the sodium intake, milk production and fat corrected milk were not affected by forage cactus levels.

Nefzaoui and Ben Salem (2001, 2002) summarized a typical feed calendar for agro pastoral systems of the arid and semi-arid zones of the Western Asia and North African region. They showed that *Opuntia* was not a balanced feed, but it was considered a cheap source of energy and supplemental protein improved the nutritive value of cactus-based diets fed to lambs and increased their daily body weight gain. There was a further improvement when the level of by-pass protein in the diet was increased (Ben Salem *et al.*, 2002 a,b).

The best way to feed *Opuntia ficus-indica* to ruminants is by chopping it into small blocks of about 20 to 30 mm (De Kock, 1965, 1980, 2001; Steenkamp & Hayward, 1981). Cutting the cladodes into strips of 20 to 30 mm is another cheap option of processing (Steenkamp, 1973).

A method that requires little labour and is also quick to apply is the use of a portable shredder in the orchard. The slashed or shredded cladodes can be left between the rows in the orchard where sheep will pick it up. Nevertheless, this method causes waste and, therefore, it is recommended that the slashed or shredded material should rather be fed in troughs (Steenkamp, 1973; Steenkamp & Hayward, 1981).

Chopped spineless cactus pear cladodes can be dried on clean and hard surfaces. A cement surface is probably the most ideal surface to dry (Terblanche *et al.*, 1971; Steenkamp, 1973; Steenkamp & Hayward, 1981). Chopped spineless cactus pear cladodes should be spread on the surface and regularly turned over, if at all possible on a daily basis with a hay or garden fork (Zeeman, 2005). After being dried it should be ground to pass through a 6 mm sieve (Steenkamp, 1973). It is not only utilised better, but it is also stored more easily in bags once it is in the ground form and to be utilized during drought periods (Steenkamp, 1973; Steenkamp & Hayward, 1981).

A rapid rate of digestion leads to a faster passage of the material through the digestive tract, which increases feed intake. Because of the low gut fill of cladodes, an increase of cactus in the diet does not reduce the intake of other components of the ration (Nefzaoui & Ben Salem, 2002). Tegegne *et al.* (2005) studied the effects of including *Opuntia* to substitute partly wheat bran and showed the inclusion of *Opuntia* increased total feed intake of sheep and also that *Opuntia* could substitute wheat bran.

Nevertheless, spineless cactus pears have their limitations. It is not a balanced diet and should only be seen as a reasonably good and cheap energy source (Steenkamp, 1973; Nefzaoui & Ben Salem, 2000). Moreover, when feeding large amounts of spineless cactus pear cladodes to ruminants, a particular concern is the laxative effect (De Kock, 2001; Nefzaoui & Ben Salem, 2001; Ben Salem *et al.*, 2002a). In this regard, Nobel (1994) stated that the relatively high potassium (K), magnesium (Mg) and Ca contents of *Opuntia* might be the cause of the laxative action when animals are fed large amounts of cactus pear cladodes. Nefzaoui and Ben Salem (2001) suggested that a high oxalate content might explain the laxative effect of spineless cactus pear cladodes. The wet faeces produced by animals, almost like diarrhoea, do not have a negative effect on the animals, except that digestibility of the diet is slightly decreased and require precautionary measures to guard against increased blowfly attacks (Nefzaoui & Ben Salem, 2000, 2001; Ben Salem *et al.*, 2002a). The inclusion of lucerne hay into *Opuntia* diets could reduce the laxative effects in sheep because lucerne has a high fibre content (Steenkamp, 1973).

Opuntia contains mucilage that is commonly described as a water-soluble pectin-like polysaccharide (Cárdenas *et al.*, 1997). The precise function of the mucilage in the cactus pear plant is not known, but it is generally believed to help retain water in the plant (Sudzuki Hills, 1995).

In a current initiative launched at the University of the Free State (Zeeman, 2005; De Waal *et al.*, 2006; Einkamerer, 2008), the inclusion of sun-dried and coarsely ground *Opuntia* cladodes in balanced diets for sheep has been evaluated as partial substitution of lucerne hay. The ingestion of sun-dried and coarsely ground *Opuntia* cladodes increased water intake by sheep and resulted in increased water excretion in the faeces (De Waal *et al.*, 2006).

However, the effects of the *Opuntia* cladodes on the absorption of water from the gastrointestinal tract (GIT) in ruminants have not been investigated. De Waal *et al.* (2006) postulated that the wet faeces produced by sheep may have been caused by the mucilage contained in *Opuntia* cladodes, even after the cladodes have been sun-dried. The production of wet faeces in feedlots, especially by sheep, creates unattractive conditions that may reduce the acceptability of sun-dried *Opuntia* cladodes as a major feed component for ruminants (De Waal *et al.*, 2006). It is important to understand why the increased water intake is mostly excreted in the faeces and not as would have been expected via the urine (De Waal *et al.*, 2006). There is also no information about the composition of digesta in the GIT as well as their possible effects on the histological changes when the sheep are fed *Opuntia*. These aspects may cast some light on the mode of water absorption and economy in the GIT.

Based on two previous studies (Zeeman 2005; Einkamerer, 2008) conducted at the University of the Free State, the following hypotheses regarding sun-dried and coarsely ground *Opuntia ficus-indica* cladodes in sheep diets guided this present study:

- ✓ *Opuntia* cladodes can be used to a certain extent to replace lucerne in the diet of sheep without significant changes in feed intake and digestibility in young Dorper wethers.
- ✓ Inclusion of *Opuntia* cladodes increased the water intake of young Dorper wethers.
- ✓ Consumption of *Opuntia* cladodes as partial substitute of lucerne hay will not affect the composition of the digesta in different parts of the gastrointestinal tract (GIT).

- ✓ Inclusion of incremental levels of *Opuntia* cladodes may rapidly change the histological characteristics of segments of the lower GIT, which may explain the production of wet faeces.

The objective of this study was, therefore, to evaluate the effects of the incremental inclusion levels of sun-dried and coarsely ground *Opuntia ficus-indica* cladodes in balanced sheep diets on:

- the feed and water intake of young Dorper wethers
- the feed digestibility of young Dorper wethers
- the chemical composition of the digesta in different parts of the gastrointestinal tract (GIT) of young Dorper wethers
- the possible histological changes (to absorb water) in parts of the large intestine of young Dorper wethers.

2. Materials and Methods

2.1 Study area and trial period

This trial was conducted on the campus of the University of the Free State (UFS) in Bloemfontein, South Africa (latitude 29.10° south and longitude 26.29° east and an altitude of 1 351 m above sea level). The trial was conducted with the approval of the UFS Interfaculty Animal Ethics Committee (**Animal experiment nr. 14/08; dated 20 May 2008**) in the metabolic building and animal nutrition laboratory of the Department of Animal, Wildlife and Grassland Sciences from 20 May to 26 July 2008.

2.2 Experimental animals

Twenty one young Dorper wethers (7 months old) with a mean live weight of 45.3±1.9 kg were used in the trial. The 21 wethers were randomly divided according to body weight and 18 wethers allocated into three homogeneous groups of six wethers to each of the three treatment diets (T0, T24, and T36). The remaining seventh group of three wethers served as the TLM group, and were slaughtered on day 0 of the trial.

Initially all 21 Dorper wethers were housed outdoors in kraals and subjected to adaptation on a common diet, namely TLM (lucerne hay and yellow maize meal). On 20 May 2008 the wethers were weighed, three (3) animals (TLM group) were selected to be slaughtered and the other 18 wethers randomly housed in individual metabolism crates indoor. The feed intake and digestibility trial commenced on 20 May 2008 and concluded on 3 June 2008.

2.3 Housing

During an adaptation period of 18 days the 21 Dorper wethers were housed outdoors in an open-sided shed in three kraals (Figure 2.1). All the wethers received diet TLM comprising a mixture of 80% coarsely ground lucerne hay and 20% coarsely ground maize meal. At the end of the adaptation period, three wethers were randomly selected and slaughtered to provide baseline values. The remaining 18 Dorper wethers were housed indoors and kept individually in metabolism cages (see 2.5.3 for detail) in a well-ventilated building.

The metabolic cages were designed to prevent the sheep from turning around (Figure 2.2), they could only face towards the food and water troughs, thus preventing the contamination of feed and water with faeces. In addition, the metabolic cages were designed to separate and collect the faeces and urine excretion quantitatively on a daily basis. The daily feed and water intake of each sheep could be determined (Zeeman, 2005; Einkamerer, 2008).

Figure 2.1 Some of the experimental animals in an outdoor kraal.

Figure 2.2 Dorper wethers housed individually in metabolic cages.

2.4 Experimental diets

The treatments were based on incremental inclusion levels of 0%, 24% and 36% sun-dried and coarsely ground *Opuntia* cladodes in three balanced treatment diets designated T0, T24 and T26, respectively (see Table 2.1).

Table 2.1 Composition of the three treatment diets containing increasing levels of sun-dried and coarsely ground *Opuntia* cladodes

Feed ingredients (kg)	Treatment diets*		
	T0 (control)	T24	T36
Coarsely ground *Opuntia* cladodes	0	240	360
Coarsely ground lucerne hay	660	410	285
Yellow maize meal	300	300	300
Feed grade urea	0	10	15
Molasses meal (Calori 3000)	40	40	40

*Inclusion levels of coarsely ground *Opuntia* cladodes: T0 – 0%; T24 – 24%; T36 – 36%

The *Opuntia ficus-indica* var. Algerian cladodes used in this study were produced during the growing season of 2007/2008 on the farm Waterkloof situated 20 km west of Bloemfontein in the Free State Province, South Africa. The *Opuntia* cladodes used in the studies by Zeeman (2005) and Einkamerer (2008) were sourced from the same orchard. After being harvested, the fresh *Opuntia* cladodes were packed into bags and transported to the metabolic unit at the campus of the UFS in Bloemfontein for further processing.

The cladodes were cut lengthways into strips wide with a cladode cutter, specifically designed for this purpose (HO de Waal & Willie Combrinck, 2008; personal communication, Department of Animal, Wildlife and Grassland Sciences, University of the Free States, P.O. Box 339, Bloemfontein, 9300). The cladode cutter (Figure 2.3) comprises a set of 20 circular saw blades, mounted in-line 15 mm apart on a drive shaft, and powered by a small internal combustion engine. The machine (cladode cutter) has a potential capacity of cutting about 800 kg fresh *Opuntia* cladodes per hour.

The cladode strips were dried in the sun on a corrugated iron roof for about 10 days (Figure 2.4). Cut *Opuntia* cladodes dried rapidly in the sun. However, local experience (Zeeman, 2005; Einkamerer, 2008) have shown that after being ground through the hammer mill, the coarsely ground *Opuntia* material needs further drying in the sun for a few days (2 to 5 days depending on the season) on a dry, clean cement surface while being turned over frequently, once a day, to prevent it from moulding.

Figure 2.3 The *Opuntia* cladode cutter.

The sun-dried *Opuntia* cladode strips were ground to pass through a 20 mm sieve in a small hammer mill (Figure 2.5). This specific larger sieve aperture of 20 mm was in line with the procedure set by Zeeman (2005) and Einkamerer (2008) in previous studies.

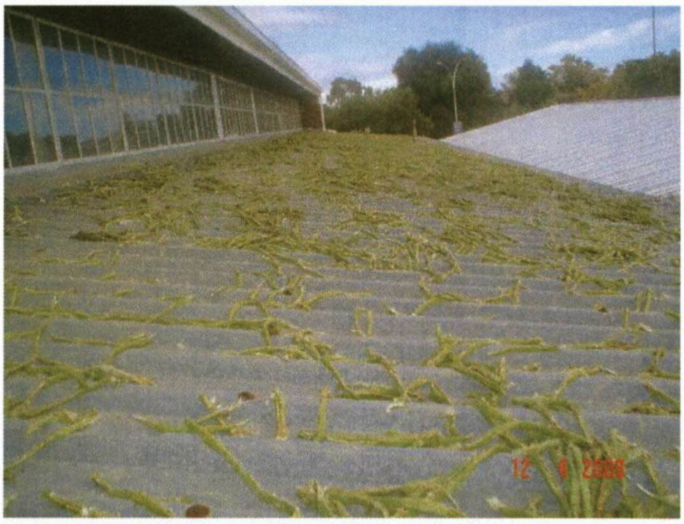

Figure 2.4 *Opuntia* cladode strips being dried in the sun on a corrugated iron roof.

After the first grinding process through the hammer mill some larger pieces of *Opuntia* cladode strips passed almost unaltered through the 20 mm sieve because they were still moderately moist and thus flexible when ground the first time. Therefore, it was necessary to ground a second time to produce more homogenous material.

Figure 2.5 Small hammer mill used to coarsely ground the sun-dried *Opuntia* cladodes and lucerne hay.

Before mixing the diets, the lucerne hay was also ground to pass through a 20 mm sieve in the hammer mill. The other feeds required for the diets, namely yellow maize meal, feed grade urea and molasses meal were included in the physical form in which these feeds were purchased. Because of the small quantities of feeds required in this study, the three treatment diets were thoroughly mixed by hand with a conventional garden spade on a clean cement floor (Zeeman, 2005; Einkamerer, 2008).

2.5 Trial procedures

2.5.1 Body weight of experimental wethers

At the start of the adaptation period the Dorper wethers were weighed. Thereafter, they were weighed every week on Tuesdays at 08h00. All weights were taken without the animals being fasted or withheld from water. Before being slaughtered, those Dorper wethers were also weighed in the same way. Body weight was measured with an electronic scale.

2.5.2 Adaptation period

Adaptation period on the common diet TLM was done outdoor in the kraal.

2.5.2.1 Feed intake

During the adaptation period of 18 days, the wethers had free access to the common diet TLM. Fresh clean water was available *ad lib.* for the entire trial period.

The 21 Dorper wethers were fed three times a day: about 25% of the daily feed was given at 08h00, another 25% at 12h00 and the rest of the daily food was given at 16h00.

2.5.2.2 Water intake

Automatic plastic troughs with a volume of about 20 litres were used to provide water *ad lib.* to the wethers in an open-sided roofed shed. The water troughs were distributed at different points of the kraal, opposite to the line of feed troughs. The daily water intake was recorded.

2.5.3 Experimental period (feed intake and digestibility period)

The 18 young Dorper wethers were randomly allocated and housed indoors in individually pens. The metabolism cages are about 1.8 m long and 0.7 m wide. The width of each cage can be adjusted according to the animal's size, preventing the wethers from being able to turn around in the cage. The cages were arranged in 3 rows of 8 cages each (next to each other). The cages were placed, in such a way that the wethers were visible to one another. The metabolic cages were designed to separate and collect the faeces and urine excretion quantitatively on a daily basis and to determine the daily feed and water intake of each sheep (Zeeman, 2005; De Waal *et al.*, 2006; Einkamerer, 2008).

2.5.3.1 Water intake

Individual plastic buckets with a volume approximate of 5 litres were used to provide water *ad lib.* in the metabolism cages. The buckets were filled with 4 litres of water to a calibrated mark at the start of the trial period. The water level in each bucket was checked and replenished twice a day to the calibrated marker using a plastic measuring cylinder. These buckets were filled and refilled after the sheep were fed in the mornings and afternoons. The quantity of water added was recorded when required and water intake drunk by experimental animals was measured.

The buckets were emptied and cleaned when required to prevent the feed that fell into the water from fouling the water making it less acceptable to the sheep. Water intake was measured by subtracting the volume of water remaining in a bucket at the time when it was cleaned. No allowance was made for evaporation loss of water outdoors and indoors from the buckets.

2.5.3.2 Feeds and refusals

The 18 Dorper wethers were fed three times a day, namely at 08h00, 12h00 and 16h00. This routine of feeding has been established while the wethers were fed the common TLM diet (see 2.2.5.1).

On the first day, the animals were offered 1 500 g food. On the second and third day the amount of food offered to sheep was calculated at a 15% refusal level, namely 15% more food than ingested the previous days. From the fourth day and the days after, the food for a 24-hour period were offered at a 15% refusal level of intake, calculated on a daily basis by using a 3-day moving average of the feed intake during the preceding three days.

About half of the daily feed weighed in this way was given to each wether at the start of each 24-hour cycle. The remaining feed was then given in two portions, namely at 12h00 and 16h00. More feed was weighed; recorded and provided to a specific wether if that wether has eaten all its weighed feed before the end of a 24-hour cycle.

During the trial period the daily food refused by each wether was collected, pooled in brown paper bags, and dried in a force draught oven at 100°C. When it was completely dry these feed refusals for each animal were mixed and representative samples were taken for each wether, ground to pass through a 1 mm sieve, and stored in plastic bottles with sealed screw tops pending chemical analysis.

A composite feed sample from each treatment diet offered was collected on a daily basis for the duration of the trial. These composite or pooled samples from each treatment diet were dried in a force draught oven at 100°C to determine the dry matter (DM) content. It was then ground to pass through a 1 mm sieve and stored in plastic bottles with sealed screw tops pending chemical analysis.

2.5.3.3 Faeces

The total faeces excreted by each wether was collected daily in separate brown paper bags, pooled, and dried in a force draught oven at 100°C until assessed to be sufficiently dry. The faeces resulting from treatment diets T24 and T36 took more time to dry than treatment diet T0. The reason for longer time needed for the faeces to dry was because the faeces from treatment diets T24 and T36 were very wet. The wet faeces formed a crust once it started drying in the oven that impeded the drying process. These faeces had to be left drying in the oven for a longer period as any crusts that formed were broken frequently when noted before it was considered to be at the DM level. The faeces that were excreted in the more usual form of small sheep pellets from treatment diet T0 dried quicker and could therefore be removed from the oven after about 48 hours.

When the faeces were deemed dry it was weighed and after thorough mixing of the total faecal excretion from each wether, a representative sample was taken and ground to pass a 1 mm sieve. The ground faeces were stored in plastic bottles with sealed screw tops pending chemical analysis.

2.5.3.4 Urine collection

The urine for each sheep was collected in 4 litre dark brown glass bottles. The urine was collected on a sheet metal chute from the base of the metabolism crates and directed via urine collection plates to the bottles. A plastic funnel, protected over the top with a sieve, was inserted in each bottle to prevent faeces and other type of material declining into urine collection bottles. The funnels and bottles were positioned under the urine collection plates of the metabolism crates. Consequently, all urine passed through the glass bottles. Nevertheless, due to the wet nature of some of the faeces, the urine of a number of the wethers was apparently more contaminated than would normally be expected which could have affected among others the nitrogen (N) content of the urine.

Every day before the morning feeding, the urine for each animal was collected into a plastic measuring cylinder, the urine volume recorded and the urine flushed away. The empty bottles were then placed back with the funnels and sieves properly placed under the urine collection plates of the metabolism crates.

2.6 Digesta composition in different segments of the gastrointestinal tract (GIT)

The major goal of this trial was to analyse the composition of digesta in different parts of the gastrointestinal tract from wethers in the different treatments. At the end of the adaptation period (see 2.5.2), a reference group of three wethers were randomly selected in the morning, without being withheld from feed or water, and slaughtered in a registered abattoir.

Immediately after the carcasses have been opened the two ends of the GIT, namely the proximal part of the oesophagus and distal part of the rectum were tied up with a string, before the complete viscera was removed. The complete viscera was deposited in large plastic refuge bags, closed with nylon rope and transported to the meat laboratory of the Department of Animal, Wildlife and Grassland Sciences at the University of the Free State. This process was repeated during the next two weeks for the two groups of nine Dorper wethers each.

The chemical analysis, namely dry matter (DM), crude protein (CP), neutral (NDF) and acid detergent fibre (ADF), lipids (fat), energy and organic matter (OM) of the digesta retrieved from the respective sections of the gastrointestinal tract (GIT) was used to compare the effects of the different treatment diets.

2.6.1 Digesta collection

In the meat laboratory each gastrointestinal tract was placed on a clean working table, the viscera was bluntly dissected, mesenteric fat was removed (Figure 2.6; plate 1) and representative samples collected from the digesta in the reticulo-rumen, omasum, small intestine and large intestine. In the case of the reticulo-rumen the digesta was collected as one sample. The digesta in the small intestine was sampled at two sites (Figure 2.6; plates 4 and 5), namely proximal jejunum (duodeno-jejunum) and distal jejunum (jejuno-ileum). In the large intestine the digesta samples were collected from three different sites, namely caecum, *gyrus centripetalis*, and colon *descendens*.

2.6.1.1 Digesta collection from the reticulo-rumen

Before collecting samples from the reticulum and the rumen, and with both organs lying on a table with their right lateral aspect facing down, the entire structure was shaken in order to mix the contents of the reticulo-rumen. After that, a small window was opened with the aid of a pair of scissors in the ruminal wall, across the *sulcus longitudinalis sinextra*, between the *sulcus cranialis* and the *sulcus caudalis* (Figure 2.6; plate 2). The digesta sample was scooped from the rumen by hand, placed in a plastic bottle, dried, and stored as described previously (see 2.6.1). All anatomical names cited in this study are according to Bezuidenhout *et al.* (1997).

2.6.1.2 Digesta collection from the omasum

The absorption of water from the digesta starts in this organ which is part of the composite ruminant fore stomach. Therefore, a separate sample was collected from the omasum. The omasum was detached from the abomasum with the aid of a pair of scissors by cutting along the *sulcus omaso-abomasicum*. The sample collection started by opening the spherical organ longitudinally with the aid of a pair of scissors. The interior of the omasum contains broad longitudinal folds or leaves reminiscent of the pages in a book (a lay term for the omasum is the 'book stomach'). The digesta is packed between the folds and, therefore, to take all the digesta out, it was necessary to remove it, fold by fold (Figure 2.6; plate 3).

A composite sample of the digesta from the omasum of each animal was collected by gently removing it from the spaces between the folds and dried as described previously (2.6.1) and stored pending chemical analysis (see 2.6).

2.6.1.3 Digesta collection from the small intestine

The digesta from the small intestine was sampled from two different sections/sites, namely the duodenum and proximal/anterior jejunum and distal/posterior jejunum and ileum.

First of all, the small intestine was bluntly dissected by hand (uncoiling) with the aid of a pair of scissors and distended on the table top from the pylorus until the junction of the ileum with the caecum, namely *os ileocaecalis*. After that, the gut was severed with the aid of a pair of dissecting scissors (Figure 2.6; plate 4) at a distance of 10 m from the pylorus. Finally, the content of the duodenum and jejunum (proximal part) was gently expressed from the intestine and collected into a bottle by moving the thumb and index finger along the intestinal tube (Figure 2.6; plate 5).

The second digesta sample from the small intestine consisted of the contents of the last 3 m of the small intestine (from the *os ileocaecalis*), corresponding to the contents of the jejunum (distal part) and ileum. The content of the last 3 m of the small intestine was gently extruded and collected in a plastic bottle by moving the thumb and index finger along the tube obtain enough digesta. Samples was collected, dried (see 2.6.1) and preserved for analysis (see 2.6).

2.6.1.4 Digesta collection from the large intestine

The digesta from the large intestine was sampled at three different sections. One sample was collected from the caecum and other two were taken from the colon.

The first sample from the large intestine was collected from the caecum bag. Before sampling, the digesta content of the caecum was mixed by shaking the bag a few times and then a small window (3 x 3 cm) was opened with the aid of a pair of scissors in the region opposite to the *os ileocaecalis* and approximately 250 ml of caecal digesta content was collected in a plastic bottle. The second sample from the large intestine was taken from the last 1 m of the *gyrus centripetalis* of the spiral colon. The spiral colon was dissected and distended by gently but firmly securing the *flexura centralis* between the thumb and the index finger and carefully pulling it away from the viscera. The *gyrus centripetalis* and *centrifugalis* of the spiral colon were laid straight next to one another. After locating the *flexura centralis,* this was opened (cut through transversally with the aid of a pair of scissors), and the digesta contents in the last 1 m of the *gyrus centripetalis* were gently expressed from the intestinal tube into the collecting bottle. The last sample of digesta represented the content of the distal 3 m of the GIT, namely in the last part of the colon (colon *descendens*) and rectum. The same procedures to express the digesta contents described earlier (see 2.6 and 2.6.1) were followed to collect the digesta (faeces) from the last part of the GIT. All sample as done the same process as explained previously.

Plate 1 Gastrointestinal tract being dissected and mesenteric fat removed.

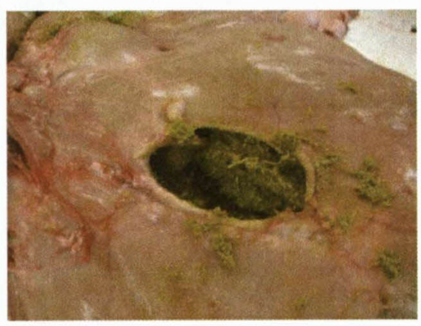

Plate 2 Digesta collection from the rumen-reticulum.

Plate 3 Omasum with digesta content being removed from between the folds.

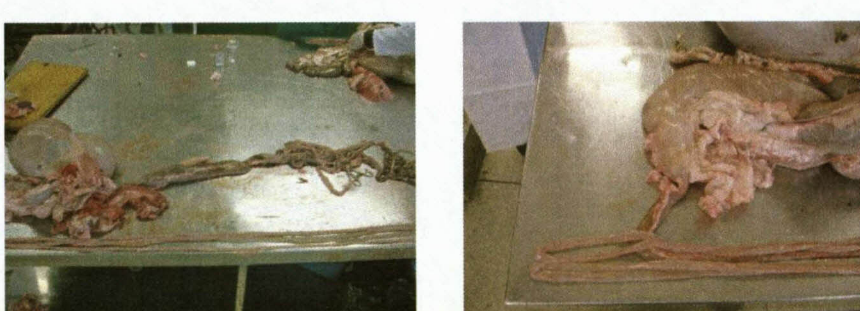

Plate 4 Small intestine extended from the pylorus to the caecum (*papilla ilealis*).


Plate 5 Digesta being gently expressed from pylorus (first 10 m of the small intestine).

Figure 2.6 Procedure used to collect digesta content in different segments of the gastrointestinal tract.

2.6.2 Preservation of digesta samples

After collecting all digesta samples from different sections of the GIT, the material was deposited in 250 ml plastic bottles and closed with plastic lids.

Because the digesta samples contained substantial quantities of water, it was necessary to place them in the oven (60°C) immediately after collection to decrease the water content rapidly while preserving the samples. When the material was completely oven dry (Figure 2.7) the samples were again deposited in the same plastic bottle as used before to dry. It was then ground in a Wiley mill to pass through a 1 mm sieve and stored in small plastic bottles pending chemical analysis (see 2.6).

To investigate in more detail the phenomenon of wet faeces reported by several authors when ruminants are fed on large quantities of *Opuntia* cladodes (De Kock, 2001; Nefzaoui *et al*., 2001; Ben Salem *et al*., 2002a; De Waal *et al*., 2006), the histological characteristics of different parts of the lower intestine were evaluated and compared across treatments.

For histological analysis, tissue samples were collected from the first three wethers (TLM group) slaughtered at the outset of the experiment to provide baseline reference values. The histological characteristics of the young Dorper wethers in the experimental groups were compared after being 7-days and 14-days in the trial.

Figure 2.7 Digesta from the reticulo-rumen after being dried in an oven.

2.7 Histological characteristics of segments of the lower gastrointestinal tract

2.7.1 Lower gastrointestinal sampling

Four tissue samples of the lower intestine were taken from each animal as illustrated in the diagram below (Figure 2.9). These were the (i) caecum wall (H0), (ii) colon *spiralis* (H1), (iii) *flexura centralis* (H2), and (iv) colon *descendens* (H3). The first sample was collected from the caecum wall region directly opposite to the *os ileocaecalis* (H0). The last three samples for histology were collected from the colon part of the GIT. The samples H1 and H2 were taken from the colon *spiralis*, in the *gyrus centripetalis* 1 m away from the *flexura centralis* and *flexura centralis* (Figure 2.8), respectively. Finally the last tissue sample (H3) was collected from the colon *descendens* 1.5 m away from the anus.

All samples of intestinal wall (about 2 x 3 cm) were cut with the aid of a pair scissors, the segment opened to form a rectangle and then stored in separate tightly closed plastic 30 ml vials. The vials were all previously filled with about 20 ml of 10% buffered neutral formalin solution for preservation pending histological analysis.

All the vials containing tissue samples were transported to the Histological Laboratory of the Faculty of Medicine of the University of the Free State, Bloemfontein for further processing and analysis.

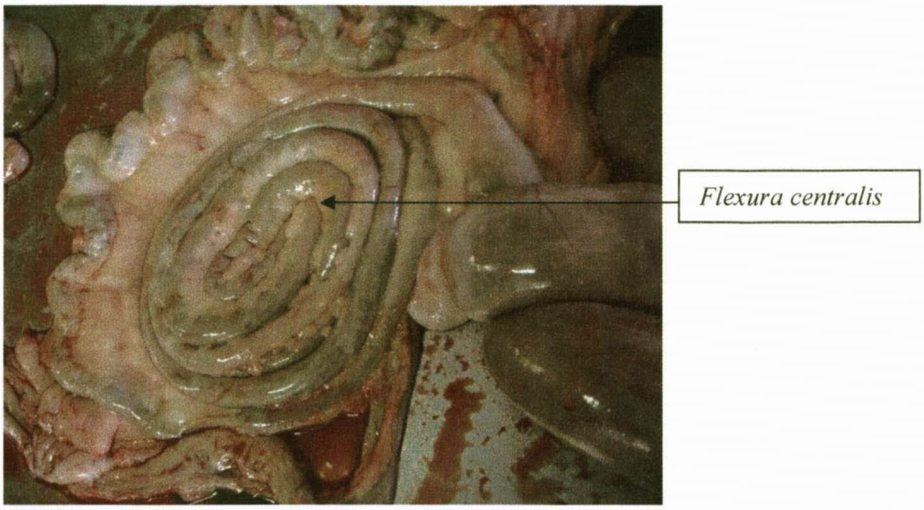

Figure 2.8 The *flexura centralis* shown in the middle of the colon.

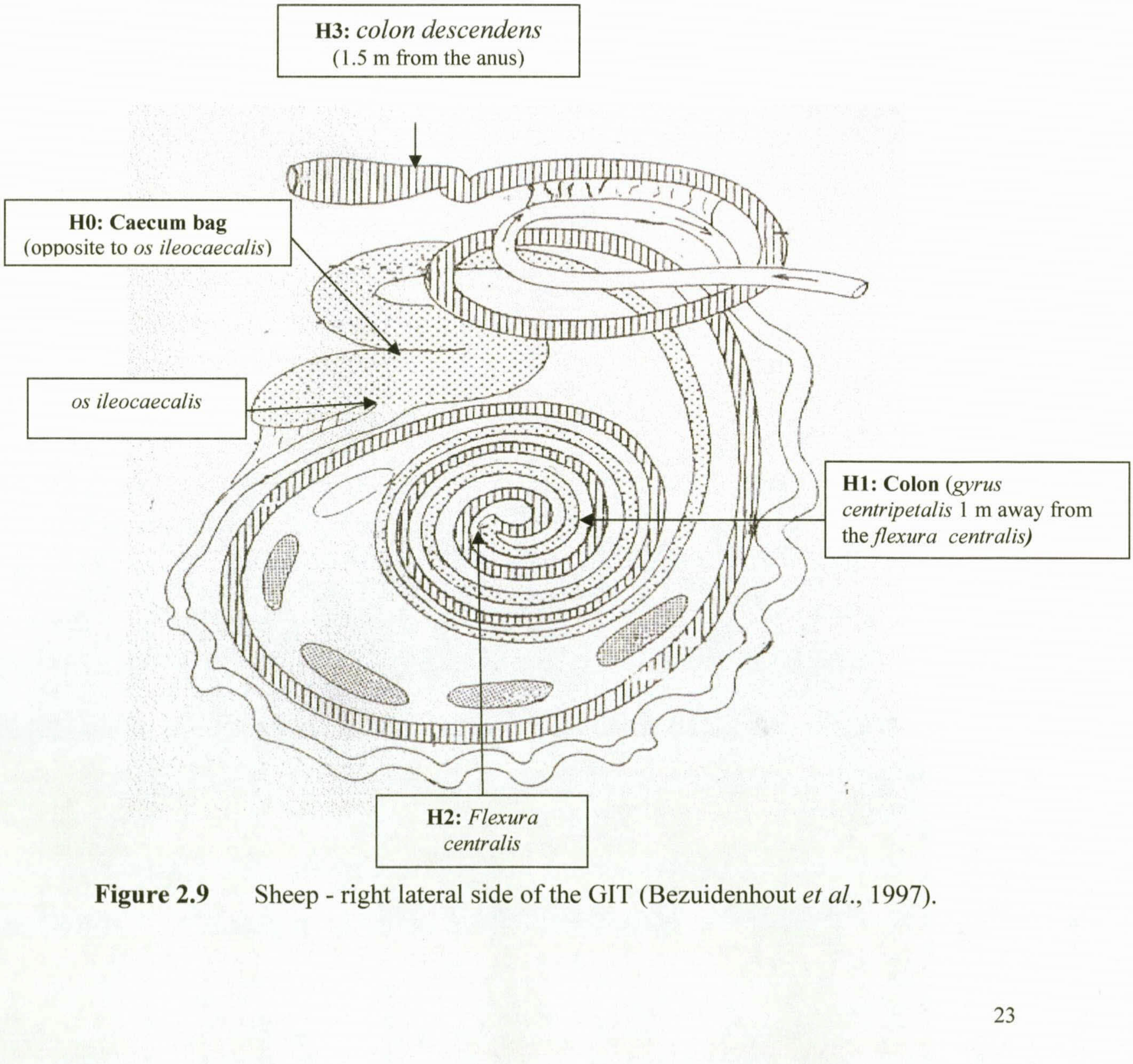

Figure 2.9 Sheep - right lateral side of the GIT (Bezuidenhout *et al.*, 1997).

2.8 Laboratory analysis

2.8.1 Sample preparation

All composite feed and refusal samples were prepared for analysis by grinding them in a Willey mill to pass through a 1 mm sieve (see 2.5.3.2). After being dried in a force draught oven at 100°C for more than 48 hours, the faecal samples were ground to pass through a 1 mm sieve (see 2.5.3.2).

The drying process for the digesta was conducted over a longer period of at least 96 hours (see 2.6.1) because some of the digesta was very wet. For example the digesta from the lower intestine of animals that were on treatment diets T24 and T36 was wetter than for animals ingesting treatment diet T0. Consequently the digesta from these first two groups of animals took longer to dry. However, drying period for digesta did not depend on treatment diets only, but also on the site where the digesta was collected. For example, the digesta collected in the rumen was wetter than for digesta collected from the omasum.

2.8.2 Dry matter (DM)

The dry matter (DM) content of feed offered and refusals collected was determined by weighing samples before and after being dried in a force draught oven at 100°C for 24 hours. Likewise, the DM content was determined for the faeces and the digesta collected from the reticulo-rumen, the omasum and the small and large intestine of each wether. As described previously the faeces of some experimental animals and the digesta contents of the gastrointestinal tract were wetter and, therefore, had to be left in the oven for longer periods to dry (see 2.5.3.3 and 2.6.1).

The DM of all samples was calculated as follows:

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

2.8.3 Ash or inorganic matter

Porcelain crucibles were weighed to determine the ash or inorganic matter content of each sample. About 2 g of the respective material was weighed accurately into the crucibles. The crucibles plus samples were dried overnight at 100°C in oven. The crucibles plus dry samples were cooled in desiccators, weighed, placed in a muffle furnace, and incinerated for 4 hours at 550°C (AOAC, 2000). Finally, crucibles plus ash were cooled in desiccators and weighed again.

The ash content of each sample was determined as follows:

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

2.8.4 Organic matter (OM)

Organic matter for all samples was calculated by subtracting the ash content from 1 000 or using the formula below:

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

2.8.5 Crude protein (CP) and nitrogen (N) content

Approximately 0.2 g DM of each sample was weighed accurately in a tiny foil cup. Each foil cup and sample was then inserted in a Leco® Nitrogen analyser (Leco® Corporation, 2001). The nitrogen (N) content was determined automatically by combustion in oxygen. A factor of 6.25 was used in the calculations to convert the N content of the samples to crude protein (CP) content of the diets, refusals, faeces and digesta content.

2.8.6 Lipid content (Ether extract)

For analysis of the ether extract (EE) content, 2 g of the respective material was weighed and inserted into a cellulose extraction bullet of filter paper (AOAC, 2000). Cotton wool was placed in the top of the extraction bullets. Bullets were placed in a Soxhlet apparatus and extracted with hexane for at least 3 hours. After the extraction period, the remaining hexane was evaporated and the flasks were placed in a draught oven at 100°C to dry overnight. The flasks were then cooled in desiccators, weighed again to determine the hexane soluble fraction.

The EE fraction of samples was determined as follows:

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

2.8.7 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 was measured in joule (J) when a sample was completely oxidised.

The quantity of sample used to determine GE depends on the type of sample. In this study about 0.2 g samples were used for faeces and content of the lower gastrointestinal tract and for other material a sample of about 0.4 g was used. All samples were weighed accurately before being analysed.

2.8.8 Acid-detergent fibre (ADF)

Similar to the procedures followed by Zeeman (2005) and Einkamerer (2008), samples of about 1 g were weighed accurately to determine the ADF according to the methods described by Goering and Van Soest (1970) and Robertson and Van Soest (1981).

Oven dry samples were weighed in sintered glass crucibles and then placed in a Tecator Fibertec System M 1020 Hot extractor for analysis. The ADF solution was added to the samples and then was boiled for an hour. The solution was drained and the samples were washed three times with boiling water and then twice with acetone. Samples were dried overnight in an oven at 100°C. Dry samples were taken from the oven and allowed to cool completely in a desiccator before being weighed. The samples were then placed in a muffle furnace and incinerated for 4 hours at 550°C. After incineration, the samples were removed from the furnace, allowed to cool in desiccators, and weighed.

The ADF content of samples was calculated as follows:

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

2.8.9 Neutral-detergent fibre (NDF)

Similar to the procedures followed by Zeeman (2005) and Einkamerer (2008), samples of about 1 g were weighed accurately to determine the ADF according to the methods described by Goering and Van Soest (1970) and Robertson and Van Soest (1981).

Oven dry samples of approximately 1 g were weighed accurately in sinter glass crucibles. The crucibles were then placed in a Tecator Fibertec System M 1020 Hot extractor for analysis. The NDF solution was added to the samples it was boiled for half an hour. After this period, 40 mg α-amylase diluted in 2 ml of distilled water was added in each sample and boiled again for half an hour.

The solution was drained and the sample was rinsed with boiling water and then with acetone. During the drying process with vacuum extraction, it was difficult to extract the NDF solution from samples containing *Opuntia* ostensibly because of its mucilage content. Mucilage is a hydrocolloid and has a high capacity to imbibe water (Sáenz *et al.*, 2004). Therefore, some samples took longer time to extract and others were completely clogged up.

After completing the vacuum extraction process, samples were placed in a force draught oven to dry overnight at 100°C. Dry samples were removed from the oven and placed in desiccators until completely cooled .The samples were weighed again before being placed in a muffle furnace and incinerated for 4 hours at 550°C. The samples were taken from the furnace, cooled in a desiccator, and weighed again.

The NDF content was calculated as follows:

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

2.8.10 Apparent digestibility coefficients

According to McDonald *et al.* (2002) the apparent digestibility of a feed or nutrient is defined as the proportion of ingested feed or nutrients not excreted in the faeces and for that reason assumed to have been digested and absorbed by the animal.

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

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

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.

2.9 Statistical analysis

The data collected in this study (feeds, faeces, food refusals, and the contents of the reticulo-rumen, omasum, caecum and colon) was subject to statistically analysis using General Linear Models Procedures of the General Linear Models Procedures Repeated Measured Analysis of Variance of SAS (2004). Furthermore, a significant difference between treatments means was tested by Turkey's multiple comparison analysis (SAS, 2004). The 95% confidence level was used for analysis.

3. Results and Discussion

3.1 Treatment diets

In this study, three treatment diets with incremental inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes were used to determine their effects on the digestive processes and histological characteristics of the large intestine. The voluntary feed intake and digestibility of diets, the water consumed and the urine excreted by young Dorper wethers were measured during two different trial periods of 7-days and 14-days.

3.1.1 Chemical composition of diets

The objective of this study was to determine the effects of increasing levels of *Opuntia* cladodes in the diet of Dorper wethers on the digestive processes. Therefore, it was deemed necessary to adapt the alimentary canals of all the Dorper wethers on a common diet (see 2.4) before they started consuming the treatment diets. The common diet TLM consisted of only two feed sources, namely 80% coarsely ground lucerne hay and 20% yellow maize meal. During the adaptation period the wethers were housed in a small kraal in an open-sided shed while receiving diet TLM (see 2.4). Thereafter, the Dorpers were subjected to the three treatment diets (T0, T24, and T36) (see 2.4).

The chemical composition of the common diet (TLM) and the three treatments diets (T0, T24, T36) used in the study are shown in Table 3.1.

The DM content of the three treatment diets varied (Table 3.1) but the differences were insignificant ($P<0.05$). Zeeman (2005) reported that the DM content of treatment diets decreased with increasing inclusion levels of *Opuntia*, while Einkamerer (2008) concluded that incremental levels of *Opuntia* had no real effect on DM content of diets.

The CP content was decreased by inclusion of *Opuntia* cladodes, but this was compensated for by the inclusion of small quantities of feed grade urea (Table 2.1). The ADF, NDF, and OM content of the three treatment diets decreased with incremental level of *Opuntia* cladodes (Table 3.1). This was the result of the lower ADF and NDF (Felker, 1995; Nefzaoui & Ben

Salem, 2002; Verás *et al.*, 2005) and the higher ash content of *Opuntia* reported by several studies (Nobel, 1994; Ben Salem *et al.*, 1996; Ben Salem *et al.*, 2002; Batista *et al.*, 2003). These effects were also reported by Zeeman (2005) and Einkamerer (2008). However, it must be noted that the ADF and NDF values of *Opuntia* are substantially higher than the NDF and ADF content for maize, but lower than the ADF and NDF values for lucerne hay (McDonald *et al.*, 2002).

Table 3.1 Chemical composition of the common diet (TLM) and the three treatment diets (T0, T24, T36) with incremental inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes

Chemical constituent	Common diet	Treatment diets*		
	TLM	T0	T24	T36
Dry matter (g DM/kg feed)	_	876.3	886.4	815.5
Crude protein (g CP/kg DM)	175.0	163.9	157.7	161.0
Acid-detergent fibre (g ADF/kg DM)	393.1	338.1	231.8	199.8
Neutral-detergent fibre (g NDF/kg DM)	571.6	516.3	368.2	365.0
Ether extract (g EE/kg DM)	15.2	16.9	24.2	22.2
Ash (g ash/kg DM)	85.2	93.8	115.6	128.8
Organic matter (g OM/kg DM)	914.8	906.3	884.4	871.2
Gross energy (MJ/kg DM)	18.52	22.36	17.06	15.98

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

The lipid content or EE extract (Table 3.1) of the two treatments diets that contained *Opuntia* was slight higher than the control diet (T0). This is in agreement with the lower lipid values of *Opuntia* cladodes ranging from 15.5 to 25 g/kg DM (Terblanche, 1971; Nefzaoui & Ben Salem, 2000; Baptista *et al.*, 2003).

The gross energy (GE) decreased with increasing inclusion level of *Opuntia* cladodes (Table 3.1) and showed considerable difference between T0 and T24. The GE value for most feeds is about 18.5 MJ/kg DM (McDonald *et al.*, 2002). The GE content reported by Einkamerer (2008) and values found in this study are in good agreement.

The ash content of treatment diets containing *Opuntia* cladodes are higher than diets without and increased with incremental levels of *Opuntia* (Table 3.1). The higher ash content found in this study corresponds with several reports (Baptista *et al.*, 2003; Zeeman, 2005; Einkamerer, 2008). The minerals in *Opuntia* cladodes are calcium (Ca), potassium (K), magnesium (Mg) and sodium (Na), but the Ca content is the highest.

3.1.2 Feed intake and faeces excretion

The feed intake and faeces excretion was determined for 18 Dorper wethers, which were divided in two groups of nine animals each. The first group was slaughtered seven days after the start of the trial and the second group was slaughtered 14 days after the start of the trial.

3.1.2.1 Feed intake and faeces excretion during the 7-day trial period

Before slaughtering the first group of nine Dorper wethers, feed intake was determined and faeces excretion collected during a period of seven days. The average daily feed intake and faeces excreted by the Dorper wethers in three different treatments are presented in Table 3.2.

Table 3.2 The average (mean±s.e.) daily feed intake and faeces excreted during a 7-day trial period by Dorper wethers fed diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments*				
	T0	T24	T36	P	CV[1] (%)
Feed intake (g DM/day)	1096.3±84.8[a]	1295.6±80.9[a]	1086.9±95.8[a]	0.24	13.06
Faeces excreted (g DM/day)	345.2±20.1[a]	351.2±21.0[a]	250.0±21.1[b]	0.02	11.39

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at $P<0.05$.

Daily feed intake was not influenced by addition of *Opuntia* cladodes to the diet ($P>0.05$). This is in agreement with the results by Zeeman (2005). Comparing two extreme diets, with and without inclusion of *Opuntia* cladodes, the diet intake decreased slightly (Table 3.2) as *Opuntia* inclusion increased. The highest feed intake was recorded for diet T24 while the intake on diets T0 and T36 was very similar.

Significant differences (P<0.05) in the level of faeces excretion were recorded between treatment diets T36 vs. T0 and T24 vs. T36. The faeces excreted decreased at the highest level of *Opuntia* cladode inclusion (Table 3.2). These findings are in agreement with the results of Zeeman (2005) and De Waal *et al.* (2006).

In this study a general relationship existed between feed intake and faeces excreted, namely the higher the feed intake the more faeces were excreted by Dorper wethers (Table 3.2).

3.1.2.2 Feed intake and faeces excretion during the 14-day trial period

Similarly to the procedures described previously (see 3.1.2.1) the feed intake was determined and the faeces excretion collected from nine young Dorper wethers during a period of 14-days. The average daily feed intake and faeces excreted by the Dorper wethers in three different treatments are presented in Table 3.3.

Table 3.3 The average (mean±s.e.) feed intake and faeces excreted during a 14-day trial period by Dorper wethers fed diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments*				
	T0	T24	T36	P*	CV[1] (%)
Feed intake (g DM/day)	1080.5±125.1	1126.7±118.0	1199.2±130.8	0.80	19.01
Faeces excreted (g DM/day)	664.2±77.5	498.9±24.7	504.3±63.4	0.16	18.55

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

P* No statistical differences between means in the same row (P<0.05).

The feed intake by Dorper wethers increased moderately during the 14 days (Table 3.3) with incremental levels of *Opuntia* cladodes in the diet, but these increases were not statistically significant (P>0.05). Similar results were found in feed intake during seven days (see 3.1.2.1). Moreover, these results are in agreement with the findings by Zeeman (2005) and De Waal *et al.* (2006). This suggests that addition of sun-dried and coarsely ground *Opuntia* cladodes up to 36% in sheep diets does not change its acceptability for sheep.

With regard to faecal excretion the picture is slightly different from what was discussed earlier (see 3.1.2.1). In this case the differences in faeces excreted by the Dorper wethers were no statistically different (P>0.05). The highest faecal excretion was recorded for treatment diet T0, followed by treatment diet T24 and finally treatment diet T36 (Table 3.3). However, differences in the amount of faeces excreted between diets T0 and T24 were quite high. The faeces excreted by sheep on treatment diets T24 and T36 were very similar.

Comparing feed intake between the two different periods, showed the highest daily feed intake to be on treatment diets T24 and T36 for the 7-day and 14-day periods, respectively.

3.1.3 Nutrient intake and apparent digestibility

The same procedure as described previously (see 3.1.2) was used to determine nutrient intake and apparent digestibility during two different periods, namely for 7- and 14-day trial periods.

3.1.3.1 Nutrient intake and apparent digestibility during the 7-day trial period

The daily intake of DM and chemical constituents by nine young Dorper wethers throughout the 7-day trail period on treatment diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes are shown in Table 3.4.

The intake of DM, OM and GE of the Dorper wethers were significantly (P<0.05) higher on diet T36 when compared with diets T24 and T0 (P<0.05). However, no significant differences (P>0.05) between diets T0 and T24 were illustrated (Table 3.4). In the case of diet T36 discussed previously, a significant difference (P<0.05) was showed in the intake of lipid and ash between treatment diets T24 and T36, but no significant difference (P>0.05) was observed between treatment diets T0 and T36.

No significant difference (P>0.05) was showed between the CP intake of the Dorper wethers as *Opuntia* cladodes incrementally substituted lucerne hay in two of the treatment diets (Table 3.4). This is in agreement with the results reported by Einkamerer (2008). The highest CP intake occurred on treatment diet T24 and the CP intake for treatment diets T0 and T36 were very similar (Table 3.4).

Table 3.4 The daily intake (mean±s.e.) of DM and chemical constituents by Dorper wethers during the 7-day trial period on treatment diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments*				
Intake of chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/day)	995.5±57.6[a,b]	1215.8±22.1[a]	904.2±75.3[b]	0.02	9.37
Crude protein (g CP/day)	170.8±57.6[a]	198.6±4.1[a]	165.8±1.0[a]	0.07	8.38
Acid-detergent fibre (g ADF/day)	318.0±14.3[a]	253.3±3.8[b]	182.1±15.5[c]	0.001	8.52
Neutral-detergent fibre (g NDF/day)	500.4±24.0[a]	418.0±5.2[a,b]	339.5±27.4[b]	0.005	8.79
Lipids (g lipid/day)	17.4±1.0[a]	29.2±2.3[b]	21.2±1.9[a]	0.09	13.82
Gross energy (MJ GE/day)	18.66±1.01[a,b]	20.63±0.49[a]	14.8±1.2[b]	0.01	9.06
Ash (g ash/day)	88.5±10.3[a]	141.8±3.8[b]	101.05±8.03[a]	0.007	12.35
Organic matter (g OM/day)	907.0±49.2[a,b]	1074.0±18.3[a]	803.1±68.2[b]	0.02	7.57

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b,c] Means followed by different superscripts within the same row differ significantly at P<0.05.

The ADF and NDF intake declined with incremental levels of *Opuntia*. Statistical (P<0.05) differences between treatment diets T0, T24 and T36 were observed for ADF intake and treatment diets T0 and T36 for NDF intake (Table 3.4). Similar results were reported by Einkamerer (2008). The lower intake of NDF and ADF was the result of substituting lucerne hay with its higher fibre content with the sun-dried and coarsely ground *Opuntia* cladodes.

On the other hand, different results were found regarding the apparent nutrient digestibility (Table 3.5) compared to nutrient intake. The apparent digestibility of ADF, GE, ash and OM in the different treatments (T0, T24, T36) were not significantly different (P>0.05).

However, there were significant differences (P<0.05) between apparent DM digestibility between diet T36 and control diet T0 that contained no sun-dried and coarsely *Opuntia* cladodes, but the DM digestibility of diets T24 and T36 were similar (P>0.05) (Table 3.5). Similar results were also reported by Zeeman (2005) and Einkamerer (2008) and these authors concluded that the apparent DM digestibility increased with the addition of *Opuntia* cladodes with its higher content of easily digestible carbohydrates (Ben Salem *et al.*, 1996).

The apparent CP and lipid digestibility were not statistically different (P>0.05) for treatment diets T24 and T36, but statistically higher for T36 compared to T0 (P<0.05) (Table 3.5). The higher apparent digestibility of CP with incremental levels of *Opuntia* cladodes found in this study was also reported by Zeeman (2005) and Einkamerer (2008).

Table 3.5 Apparent digestibility coefficients (mean±s.e.) of DM and chemical constituents during the 7-day trial period on treatment diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments*				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (DM)	0.653±0.01[a]	0.712±0.01[b]	0.723±0.01[b]	0.002	2.07
Crude protein (CP)	0.730±0.01[a]	0.765±0.01[a,b]	0.793±0.01[b]	0.007	1.98
Acid-detergent fibre (ADF)	0.509±0.01[a]	0.458±0.02[a]	0.503±0.01[a]	0.069	4.70
Neutral-detergent fibre (NDF)	0.582±0.01[a,b]	0.562±0.02[b]	0.638±0.01[a]	0.015	3.81
Lipid	0.587±0.03[a]	0.715±0.04[a,b]	0.725±0.02[b]	0.035	7.93
Gross energy (GE)	0.647±0.03[a]	0.725±0.01[a]	0.730±0.003[a]	0.045	4.96
Ash	0.330±0.06[a]	0.490±0.02[a]	0.430±0.02[a]	0.061	15.58
Organic matter (OM	0.323±0.06[a]	0.222±0.02[a]	0.294±0.03[a]	0.222	23.03

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at P<0.05.

It is important to remind the reader about the use of urea in this study (Table 2.1) and the fact that urea is quickly and completely utilized by the micro-organisms in the reticulo-rumen (McDonald *et al.*, 2002). Urea was included in diets T24 and T36 to increase their CP content and this have also been reflected the higher apparent CP digestibility of these two diets. Similar findings were reported by Zeeman (2005) and Einkamerer (2008). By substituting lucerne with its higher CP content, urea was used to offset the reduction in CP when including *Opuntia* cladodes (Zeeman, 2005; Einkamerer, 2008) with its much lower CP content (Ben Salem *et al.*, 1996; Tegegne, 2002).

The apparent NDF digestibility coefficient was not statistically significant (P>0.05) between treatments T0 vs. T24 and T0 vs. T36, but was significant different (P<0.05) among the two treatments diets containing *Opuntia* cladodes (T24 vs. T36). Because of the low fibre content of *Opuntia* cladodes that is positively linked to a lower digestibility of a feed, it was to be expected that *Opuntia* would contribute to a higher apparent digestibility (Nefzaoui & Ben Salem, 2000).

3.1.3.2 Nutrient intake and apparent digestibility during the 14-day trial period

The daily intake of DM and chemical constituents by nine young Dorper wethers throughout the trial period of 14-days as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes is presented in Table 3.6.

Table 3.6 The daily intake (mean±s.e.) of DM and chemical constituents by Dorper wethers during the 14-day trial period on treatment diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Intake of chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/day)	957.4±109.0^{a}	1011.5±105.0^{a}	979.2±108,02^{a}	0.93	18.92
Crude protein (g CP/day)	165.7±19.1^{a}	167.8±16.7^{a}	161.5±11.4^{a}	0.96	16.84
Acid-detergent fibre (g ADF/day)	292.5±33.0^{a}	202.7±30.5^{a}	210.8±11.8^{a}	0.10	19.74
Neutral-detergent fibre (g NDF/day)	469.4±53.5^{a}	339.9±44.4^{a}	330.5±23.1^{a}	0.11	19.28
Lipid (g lipid/day)	16.0±1.6^{a}	27.44±2.7^{b}	21.4±1.3^{a,b}	0.02	15.84
Gross energy (MJ GE/day)	17.59±2.10^{a}	17.33±1.89^{a}	14.23±1.03^{a}	0.41	18.27
Ash (g ash/day)	89.7±12.1^{a}	115.0±9.3^{a,b}	135.4±7.6^{b}	0.05	15.01
Organic matter (g OM/day)	867.7±96.9^{a}	896.5±95.8^{a}	843.8±102.4^{a}	0.93	19.60

* *Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at P<0.05.

The DM intake of the diets was not statistically (P>0.05) different with increasing inclusion levels of sun-dried and coarsely *Opuntia* cladodes during the 14-day trial period (Table 3.6).

The intake of CP, GE, OM, NDF and ADF during the 14-day period was very similar amongst the different treatment groups (P>0.05). The GE intake was observed to be markedly, yet not significantly (P>0.05), lower on treatment diet T36 (Table 3.6).

The ether extract or lipids intake on treatment diet T24 was significantly higher (P<0.05) than the diet without *Opuntia* cladodes (T0) but did not differ from that of treatment diet T36 (Table 3.6). Similar results have been presented for the lipid intake during the 7-day period.

Significant difference (P<0.05) was showed for the apparent digestibility coefficients (Table 3.9) for DM, lipids and ash. The digestibility coefficients for DM, lipids and ash were lower in the diet without *Opuntia* cladodes (T0). This is contrary to the results presented during the 7-day period for lipid and ash (Table 3.7).

Table 3.7 Apparent digestibility coefficients (mean±s.e.) of DM and chemical constituents during the 14-day trial period on treatment diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (DM)	0.653±0.01^{a}	0.751±0.01^{b}	0.743±0.01^{b}	0.001	2.40
Crude protein (CP)	0.732±0.01^{a}	0.797±0.02^{b}	0.785±0.02^{a,b}	0.039	3.23
Acid-detergent fibre (ADF)	0.523±0.02^{a}	0.541±0.05^{a}	0.959±0.01^{b}	<.0001	7.53
Neutral-detergent fibre (NDF)	0.591±0.02^{a}	0.639±0.02^{a}	0.630±0.05^{a}	0.598	9.48
Lipid	0.503±0.06^{a}	0.768±0.02^{b}	0.741±0.01^{b}	0.004	9.37
Gross energy (GE)	0.643±0.04^{a}	0.768±0.01^{a}	0.726±0.03^{a}	0.069	7.46
Ash	0.252±0.02^{a}	0.507±0.03^{b}	0.590±0.02^{b}	0.0002	9.43
Organic matter (OM)	0.400±0.02^{a}	0.244±0.03^{b}	0.154±0.02^{b}	0.002	17.44

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

^{a,b} Means followed by different superscripts within the same row differ significantly at P<0.05.

The apparent digestibility of ash on treatment diet T0 was significantly lower (P<0.05) than diets T24 and T36, while those of diets T24 and T36 (Table 3.7) did not differ statistically (P>0.05) but increased with incremental level of *Opuntia* cladodes. However, Einkamerer (2008) found no significant differences (P>0.05) between the apparent digestibility of the ash in all treatments. This conclusion by Einkamerer (2008) differs partly from the current study.

The digestible CP only increased (P<0.05) from diet T0 to T24 but was not affected (P>0.05) from diet T0 to T36 and from T24 to T36 over the period of 14-days (Table 3.7). Similar results were found for digestible CP intake from diet T24 to T36 on the 7-day period.

In Tables 3.5 and 3.7 the incremental values of the digestible CP are shown with higher inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes in the diets. The wide range was illustrated from treatment diets T0 to T24 or from T0 to T36. However, smaller changes occurred from diets T24 to T36 (Table 3.5 and Table 3.7).

The apparent ADF digestibility of experimental diet T36 was significantly higher (P<0.05) than diets T0 and T24. However, the ADF digestibility from diets T0 to T24 did not differ statistically (P>0.05) on the 14-day period (Table 3.7). But, that value increased with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes in diets. Different results were found by Zeeman (2005) and Einkamerer (2008). Zeeman (2005) obtained significant differences (P<0.05) between all treatment diets studied, namely T0, T12, T24 and T36. However, Einkamerer (2008) found the apparent ADF digestibility was significantly lower (P<0.05) between diet T0 and diets T24 and T36, namely diets that contain sun-dried and coarsely ground *Opuntia* cladodes to partly substitute lucerne hay.

According to the results in Table 3.7 there was no significant difference (P>0.05) between treatment diets in apparent digestibility of the NDF during the 14-day trial period. The same conclusion was reached by Zeeman (2005), but Einkamerer (2008) reported lower (P<0.05) digestibility of diet T0 compared to T36. No significant difference in apparent NDF digestibility was found in this study over the 14-day trial period, suggesting that the fibre present in the three treatment diets was almost equally digestible. However, a different result was shown for apparent digestibility of NDF during the 7-day period (Table 3.5).

The apparent GE digestibility coefficients of all treatments diets (T0, T24 and T36) did not differ statistically (P>0.05) during the 14-day period (Table 3.7). Conversely, Zeeman (2005) and Einkamerer (2008) obtained significant difference (P<0.05) for apparent digestibility of GE from diet T0 to diets T24 and T36. But these authors stated that the DE content of diets T24 and T36 did not differ (P>0.05). Ben Salem *et al.* (1996) and Tegegne (2002a) stated that the *Opuntia* cladodes contain more easily digestible carbohydrates, and that could explain the higher DE compared to diets with lucerne hay.

The apparent OM digestibility coefficients of treatment diets during the 14-day trial period decreased significantly (P<0.05) with the inclusion of *Opuntia* cladodes from diet T0 to diets T24 and T36 (Table 3.7), however the DOM content of diets T24 and T36 did not differ statistically (P>0.05; Table 3.7). In line with these findings, Zeeman (2005) and Einkamerer (2008) have also observed a significant increase (P<0.05) in apparently digestible OM in diet T36 when compared to diet T0, but no differences (P>0.05) between diets T24 and T0 as well as between T24 and 36.

The apparent digestibility of ash in the treatment diets increased significantly (P<0.05) from diet T0 to diets T24 and T36 (Table 3.7) during the 14-day trial period. But, the apparent digestibility of ash did not differ between treatments diets T24 and T36 (Table 3.7). In contrast, Einkamerer (2008) reported no significant differences (P>0.05) between the apparent ash digestibility of all treatment diets.

Comparing the two different trial periods (7-days or 14-days) the results in terms of apparent digestibility for most nutrients are in general similar, with very small differences in apparent digestibility coefficients as well as digestible energy content of the three treatments diets with incremental inclusion levels of sun-dried and coarsely *Opuntia* cladodes.

3.1.4 Water intake and urine excretion

The water intake and urine excretion from the 18 Dorper wethers, divided in two groups of nine animals each, were measured. The first group of wethers was slaughtered seven days after the start of the trial and the second group was slaughtered 14-days after the start of the trial.

3.1.4.1 Water intake and urine excretion during the 7-day trial period

The daily water intake and urine excreted by the Dorper wethers on the different treatment diets (T0, T24, T36) during the first 7-day trial period are shown in Table 3.8.

Not statistically differences (P>0.05) between treatments T0, T24 and T36 were found in water intake on the 7-day trial period (Table 3.8). The results contrast with other studies

(Zeeman, 2005; Einkamerer, 2008) which concluded the water consumption increased with incremental levels of *Opuntia*. In this part of the study the water intake was measured over one week only, which is much shorter than in other studies that lasted longer (Zeeman, 2005; Einkamerer, 2008).

Table 3.8 Average (mean±s.e.) daily water intake and urine excretion by the Dorper wethers during the 7-day trial period on treatment diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments*				
	T0	T24	T36	P*	CV[1] (%)
Water intake (ml/day)	1993.3±75.1	2430.5±265.3	2295.2±273.78	0.42	17.35
Urine excreted (ml/day)	921.4±33.8	959.5±42.9	947.6±144.4	0.95	16.38

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

P* No statistical differences between means in the same row (P<0.05).

Although not statistically different between treatments, the water intake increased with the addition of *Opuntia* in diets (Table 3.8). This is in line with results by Cárdenas *et al.* (1997) and Tegegne (2002b) who reported that *Opuntia* cladodes contain a complex carbohydrate, mucilage with a great capacity to retain water. The mucilage may provide the capacity to retain water inside the cactus (Sudzuki, 1995), but this water could be unavailable for absorption, when cactus is fed to animals. As discussed previously cactus contain mucilage and that binds strongly to water, consequently feeding animals with cactus may increase their water intake.

In line with the results observed for water intake, urine excretion also showed no significant differences (P>0.05) between treatment T0, T24 and T36 (Table 3.8). Zeeman (2005) and Einkamerer (2008) obtained similar results.

Comparing the daily water intake and urine excretion between treatment diets T0 and T24, the Dorper wethers on diet T24 drank on average more water (± 450 ml) than the Dorper wethers on diet T0, but the difference of urine eliminated between each other (T0 and T24) was only 39 ml/day in favour of treatment diet T24 during the 7-day period (Table 3.8).

3.1.4.2 Water intake and urine excretion during the 14-day trial period

The daily water intake and excreted in urine by nine Dorper wethers fed the three treatment diets (T0, T24 and T36) during the 14-day trial period are presented in Table 3.9.

Table 3.9 Average (mean±s.e.) daily water intake and urine excretion by the Dorper wethers during the 14-day trial period on treatment diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments*				
	T0	T24	T36	P*	CV[1] (%)
Water intake (ml/day)	1436.2±160.2	2125.48±181.6	2578.1±430.3	0.08	24.13
Urine excreted (ml/day)	642.9±68.1	694.05±60.6	879.3±47.9	0.07	13.93

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

P* No statistical differences between means in the same row ($P<0.05$).

The daily water intake tended to increase with inclusion of *Opuntia* cladodes in the diet, but these differences were no significant ($P>0.05$; Table 3.9). Comparing the water intake for treatments T0 and T24 the average increase in water intake approximately 690 ml/day and on average each Dorper wether drank about 1 100 ml more water when *Opuntia* was added at 36%. The differences in water intake between treatments T24 and T36 were about 490 ml/day, more for Dorper wethers on diet T36. Regarding the water content of feeds, the total water intake was higher for diet T36 than diets T0 and T24 during the 14-day period.

With reference to urine excretion it seems that replacing lucerne by *Opuntia* has no effect ($P>0.05$) upon the urine excretion (Tables 3.8 and 3.9) within the 14-day trial period as discussed previously (see 3.1.4.1). The results reported by Zeeman (2005) and Einkamerer (2008) are similar to the present study.

However, regardless of the lack of statistical differences, there is a clear tendency for higher water intake and urine excretion (Table 3.9) because P values are close to 0.05 (Table 3.9). For that reason one should consider some effects (an increase) in water intake and urine excretion between treatments T0, T24, and T36. As more *Opuntia* cladodes were added in the diets, more water was consumed and more urine was eliminated.

Comparing water intake and urine excretion of the Dorper wethers between the two periods studied (7-days or 14-days) there was a slightly tendency to decreased water intake and urine excretion from the 7-day to the 14-day periods (Table 3.8 and Table 3.9 respectively).

3.2 Chemical composition of the digesta in different segments of the gastrointestinal tract

As discussed previously (see 2.6), samples of digesta in different segments of the GIT of each Dorper wether were collected, dried and stored for chemical analysis. These included DM, CP, NDF and ADF, lipid (fat), energy, ash and OM. The purpose was to study the changes in the chemical composition of the digesta in different segments of the GIT of Dorper wethers, subjected to different diets in two trial periods (7-days or 14-days).

3.2.1 Chemical composition of the digesta in the reticulo-rumen

Digesta from the rumen and reticulum were collected together (see 2.6.1) and chemical analyses were done for the two different periods and the results are presented in Table 3.10 and Table 3.11, respectively for the 7-day and 14-day trial periods.

Table 3.10 Digesta composition (mean±s.e.) in the reticulo-rumen of Dorper wethers at the end of the 7-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/kg)	155.2 ± 8.6^{a}	153.2 ± 11.3^{a}	157.4 ± 6.3^{a}	0.95	9.98
Crude protein (g CP/kg)	180.2 ± 4.2^{b}	176.0 ± 1.9^{b}	212.4 ± 10.4^{a}	0.02	6.01
Acid-detergent fibre (g ADF/kg)	530.2 ± 1.2^{a}	478.9 ± 5.1^{b}	462.9 ± 8.3^{b}	0.0004	2.01
Neutral-detergent fibre (g NDF/kg)	732.99 ± 2.2^{a}	$686.7\pm8.3^{a,b}$	667.3 ± 18.3^{b}	0.02	2.90
Lipid (g lipids/kg)	22.3 ± 1.8^{a}	21.93 ± 3.8^{a}	30.6 ± 2.9^{a}	0.14	20.60
Gross energy (MJ GE/kg)	20.05 ± 0.29^{a}	19.01 ± 0.16^{a}	19.96 ± 0.65^{a}	0.24	3.72
Ash (g ash/kg)	916.3 ± 5.0^{a}	922.2 ± 2.5^{a}	924.0 ± 1.0^{a}	0.80	9.09
Organic matter (g OM/kg)	905.7 ± 5.1^{a}	909.8 ± 2.1^{a}	909.8 ± 6.2^{a}	0.80	0.92

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at P<0.05.

There were no significant (P>0.05) differences in the DM, lipid, GE, ash and OM of digesta content of the reticulo-rumen of Dorper wethers on the three diets at the end of a 7-day trial period (Table 3.10). There was a slight increase in the lipid content of the digesta of the reticulo-rumen commensurate with 36% incremental level of *Opuntia* cladodes in the diet (Table 3.10). The variation in DM, GE, ash and OM content of digesta of the reticulum and rumen between the three treatments diets (T0, T24 and T36) at the end of the 7-day trial period was very low, but the ash content of the digesta in the reticulo-rumen content tended to increase with incremental levels of *Opuntia* cladodes in the diet. Furthermore, no variation was noted on OM content of digesta of the reticulo-rumen between treatment diets T24 and T36 at the end of this period. The highest digesta lipid content in the reticulo-rumen (P>0.05) was recorded on the treatment diet T36.

The digesta CP content of the reticulo-rumen on diet T36 (Table 3.10) was significantly (P<0.05) higher than that from diets T0 and T24 but the CP content of Dorper wethers in these diets (T0 and T24) were similar (P>0.05) at the end of the 7-day trial period.

The low NDF as well as ADF content of *Opuntia* cladodes had a significant (P<0.05) influence on the digesta ADF and NDF contents of the reticulo-rumen (Table 3.10). The highest digesta ADF and NDF content was on diet T0, while the lowest digesta ADF and NDF contents were recorded on diet T36. But, no significance difference (P>0.05) were showed in digesta regarding ADF and NDF contents of the reticulo-rumen with inclusion of *Opuntia* cladodes in diets T24 and T36. In this study the digesta NDF content in the reticulo-rumen of diet T24 did not differ significantly (P>0.05) from that of diets T0 and T36.

Slightly different results were obtained at the end of the 14-day trial period (Table 3.11) compared to the 7-day trial period discussed previously. But at the end of the 14-day trial period all digesta chemical content (DM, CP, NDF, ADF, GE, ash, OM) of the three treatments diets (T0, T24 and T36) (see 3.2.1; Table 3.11) did not differ significantly (P>0.05). Similarly to what was discussed for the 7-day trial period, the digesta ADF content decreased with increased levels of *Opuntia* cladodes in the diets (Table 3.11).

In the present trial the digesta lipid content in the reticulo-rumen of treatment T0 could not be analysed because not enough sample material was recovered to analyse. Comparing digesta lipid content of the other two treatments diets namely T24 and T36, no significant differences

(P>0.05) between each other were observed, but a slight increase of those chemical components were observed with a level of 36% sun-dried and coarsely *Opuntia* cladodes in treatment diets (Table 3.11).

Table 3.11 Digesta composition (mean±s.e.) in the reticulo-rumen of Dorper wethers at the end of the 14-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/kg)	159.5±3.7[a]	176.4±7.3[a]	170.4±3.3[a]	0.14	5.20
Crude protein (g CP/kg)	183.3±18.6[a]	179.4±14.1[a]	174.2±11.2[a]	0.91	14.49
Acid-detergent fibre (g ADF/kg)	497.1±13.4[a]	488.6±7.4[a]	472.2±22.3[a]	0.55	5.56
Neutral-detergent fibre (g NDF/kg)	692.94±24.0[a]	696.2±3.6[a]	712.2±11.3[a]	0.74	3.94
Lipid (g lipids/kg)	-	23.1±2.7[a]	24.4±5.5[a]	0.18	22.58
Gross energy (MJ GE/kg)	20.38±0.36[a]	20.04±.0.72[a]	19.76±1.15[a]	0.87	7.00
Ash (g ash/kg)	83.8±4.0[a]	77.2±2.5[a]	76.0±1.0[a]	0.36	7.70
Organic matter (g OM/kg)	916.3±4.0[a]	922.8±2.5[a]	924.0±1.0[a]	0.36	0.66

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at P<0.05.

3.2.2 Chemical composition of the digesta in the omasum

The digesta chemical composition in the omasum of Dorper wethers used in this trial is presented in Tables 3.12 and 3.13, respectively at the end of the 7- and 14-day trial periods.

From Table 3.12 it was apparent that significantly lower (P<0.05) concentrations of DM, CP and lipid occurred in the digesta content of the omasum on treatment diets T0 to T36. Comparing diets T0 and T24 no significant differences (P>0.05) were present in DM and lipid content of omasum digesta, but CP digesta content of the omasum was significantly higher on treatment diet T24 (P<0.05) when compared to treatment diet T0.

Table 3.12 Composition (mean±s.e.) of digesta from the omasum of the Dorper wethers at the end of the 7-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/kg)	219.0±5.9^{a}	240.0±7.2^{a,b}	256.2±3.1^{b}	0.01	4.13
Crude protein (g CP/kg)	121.4±7.8^{a}	198.6±4.1^{b}	196.5±7.6^{b}	0.02	6.01
Acid-detergent fibre (g ADF/kg)	494.1±17.3^{a}	424.3±3.1^{b}	405.0±5.0^{b}	0.002	4.13
Neutral-detergent fibre (g NDF/kg)	662.2±10.8^{a}	-	597.3±15.9^{a}	0.06	3.19
Lipid (g lipids/kg)	25.5±0.1^{a}	38.9±3.9^{a,b}	44.62±4.3^{b}	0.02	16.04
Gross energy (MJ GE/kg)	17.39±0.19^{a}	18.24±0.53^{a}	18.36±0.1^{a}	0.22	3.44
Ash (g ash/kg)	141.3±14.4^{a}	124.9 ±1.8^{a}	155.4±14.0^{a}	0.41	14.44
Organic matter (g OM/kg)	858.7±14.4^{a}	875.1±1.8^{a}	844.6±14.0^{a}	0.41	2.36

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at P<0.05.

The concentrations of ADF that occurred in omasum digesta content were significantly higher (P<0.05) in the T0 diet when compared with that of diets T24 and T36 in this study (Table 3.12). Higher incremental levels of sun-dried and coarsely ground *Opuntia* cladodes in the diets led to smaller ADF concentration in omasum digesta content. This confirms what was previously discussed (see 3.1.1). There was a definite decrease in the ADF content of the three diets (Table 3.1) commensurate with the incremental inclusion level of sun-dried and coarsely ground *Opuntia* cladodes.

No significant differences (P>0.05) were noted on the concentration of NDF on omasum digesta content (Table 3.12) whilst comparing two treatment diets utilized in this trial, namely T0 and T36. But, the NDF concentration in omasum digesta decreased when *Opuntia* cladodes was added on the diet to partly substitute lucerne hay.

No significant differences (P>0.05) were observed between the treatment diets in GE, ash and OM on omasum digesta as *Opuntia* cladodes incrementally substituted lucerne hay (Table 3.12).

Table 3.13 Composition (mean±s.e.) of digesta from the omasum of the Dorper wethers at the end of the 14-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P*	CV[1] (%)
Dry matter (g DM/kg)	244.3±6.7	240.0±5.6	245.1±2.5	0.77	3.73
Crude protein (g CP/kg)	162.1±18.1	193.8±21.2	216.0±25.0	0.28	19.63
Acid-detergent fibre (g ADF/kg)	461.4±14.7	414.6±23.6	392.5±16.3	0.10	7.62
Neutral-detergent fibre (g NDF/kg)	630.8±60.6	609.6±36.7	-	0.38	7.39
Lipid (g lipids/kg)	42.7±6.0	44.2±3.7	32.0±14.9	0.64	41.66
Gross energy (MJ GE/kg)	18.58±0.36	19.63±.0.36	19.31±0.38	0.19	3.27
Ash (g ash/kg)	153.8±12.4	120.0±3.2	150.8±3.0	0.36	7.70
Organic matter (g OM/kg)	846.2±12.4	880.1±3.2	849.2±3.0	0.15	1.81

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

P* No statistical differences between means in the same row ($P<0.05$).

From Table 3.13 it is evident that there are no significant effects ($P>0.05$) of *Opuntia* in the concentration of all chemical constituents considered in the omasum digesta at the end of the 14-day trial period. Similar results were also observed in the same period in the reticulo-rumen digesta (see Table 3.11). However, Table 3.13 shows a clear tendency for increased CP concentration with incrementally levels of *Opuntia* cladodes in diets. Slightly incremental levels of GE were also seen when *Opuntia* cladodes were added in the diets (Table 3.13). Moreover, ADF and NDF concentrations in the omasum digesta decreased as *Opuntia* incrementally increased in treatment. These results are in agreement with what was discussed previously (see 3.1.1 and 3.2.2).

Comparing the results of the omasum digesta contents at the end of the 7- and 14-day trial periods, similar GE, ash contents were recorded in all diets ($P>0.05$; Tables 3.12 and 3.13).

3.2.3 Chemical composition of the digesta contained in the first 10 m of the small intestine (duodenum and anterior jejunum)

The chemical composition of the digesta collected from the first 10 m of the small intestine, was analysed at the end of the two trial periods. The results are presented in Tables 3.14 and 3.15, respectively for the 7-day and 14-day trial periods.

Table 3.14 Composition (mean±s.e.) of digesta collected from the first 10 m of the small intestine of the Dorper wethers at the end of the 7-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P*	CV[1] (%)
Dry matter (g DM/kg)	123.6±6.4	110.1±11.9	114.5±9.2	0.61	14.07
Crude protein (g CP/kg)	518.2±68.6	519.7±51.2	511.8±40.8	0.99	18.35
Acid-detergent fibre (g ADF/kg)	94.9±33.2	86.5±34.7	89.3±2.9	0.98	53.30
Lipid (g lipids/kg)	72.1±5.6	95.6±4.3	-	0.07	11.09

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

P* No statistical differences between means in the same row ($P<0.05$).

Table 3.15 Composition (mean±s.e.) of digesta collected from the first 10 m of the small intestine of the Dorper wethers at the end of the 14-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P*	CV[1] (%)
Dry matter (g DM/kg)	131.5±5.2	115.2±1.7	127.3±7.1	0.14	7.23
Crude protein (g CP/kg)	541.5±21.8	509.4±24.8	519.0±5.7	0.52	6.40
Acid-detergent fibre (g ADF/kg)	71.1±18.2	82.2±17.2	65.9±5.0	0.74	34.99
Lipid (g lipids/kg)	70.4±1.7	73.0±0.8	74.2±8.9	0.87	12.54

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

P* No statistical difference between means in the same row ($P<0.05$).

Samples of small intestine digesta collected were small and had not enough DM to do all the chemical analysis and, therefore, only results for DM, CP, ADF and lipid content for the first part of the small intestine digesta are presented.

The average DM, CP, ADF and lipid concentration of the digesta from the first 10 m of the small intestine digesta did not differ significantly (P>0.05) with incremental levels of *Opuntia* in the diets at end of the 7- and 14-day trial periods (Table 3.14 and Table 3.15), respectively.

3.2.4 Chemical composition of the digesta contained in the last 3 m of the small intestine (posterior jejunum and ileum)

The chemical composition of the intestinal digesta contained in the last 3 m of the small intestine of the Dorper wethers as influenced by incremental levels of sun-dried and coarsely grounded *Opuntia* cladodes at end of the two different trial periods are presented in Tables 3.16 and 3.17, respectively for the 7- and 14-day trial periods.

No significant differences (P>0.05) were observed for all components considered in the digesta collected from the last 3 m of the small of Dorper wethers at the end of both periods, namely the 7- and 14-day trial periods (Tables 3.16 and 3.17, respectively). These results are in line with those found in the first 10 m of the small intestine of Dorper wethers (see 3.2.3).

The CP values of CP concentration were lowest in the digesta collected from the last 3 m of the small intestine of Dorper wethers that were given treatment diet T36 at the end of the 7-day trial period (Table 3.16). However, different results were obtained at the end of the 14-day trial period. The lowest CP concentrations were present in digesta of Dorper wethers on treatment diet T24 and the highest demonstrated in treatment diet T36 (Table 3.17).

The ADF concentration in the digesta of the last 3 m of the small intestine decreased with increasing inclusion level of sun-dried and coarsely ground *Opuntia* cladodes substituting lucerne hay in Dorper wether diets at the end of both the 7- and 14-day trial periods (Table 3.16 and 3.17). The only exception was the GE contents in the digesta of the last 3 m of the small intestine. The GE values in both tables (Tables 3.16 and 3.17) were statically higher (P<0.05) for diets containing *Opuntia* at the end of both trial periods.

Table 3.16 Composition (mean±s.e.) of digesta collected from last 3 m of the small intestine of Dorper wethers at the end of the 7-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P*	CV[1] (%)
Dry matter (g DM/kg)	108.5±4.3	92.1±14.1	124.5±19.8	0.34	22.81
Crude protein (g CP/kg)	215.6±26.1	208.6±8.1	151.6±1.3	0.10	17.14
Acid-detergent fibre (g ADF/kg)	339.0±12.2	249.3±53.1	247.6±18.8	0.17	20.68
Lipid (g lipids/kg)	33.2±12.1	21.3±2.8	44.9±24.7	0.64	41.66
Gross energy (MJ GE/kg)	16.37±0.14^{a}	18.47±0.34^{a}	-	0.0131	2.20

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

P* No statistical differences between means in the same row (P<0.05).

Table 3.17 Composition (mean±s.e.) of digesta collected from last 3 m of the small intestine of Dorper wethers at the end of the 14-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/kg)	95.9±4.0^{a}	95.7±5.04^{a}	98.2±5.8^{a}	0.93	8.98
Crude protein (g CP/kg)	219.3±12.7^{a}	212.2±18.3^{a}	278.0±39.3^{a}	0.23	19.11
Acid-detergent fibre (g ADF/kg)	360.6±10.5^{a}	326.2±12.0^{a}	208.4±64.7^{a}	0.03	14.36
Lipid (g lipids/kg)	22.0±3.0^{a}	24.7±1.73^{a}	_	0.65	14.47
Gross energy (MJ GE/kg)	16.8±0.5^{a}	18.2±0.7^{b}	_	0.01	2.20

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at P<0.05.

3.2.5 Chemical composition of digesta collected from the caecum

The of chemical composition of the caecal digesta of Dorper wethers as influnced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes at end of the two trial periods (7- and 14-days) are summarized in Tables 3.18 and 3.19, respectively.

Table 3.18 Composition (mean±s.e.) of the caecum digesta collected from Dorper wethers at the end of the 7-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

Chemical constituents	Treatments *			P	CV[1] (%)
	T0	T24	T36		
Dry matter (g DM/kg)	117.1±16.1[a]	124.2±5.3[a]	129.2±7.2[a]	0.06	13.15
Crude protein (g CP/kg)	107.0±6.9[a]	131.8±5.6[a]	133.9±2.0[b]	0.02	7.31
Acid-detergent fibre (g ADF/kg)	357.0±45.9[a]	322.5±18.2[a]	289.4±22.6[a]	0.23	16.68
Neutral-detergent fibre (g NDF/kg)	377.6±23.1[a]	431.7±32.0[a]	355.1±9.9[a]	0.21	11.14
Lipid (g lipids/kg)	22.2±2.5[a]	25.3±2.6[a]	28.9±2.3[a]	0.23	16.68
Gross energy (MJ GE/kg)	13.96±1.34[a]	16.11±0.0.82[a]	14.62±0.98[a]	0.41	12.45
Ash (g ash/kg)	310.2±67.9[a]	213.5 ±26.3[a]	269.7±21.1[a]	0.41	30.65
Organic matter (g OM/kg)	689.8±67.9[a]	786.5±26.3[a]	730.3±21.1[a]	0.41	10.98

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Results followed by different superscripts within the same row differ significantly at P<0.05.

The DM and lipid concentrations in the ceacal digesta collected at the end of the 7-day trial period increased with incremental levels of *Opuntia* cladodes in the diets, but was not statistically significant (P>0.05). The DM content increased with higher levels of *Opuntia* in the diet (P=0.06). However, the inclusion CP content in the ceacal digesta increased significantly (P<0.05) with the inclusion of *Opuntia* to the diet (Table 3.18), but within treatment diets with *Opuntia* cladodes (T24 and T36) no significant effect (P>0.05) was observed at the end of the 7-day trial period.

The ADF content of the ceacum digesta decreased as the inclusion level of sun-dried and coarsely *Opuntia* cladodes increased during the 7-day trial period but did not differ statistically (P>0.05). These results were in agreement with those previously discussed (see 3.1.1).

Conversely, no significance effect (P>0.05) was found in the other chemical content such as OM, ash, NDF and GE between treatments for the 7-day trial period.

The chemical composition of the ceacum digesta were similar for all dietary treatments after the 14-day trial period (P>0.05). These results were found in other sites of the gastrointestinal tract, previously discussed. Although, the NDF and ADF concentration in ceacum digesta decreased when *Opuntia* cladodes was added in diets (Table 3.19) but after a 14-day trial period the differences were not significant (P>0.05).

The lipid content in the ceacal digesta increased slightly as the level of *Opuntia* cladodes in the diet increased (Table 3.19), but these were not statistically different (P>0.05).

Table 3.19 Composition (mean±s.e.) of the caecum digesta collected from Dorper wethers at the end of the 14-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P*	CV[1] (%)
Dry matter (g DM/kg)	152.2±5.7	131.5±12.9	149.7±8.1	0.31	11.25
Crude protein (g CP/kg)	126.7±3.2	136.6±9.6	183.1±46.4	0.36	31.93
Acid-detergent fibre (g ADF/kg)	399.1±17.6	314.3±34.9	245.1±60.2	0.10	22.46
Neutral-detergent fibre (g NDF/kg)	447.5±71.1	417.8±59. 7	289.1±33.4	0.31	26.17
Lipid (g lipids/kg)	26.1±1.7	26.6±1.9	35.6±11.2	0.55	38.99
Gross energy (MJ GE/kg)	16.38±0.99	15.23±1.35	16.70±0.48	0.65	11.59
Ash (g ash/kg)	219.6±30.6	248.2±78.5	231.6±41.5	0.93	41.16
Organic matter (g OM/kg)	781.0±30.6	751.8±78.5	768.4±41.5	0.93	12.51

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

P* No statistical differences between means in the same row (P<0.05).

3.2.6 Chemical composition of the digesta collected from the spiral colon

The chemical composition of the digesta content of the spiral colon (last 1 m of the *gyrus centripetalis* from the *flexura centralis)* of 18 Dorper wethers as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes at end of two different trial periods (7-days or 14-days) are shown in Tables 3.20 and 3.21, respectively. Not all chemical analysis was done due to the limited amount of digesta content recovered from this segment of the GIT of the Dorper wethers.

Table 3.20 Composition (mean±s.e.) of the digesta collected from the spiral colon (last 1 m of the *gyrus centripetalis)* of the Dorper wethers at the end of the 7-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/kg)	213.4±18.8[a]	151.1±8.7[a,b]	156.9±9.5[b]	0.03	13.12
Crude protein (g CP/kg)	124.9±1.6[a]	148.5±5. 7[a,b]	152.9±9.1[b]	0.04	7.60
Acid-detergent fibre (g ADF/kg)	377.1±33.3[a]	316.1±30.7[a]	267.9±4.07[a]	0.07	14.19
Lipid (g lipids/kg)	47.3±22.2[a]	30.2±3.1[a]	41.3±12.06[a]	0.71	64.15
Gross energy (MJ GE/kg)	17.62±0.90[a]		15.55±0.15[a]	0.20	7.93

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at P<0.05.

The DM content of the digesta of Dorper wethers fed diet T0 collected from the spiral colon region was significantly higher (P<0.05) than that in diet T36, while a similar composition was found in treatments T24 and T36 at the end of the 7-day trial period (Table 3.20). Moreover, there was a marked decreased in the DM digesta collected from the spiral colon region (Table 3.20) commensurate with the incremental inclusion levels of *Opuntia* cladodes in the diets. These findings confirmed the results of Zeeman (2005) and are also in line with the DM composition of the three treatment diets and feed intake recorded during the first seven days of this trial (see 3.1.1 and 3.1.3.1).

There was a significant higher (P<0.05) CP digesta content from the spiral colon region of Dorper wethers fed diet T36 when compared to those on diet T0 at the end of the 7-day trial period (Table 3.20). However, no differences were observed between diets T24 and T36 or T0 (P>0.05). These results are in agreement with findings of previous chemical composition of diets in this study (see 3.1.1) and other authors (Ben Salem *et al.*, 2002; Tegegne, 2002; Batista *et al.,* 2003; Zeeman, 2005; Einkamerer, 2008). But, it must be noted that feed grade urea was added to balance the CP concentration of the two treatment diets containing *Opuntia* (T24 and T36; see Table 2.1).

ADF, lipid and GE content of the digesta collected from the spiral colon region of Dorper wethers at the end of the 7-day trial period were similar in all groups (P>0.05). However, the ADF concentration tended to decrease as *Opuntia* cladodes were incrementally added to the diet (Table 3.20).

Table 3.21 Composition (mean±s.e.) of the digesta collected from the spiral colon (last 1 m of the *gyrus centripetalis)* of the Dorper wethers at the end of the 14-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/kg)	181.1±23.2^a	171.6±17.7^a	156.6±10.1^a	0.64	18.18
Crude protein (g CP/kg)	138.5±4.1^a	161.9±6.5^a	155.4±18.2^a	0.39	12.99
Acid-detergent fibre (g ADF/kg)	427.8±19.3^a	302.6±38.7^b	302.2±32.5^b	0.05	15.71
Lipids (g lipids/kg)	31.7±0.3^a	30.5±2.5^a	29.8±3.2^a	0.83	12.43
Gross energy (MJ GE/kg)	18.17±0.21^a	-	17.37±0.79^a	0.56	5.59

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

^{a,b} Means followed by different superscripts within the same row differ significantly at P<0.05.

From the results presented in Table 3.21, it is clear that except for the ADF content, the inclusion of *Opuntia* cladodes to the treatment diets, had no significant effect (P>0.05) on all other constituents of the digesta in the *gyrus centripetalis* of the spiral colon. These results are in line with those found in other segments of the GIT at the end of the 14-day trial period (see 3.2.1 to 3.2.6).

The concentration of ADF of the digesta collected from the last part of the *gyrus centripetalis* of the spiral colon was significantly higher (P<0.05) in Dorper wethers fed diet T0, when compared to diets T24 and T36 at the end of 14-day trial period (Table 3.21). However, the ADF content of the digesta in this segment of the lower GIT was similar (P>0.05) on diets with *Opuntia* (T24 and T36) at the end of the 14-day trial period (Table 3.21).

3.2.7 Chemical composition of the digesta from the last 3 m of the gastrointestinal tract (colon *descendens* and rectum)

The chemical composition of the digesta collected from the last 3 m of the GIT of Dorper wethers at the end of the 7- and 14-day trial periods are illustrated in Tables 3.20 and 3.21, respectively.

Table 3.22 Composition (mean±s.e.) of the digesta collected from the last 3 m of the GIT (colon *descendens* and rectum) of Dorper wethers at the end of the 7-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/kg)	353.3±24.2[a]	172.5±15.4[b]	184.9±9.8[b]	0.001	12.80
Crude protein (g CP/kg)	127.4±4.1[a]	188.0±33.5[a]	154.2±4.6[a]	0.17	21.77
Acid-detergent fibre (g ADF/kg)	415.6±24.4[a]	331.5±24.2[a,b]	270.3±7.5[b]	0.01	9.38

Inclusion level of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at $P<0.05$.

Table 3.23 Composition (mean±s.e.) of the digesta collected from the last 3 m of the GIT (colon *descendens* and rectum) of Dorper wethers at the end of the 14-day trial period as influenced by incremental levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments *				
Chemical constituents	T0	T24	T36	P	CV[1] (%)
Dry matter (g DM/kg)	352.1±36.4[a]	182.5±4.3[b]	191.2±5.3[b]	0.002	15.32
Crude protein (g CP/kg)	129.1±1.6[a]	173.0±6.7[b]	168.4±5.5[b]	0.04	10.79
Acid-detergent fibre (g ADF/kg)	419.3±19.7[a]	286.5±43.2[a]	306.3±28.1[a]	0.05	16.36
Lipid (g lipids/kg)	35.9±2.4[a]	33.1±0.8[a]	44.3±11.8[a]	0.63	34.28
Gross energy (MJ GE/kg)	21.48±1.96[a]	16.28±0.81[a]	18.97±1.38[a]	0.18	10.92

*Inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes: T0 - 0%; T24 - 24%; T36 - 36%

[1] Coefficient of variance

[a,b] Means followed by different superscripts within the same row differ significantly at $P<0.05$.

The DM concentration of the digesta from the last 3 m of the GIT (colon *descendens* and rectum) of Dorper wethers fed on treatment diet T0 for 7- or 14-day periods was much higher (P<0.05) than those fed on diets containing sun-dried and coarsely ground *Opuntia* cladodes (T24 and T36). Comparing the DM content of the rectum digesta in the last part of the GIT of Dorper wethers fed diets T24 and T36 no significant effect was noted (P>0.05) in both trial periods (7- and 14-days; Tables 3.22 and 3.23, respectively). Similar results were reported by Zeeman (2005).

Different results were observed for the CP content of the digesta of the last 3 m of the GIT at the end of both trial periods (7- and 14-days). The CP content of the digesta in the last part of the GIT was affected (P<0.05) by inclusion of *Opuntia* cladodes in the diets. However, significantly higher levels (P<0.05) were recorded at the end of the 14-day trial period (Table 3.23). No significant differences (P>0.05) were recorded in the CP content of the digesta between diets T24 and T36. These results are in line with those obtained in other parts of the lower GIT of Dorper wethers, but only in the last 3 m these differences were significant.

Significantly lower ADF content (P<0.05) was recorded in the last 3 m of the GIT (colon *descendens* and rectum; Table 3.23) of Dorper wethers fed on the control diet (T0) when compared with those containing *Opuntia* cladodes at the end of the 7-day trial period (Table 3.22). However, at the end of the 14-day trial period, these differences were negligible (P>0.05; Table 3.23). Moreover, the ADF content of the digesta in the rectum of Dorper wethers fed both diets containing *Opuntia* (T24 and T36) was similar at the end of both trial periods (Tables 3.22 and 3.23). These results confirm that the inclusion of the sun-dried and coarsely ground *Opuntia* cladodes in the diet reduced its ADF content (see 3.1.1).

However, ADF content in the rectum digesta tends to reduce when *Opuntia* cladodes was added in treatment diets (Table 3.22 and Table 3.23). This confirms that the ADF concentration decreased with increasing inclusion levels of *Opuntia* cladodes in experimental diets (see 3.1.1) and corresponds with findings of Zeeman (2005) and Einkamerer (2008).

The lipid and GE concentrations of the rectum digesta of the Dorper wethers in the 14-day trial period were remarkably similar (P>0.05). The digesta after a 7-day trial period was not analyzed because samples could only be retrieved of the rectum digesta of the Dorper wethers on treatment diet T0.

The NDF, OM, and ash content were not analysed because the sample of rectum digesta recovered was too little for these purpose in both the 7-day and 14-day trial periods (Table 3.22 and Table 3.23).

3.3 Histological characteristics of segments of the lower gastrointestinal tract

Tissue samples were collected from different parts of the lower GIT (from the ileum to colon wall) from slaughtered Dorper wethers at the outset of the trial (base reference values) and at the end of the 7- and 14-day trial periods (see 2.7 and 2.7.1) for histological analysis. Microscopic parameters evaluated included the thickness of the intestinal mucosa, the cell population constituting the intestinal mucosa, presence of inflammatory cells and other mucosal alterations, such as ulcerations, oedema, glandular atrophy, metaplastic changes, fibrosis, and abnormalities in the sub-mucosal and *muscularis propria* layers of the intestinal wall.

The histologic microscopic examination of sections of caecum (marked as the H0 position) showed no differences (pathologic abnormalities) between control subjects (T0) and test animals (T24 and T36), neither between the test subjects themselves. In contrast to the mucosa of the other regions, the caecal area demonstrated the largest complement of Paneth cells in the intestinal crypts. Numerous specimens also showed the presence of submucosal lymphoid tissue, consisting of aggregates of lymphoid follicles, which may be regarded as a normal histological finding in the caecum.

Similarly, the microscopic examination of sections of specimen's marked H1 position (*colon spiralis*, in the last 1 m of the *gyrus centripetalis*) also showed no differences (pathologic abnormalities) between control subjects (T0) and test animals (T24 and T36), neither between the test subjects themselves. Mucosal lymphoid follicles were noted in all young Dorper wethers tested, which can also be considered normal.

Microscopic examination of section H2, namely the *flexura centralis,* demonstrated no differences (pathologic abnormalities) between control subjects (T0) and test animals (T24 and T36). Exception was one Dorper wether submitted to diet T24 for a 7-day trial period that showed a focal region of acute inflammatory change accompanied by a reduction in the goblet cell population. As no other Dorper wether from treatments T24 and T36 at the end of both periods (7- and 14-day trial periods fed) showed similar changes, these were regarded as not being related to the effects of the diet, but rather to other non-specific factors.

Finally, the microscopic results of the colon *descendens* sampled 1.5 m from the anus (position H3), also showed no differences (pathologic abnormalities) between control subjects (T0) and test animals (T24 and T36), neither between the test subjects themselves.

In summary, the histological tests were inconclusive in terms of providing a better understanding of the commonly observed phenomena of wet faeces, often wrongly referred to as diarrhoea when sheep are fed considerable amounts of *Opuntia* cladodes. It does not look like that feeding *Opuntia* in balanced diets to sheep up to an inclusion level of 36% changes the histological characteristics of the large intestine (lower GIT) of sheep. Further research is warranted to the development of wet faeces on animals fed *Opuntia* cladodes.

4. Conclusions

This research program at the University of the Free State aims to characterize and evaluate *Opuntia ficus-indica* as a feed source for inclusion at substantial levels in balanced diets for ruminants. Therefore, it is important to determine practical inclusion levels of *Opuntia* in diets to replace plant material from more expensive and less water-efficient feed sources.

Opuntia ficus-indica is a very productive plant and is well adapted to a wide range of soils and dry regions, capable of producing high yields of cladodes (on a dry matter basis) with high nutritive value for ruminants. Despite the fact that several *Opuntia* species have been used as ruminant feed in many parts of the world, especially in the more arid and semi-arid areas of the world, very little scientific information is available on balanced ruminant diets with appreciable inclusion levels of *Opuntia* cladodes.

The inclusion of *Opuntia* cladodes in ruminant diets results in the production of wet faeces, often wrongly referred to as diarrhoea by many. The wet faeces are caused by the presence of mucilage in the *Opuntia* - a carbohydrate with a great capacity to bind water. The exact mechanisms involved in the production of wet faeces are not known. This might be a result of histological changes in the mucosa of the digestive tract, particularly in the large intestine where most water absorption takes place in ruminants. It might also be merely binding a large amount of water in the passage of digesta through the digestive tract.

In this study Dorper wethers were fed incremental levels (0, 24 and 36%) of sun-dried and coarsely ground *Opuntia* cladodes in balanced treatment diets for a 7- and a 14-day trial period. The feed and water intake, apparent digestibility and the urine and faecal excretion were determined and evaluated. The changes in chemical composition of the digesta and the histological characteristics at different segments of the gastrointestinal tract (GIT) were also studied.

The inclusion of sun-dried and coarsely ground *Opuntia* cladodes at levels of 24 and 36% in the balanced diets for Dorper wethers resulted in a small decrease of OM, CP, and GE of diets and a considerable drop in the ADF and NDF fractions. Although the EE content of diets was small, inclusion of sun-dried and coarsely ground *Opuntia* cladodes at these levels increased the lipid content. The results obtained in this present study concur with the general recommendation to add protein (including NPN) and energy sources to sheep diets with high inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes.

The inclusion of sun-dried and coarsely ground *Opuntia* cladodes at 24 and 36% levels as partial substitution of lucerne hay in diets of Dorper wethers had no adverse effects on feed intake during the 14-day period of the feeding trial. On the contrary, the daily feed intake of the Dorper wethers tended to increase with incremental inclusion levels of *Opuntia* cladodes in the diets, especially during the 14-day trial period. This suggested that incremental levels of sun-dried and coarsely ground *Opuntia* cladodes up to a level of 36% did not affect the palatability of the diets for Dorper wethers negatively and may perhaps even improve the palatability of the diets.

The voluntary daily water intake and urine excretion of the Dorper wethers increased with the incremental inclusion of sun-dried and coarsely ground *Opuntia* cladodes up to a level of 36% in the diet. Although these differences were negligible during the 7-day trial period, the differences were more evident during the 14-day trial period.

The Dorper wethers fed on a diet with 36% sun-dried and coarsely ground *Opuntia* cladodes drank on average about 1 100 ml/day more water and produced only 237 ml urine more per day, than those fed the control diet without *Opuntia* cladodes. This suggested that a substantial part of the induced higher water intake was secreted via another route, namely through the faeces. The faeces excreted by Dorper wethers fed on diets containing *Opuntia* cladodes were softer in consistency and contained visibly more water than those produced by animals fed on the control diet without *Opuntia* cladodes.

The daily nutrient intake of DM, CP, GE, and OM was not affected by the inclusion of *Opuntia* cladodes in the diet, but the intake of ADF and NDF tended to decline with incremental levels of *Opuntia* cladodes and the concomitant reduction of lucerne hay in the diet. It is important to note the increases in apparent digestibility of the DM, CP, and lipids of the diet as the inclusion levels of *Opuntia* cladodes increase to a 36% inclusion level.

The chemical composition of the digesta collected from different parts of the GIT of Dorper wethers fed on the three treatment diets appears not have been changed by the inclusion of sun-dried and coarsely ground *Opuntia* cladodes up to a level of 36% of the diet. Most changes that were observed at the end of the first 7-day trial period of the study occurred in the reticulo-rumen, omasum and in the lower GIT (colon and rectum). The inclusion of *Opuntia* cladodes to a level of 36% in the diet had a positive increasing effect on CP while the ADF content of the digesta was reduced. Very little changes were noted in the digesta contents of the small intestine.

The histological results showed no visible pathologic alterations in the mucosa of the GIT of Dorper wethers when ingesting sun-dried and coarsely ground *Opuntia* cladodes to a level of 36% in diets for a trial period of two weeks. Therefore, the reasons and mechanism whereby wet faeces are produced when sheep is fed diets containing considerable amounts of sun-dried and coarsely ground *Opuntia* cladodes were not histological demonstrable.

Based on the results of this study, it is concluded that inclusion of sun-dried and coarsely ground *Opuntia* cladodes as partial substitution of lucerne in balanced sheep diets has no detrimental effects at a 36% inclusion level. No detrimental effects were observed in feed intake, apparent digestibility, and histological characteristics of the GIT mucosa of young Dorper wethers.

Further research is needed to establish the optimum inclusion level of sun-dried and coarsely ground *Opuntia* cladodes in the diet of different ruminant species. It is also important to further investigate the effects of *Opuntia* cladodes in ruminant diets on the digestive processes and especially also on the renal functions. The physiologic and/or biochemical mechanisms (enteric secretion and/or absorptive alterations) responsible for the production of wet faeces in ruminants ingesting considerable amounts of *Opuntia* cladodes requires further investigation.

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