ANIMAL PERFORMANCE AND UTILIZATION OF *OPUNTIA*-BASED DIETS BY SHEEP

by

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Declaration

I hereby declare that this dissertation submitted by me to the University of the Free State for the degree **Magister Scientiae Agriculturae**, is my own independent work and has not previously been submitted by me at another University/Faculty. I further cede copyright of the dissertation in favour of the University of the Free State.

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Bloemfontein

30 May 2008

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Dedication

Dedicated to the Father, and to the Son and to the Holy Spirit

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1. Introduction

Harsh climatic conditions prevail in many parts of the world. Consequently livestock is subjected to chronic feed shortages and animal products (e.g. meat, milk and wool) are produced at considerably lower levels than the genetic potential of the ruminant animals (Ben Salem *et al*., 2002c). According to De Waal *et al*. (2006) the cladodes of spiny and spineless cactus pears (*Opuntia* spp.) are used as feed for livestock during the frequent periods of food shortages or droughts in many arid and semi-arid regions. Spineless cactus pears are valued by many farmers because of their drought resistance, high biomass yield, palatability and adaptability to a range of soils and climatic regions (Batista *et al*., 2003; Zeeman, 2005; De Waal *et al*., 2006; Gebremariam *et al*., 2006). It has been referred to as “camels of the plant world”, “nature’s fodder bank” and “living fodder banks” (De Kock, 1980; Ben Salem *et al*., 2002a; Tegegne, 2002a). The spineless cactus pear has a very high water content and when fed to animals little, if any, additional drinking water is needed for long periods.

According to Anaya-Pérez (2001) there are 377 species of the genus *Opuntia* of the Cactaceae family and are called *nopal*. The name “Opuntia” comes from an ancient Greek village in the region of Leocrid, Beocia: *Opus* or *Opuntia*. The genus *Opuntia* includes 11 subgenera, namely: *Opuntia*, *Consolea*, *Austrocylindropuntia*, *Brasiliopuntia*, *Corynopuntia*, *Cylindropuntia*, *Grusonia*, *Marenopuntia*, *Nopalea*, *Stenopuntia* and *Tephrocactus* (Scheinvar, 1995; Reynolds & Arias, 2001).

According to Sirohi *et al*. (1997) the *Opuntia* genus appears to have its centre of genetic diversity in Mexico where it is widely used as forage, fruit and vegetables (“nopalitos”). Nopalitos are young green cladodes (stem-like organs) known as vegetables of less than one month of age, and are widely used in traditional Mexican cooking (Brutsch & Zimmermann, 1993; Anaya-Pérez, 2001; Sáenz *et al*., 2004; Zeeman, 2005). According to Barbera (1995), consumption of nopalitos is exclusive to Mexico.

Along with maize (*Zea mays*) and agave (*Agave* spp.), *Opuntias* are among the oldest cultivated plants in Mexico (Anaya-Pérez, 2001; Reynolds & Arias, 2001). According to Barbera (1995) and Zeeman (2005), the presence of *Opuntia* in South Africa was first reported in 1772, but it is possible that the plant was introduced at an earlier stage. *Opuntia* *ficus-indica* is believed to have been introduced to South Africa at least 250 years ago and, at the end of the 18th century and in the earlier part of the 19th century, it had invaded an estimated 900 000 ha of natural pastures, mainly in the Eastern Cape (Brutsch & Zimmermann, 1995). There is evidence that only spineless forms were introduced to South Africa, and they reverted back to the original spiny form over a period of nearly 200 years. The reason may be that plants with smooth pads (cladodes) are utilized by animals and do not survive in the wild (Mondragón-Jacobo & Pérez-Gonzáles, 2001; Le Houérou, 2002).

In contrast with its traditional utilization as a fruit and vegetable plant in Mexico, *Opuntia* entered the wider international scene as a fodder crop (Mondragón-Jacobo & Pérez-Gonzáles, 2001). According to Anaya-Pérez (2001), this happened in the early 1600's with the introduction of cattle in the northern arid and semi-arid zones during the Spanish Colonial Period and post-independence with the consequent depletion of grasslands. This situation forced stockman to cut *Opuntia* cladodes and burn off (singe) the thorns to feed to the livestock on pastures.

In times of drought *Opuntia* acts as a life saving crop for both humans and animals (Reynolds & Arias, 2001). Since it grows in degraded land, it is important because of its abundance in areas where few other crops can grow. According to Reynolds and Arias (2001) and Gebremariam *et al*. (2006), it is estimated that 900 000 ha are worldwide under cultivation with *Opuntia* for forage production. Some species are naturalized weeds in countries such as South Africa and Australia, where the environmental conditions are particularly favourable. However, according to De Kock (1980) and Reynolds and Arias (2001), problems of developed countries are not necessarily the same as those of less developed countries, and what may be considered a weed in one country may be an important economic source of food in another.

According to Noble (1995) most species of plants (92 to 93%) are C_3 plants, whose first photosynthetic product is a 3-carbon compound. Only about 1% of plant species are C_4 plants (their first photosynthetic product is a 4-carbon organic acid). Such species are quite important ecologically and agronomically and includes sugar cane (*Saccharum officinarum*), sorghum (*Sorghum bicolor*), maize or corn (*Zea mays*) and many wild tropical grasses. In comparison with C_4, as well as C_3 crops [such as alfalfa or lucerne (*Medicago sativa*), rice

(*Oryza sativa*) and wheat (*Triticum vulgare*)], Crassulacean Acid Metabolism (CAM) plants such as *Opuntia* are generally viewed as very slow growers (Nobel, 1995; Zeeman, 2005).

The evolution of members of *Opuntia* in arid and semi-arid environments has led to the development of adaptive anatomical, morphological, and physiological traits, as well as particular plant structures, in which water is the main factor limiting the development of most plant species (Reynolds & Arias, 2001). Notable among these adaptations are asynchronous reproduction and CAM, which combined with structural adaptations such as succulence, enables this plant to reach acceptable productivity levels even in years of severe drought (Reynolds & Arias, 2001). Most plants have daytime stomatal opening so that carbon dioxide (CO_2) uptake occurs concomitantly with photosynthesis, which uses the energy of light to incorporate CO_2 from the atmosphere into a carbohydrate. Plants such as *Opuntia ficus-indica* have nocturnal stomatal opening, so net CO_2 uptake and water loss occur during the cooler part of the 24 hour cycle. This is the key to water conservation by CAM plants (Nobel, 1995; Nefzaoui & Ben Salem, 2002). The CAM plants save water during the photosynthetic process (Mondragón-Jacobo *et al*., 2001; Snyman, 2004) and tend to loose only 20 to 30% as much water compared to C_3 or C_4 plants for a given degree of stomatal opening.

Opuntia is characterized by a shallow, fleshy root system (side roots), with horizontal roots spreading (4 to 8 m) at a mean depth of about 15 to 30 cm to accumulate minerals from the upper part of the soil (Sudzuki Hills, 1995; Tegegne, 2001; Ben Salem *et al*., 2002c; Nefzaoui & Ben Salem, 2002; Snyman, 2006). It can form new roots within a few hours of wetting of a dry soil and disappear as soon as the soil dries out. This facilitates a quick response to light rainfall (Snyman, 2004). According to De Kock (1980) and Snyman (2006) the roots also have the ability to withdraw water from the soil at a stage when other crops fail to do so.

Opuntia is particularly attractive as a feed because of its efficiency of converting water to dry matter (DM) (Tegegne, 2001). Biomass production per unit of water used by *Opuntia* is on average three times higher than for C_4 plants and five times higher than for C_3 plants (Reynolds & Arias, 2001). Furthermore, Noble (2001) suggested that a useful index to express benefit:cost for gas exchange by plants is the water-use efficiency (WUE); the ratio of CO_2 fixed by photosynthesis to water lost by transpiration. According to De Kock (1980) and Azócar (2001), the WUE of *Opuntia* is 267 kg H_2O used per kg DM produced. This value shows that *Opuntia* is 1.14 times more efficient than *Atriplex nummularia*, 2.8 times more efficient than wheat, 3.75 and 7.5 times more efficient than lucerne and rangeland vegetation, respectively.

In terms of area and available water, three to four ha of spineless cactus can be planted compared to each ha of lucerne. According to De Kock (1980) the question thus arises whether it is not more advantageous for the stock farmer in arid regions to use his limited supply of water more efficiently to irrigate spineless cactus rather than, with the same amount of water, a smaller area of lucerne.

The Cactaceae family is characterized by the production of a hydrocolloid commonly known as mucilage (Sepúlveda *et al*., 2007) and is part of the dietary fibre. Furthermore, Sáenz *et al*. (2004) stated that it constitutes an important fraction of *Opuntia ficus-indica* cladodes and varies between 90 to 190 g/kg DM. According to Nefzaoui and Ben Salem (2002) it is generally believed that the function of mucilage is to help retain water inside the cactus. Mucilage is a complex polymeric substance of carbohydrate nature and belongs to the polysaccharides group, namely the heteroglycans (McDonald *et al*., 2002). Mucilage is composed of several chemical components that are resistant to the digestive enzymes of the digestive tract: among these components are cellulose, hemicellulose, pectin, lignin, and gums. However, according to McDonald *et al*. (2002) mucilage is almost completely indigestible by non-ruminant animals but can be broken down by the microbial population of the rumen.

This hydrocolloid, mucilage, presents a great capacity to imbibe water (Sáenz *et* al., 2004) and the distinct concern when feeding spineless cactus pear cladodes to ruminants is the production of very wet faeces (De Waal *et al*., 2006). According to De Waal *et al*. (2006) the wetter faeces produced on diets containing sun-dried cladodes is reminiscent of diarrhoea, presumably caused by the high water holding capacity. The wet faeces produced from diets containing dried cladodes may make *Opuntia* less attractive as a feed source, especially when animals are confined to kraals or feedlots on processed *Opuntia* diets. According to De Kock (1980) and De Waal *et al*. (2006) this wet faeces is not a disease symptom and apparently has no direct detrimental effect on the animal.

The capacity to produce new cladodes and to recover quickly from pruning by sprouting new cladodes is an important feature of *Opuntia* ensuring high sustainable fodder production (Mondragón-Jacobo & Pérez-Gonzáles, 2001). A well-tended *Opuntia* orchard planted with 2 500 plants/ha can produce more than 100 ton/ha after the 5th year of planting. If densities are increased up to 40 000 plants/ha on fertile soils with intensive management practices, such as irrigation and fertilization, yields may reach 400 t/ha (López-García *et al.*, 2001). Areas with mean summer rains of 300 to 600 mm are sufficient to ensure high yields and regular fruit development (Inglese, 1995).

Nobel (2001) explained that the four highest yielding C_3 crops have an average productivity of 38 ton/ha/year and the four highest yielding C_4 crops averages 56 ton/ha/year. Of greater importance for forage production in arid and semi-arid regions is the biomass productivity when rainfall is severely limiting. Under such circumstances the advantages of CAM become apparent for water conservation, as agaves and *Opuntias* produce more biomass per unit land area than do C_3 and C_4 plants under the same conditions (Felker, 1995; Inglese *et al*., 1995; Nobel, 2001).

According to Barbera (1995), Inglese *et al*. (1995) and Snyman (2006) the general view that cactus pear needs a low input to give high yields have been very misleading, to the extent that very limited scientific information is available to farmers and the importance of appropriate orchard management has been largely neglected.

The most common feed sources to complement *Opuntia* as a feed are lucerne (fresh or as hay), sorghum stover, maize meal, cotton meal, wheat and oat straw as well as sugar cane stalks or bagasse. However, due to the high costs of most feeds, the demand for *Opuntia* is increasing (López-García *et al.*, 2001). Unlike hay when it is stored in a barn, cactus on the field does not deteriorate in quality with storage (Felker, 2001). Another method of storage is to ensile *Opuntia* cladodes (Nefzaoui & Ben Salem, 2001).

The low DM content is not an impediment for *Opuntia* to be considered a good fodder, but its water content makes handling difficult and expensive. Harvesting a large amount of *Opuntia* and storing it near the trough before providing it in small batches to livestock could solve the problem (Cordeiro dos Santos & Gonzaga de Albiquerque, 2001), but only for a short period before the cladodes will start rotting. The same problem persists when transporting fresh

Opuntia cladodes over long distances (Felker, 1995). The very high water content of about 850 g/kg fresh cladodes makes transporting prohibitively expensive. Therefore, an important challenge is to dry a large volume of cladodes effectively enabling it to be transported to where it is needed as livestock feed. A practical drying method will also enable farmers with small cactus pear orchards to store pruned and dried material as a feed for their livestock (De Waal *et al*., 2006).

The effects of *Opuntia* on the voluntary feed intake and digestion by small ruminants have been studied (Nefzaoui *et al.*, 1993; Ben Salem *et al.*, 1996; Ben Salem *et al.*, 2002a,b,d; McMillan *et al*., 2002; Murillo *et al*., 2002; Tegegne, 2002a,b; Batista *et al*., 2003; Ben Salem *et al.*, 2004; Zeeman, 2005; Gebremariam *et al*., 2006). But, according to Tegegne *et al*. (2005a,b) and Gebremariam *et al*. (2006), cactus pear is given limited research attention in spite of its wide and common use as forage for ruminants. Thus, data on its nutritive value and digestibility is limited. However, there is no reference concerning its effects on animal products and particularly meat quality (Atti *et al.*, 2006). Studies have indicated that the digestibility of *Opuntia* cladodes is comparable with high quality hay and is variable in its nutritive value (Sirohi *et* al., 1997; Azócar, 2001; Felker, 2001; Zeeman, 2005; Misra *et al.*, 2006). It should be noted that *Opuntia* is not a balanced feed and should rather be considered as a cheap source of energy (Nefzaoui & Ben Salem, 2001; Tegegne *et al*., 2005b).

The utilization of spineless cactus will differ between farms according to circumstances, such as available labour, facilities, and the volume of spineless cactus available as feed (De Kock, 1980; Nefzaoui & Ben Salem, 2001, 2002). It is often recommended to use *Opuntia* for feeding livestock by grazing cladodes *in situ* (very low cost management with the grass layer between the shrubs available for grazing livestock) or cutting harvested cladodes into small pieces or strips (with adapted machinery or manually with knives; Cordeiro dos Santos & Gonzaga de Albiquerque, 2001; López-García *et al.*, 2001) and feeding them in a confined area. De Kock (1980; 2001) and Nefzaoui and Ben Salem (2001) suggested that chaffed spineless cactus pads can be dried on any suitable surface and then ground in a hammer mill through a 6 mm sieve. In the form of a coarse meal, the spineless cactus material is not only ingested better, but is also easier to store. A supply of processed spineless cactus can thus be stored for use during droughts.

The spineless cactus pear fruit industry in South Africa has increased considerably in recent years (Zeeman, 2005). Large quantities of fruits are exported annually and this means that large quantities of fresh cladodes also come available when the plants are pruned to stimulate fruit production (Zeeman, 2005; De Waal *et al*., 2006). These pruned fresh cladodes are to a large extent considered as waste material. According to Zeeman (2005) this creates the prospect of utilizing the large quantities of plant material that is yielded annually as a feed source for livestock. Most farmers who produce spineless cactus pear fruits feed some of the pruned fresh material to their livestock or turn it into silage. Since most of these farmers are not primarily livestock farmers, they do not keep enough livestock to utilize such large volumes of fresh plant material in a short period of time. If not, large volumes of pruned fresh cladodes that could have been utilized more efficiently as livestock feed, are simply chopped slightly and left in the orchards to decay (Zeeman, 2005).

Lucerne is a popular ingredient in ruminant diets but, it may be expensive because of its high demand, notably during periods of drought. Hence, Zeeman (2005) proposed that, if substantial quantities of dried and coarsely ground *Opuntia* cladodes can be included in ruminant diets without detrimental effect on animal production and performance, the substitution of lucerne in these diets with dried and coarsely ground *Opuntia* as an alternative feed source (considered a waste product by some), may turn it into a valuable livestock feed.

Zeeman (2005) included incremental levels (0, 120, 240 and 360 g/kg) of sun-dried and coarsely ground *Opuntia* cladodes in sheep diets to determine live weight gain, voluntary feed intake, water excreted in urine and faeces, apparent digestibility and rumen fermentation variables. Sheep live weight gain was measured over a period of 19 days (commensurate with a feed intake and digestibility trial). This period of 19 days was considered too short to determine effects of the *Opuntia* inclusion in diets on live weight changes. Therefore, this follow up study was designed to evaluate the voluntary feed intake and live weight gain of sheep over a longer experimental period of 70 days and also evaluate the effects on the carcass characteristics of sheep.

The objective of this study was to evaluate the effect of the incremental inclusion of sun-dried and coarsely ground *Opuntia ficus-indica* cladodes in balanced sheep diets as partial substitution of coarsely ground lucerne hay on live weight gain, voluntary feed intake, apparent digestibility of diets, and carcass characteristics.

Therefore, it was hypothesised that inclusion of sun-dried and coarsely ground *Opuntia* cladodes would not affect food intake, digestibility and performance of young Dorper wethers.

2. Materials and Methods

Cladodes of the spineless cactus pear *Opuntia ficus-indica* var. Algerian were used in this study and will be referred to in an abbreviated form as *Opuntia* cladodes.

2.1 Drying and processing of *Opuntia* cladodes

The *Opuntia ficus-indica* var. Algerian cladodes used in this study (2006) were produced during the preceding growing seasons of 2004/5 and 2005/6. The fruit producing *Opuntia* orchard is located on the farm Waterkloof, approximately 20 km West of Bloemfontein in the Free State Province, South Africa. The fresh *Opuntia* cladodes were transported within a few hours from being pruned to the campus of the University of the Free State for further processing. The dry matter (DM) content of the *Opuntia* cladodes was assumed to be about 100 to 150 g/kg fresh cladodes (Sirohi *et al*., 1997; Ben Salem *et al*., 2002a; Atti *et al*., 2006). It was estimated that about 800 kg DM of coarsely ground *Opuntia* cladodes was needed for the trial, thus 8 000 to 9 000 kg of fresh cladodes were harvested.

Following the procedures described by Zeeman (2005), the fresh *Opuntia* cladodes were cut lengthwise by hand into strips of approximately 15 to 25 mm using a single-machete fixed to a flat wooden surface (Figure 2.1; Plate 1). The thickness of the strips was in line with the proposal by Felker (1995) that *Opuntia* cladodes must be cut into strips of approximately 20 to 30 mm. The cladode strips were dried on corrugated zinc roofs of buildings in direct sunlight (Figure 2.1; Plate 2). The cladode strips were spread as evenly as possible and turned over frequently by using a hay fork to prevent overlapping of the cladode strips and consequently, moulding or rotting in places where air circulation and maximum direct sunlight were restricted (Zeeman, 2005).

During sunny days with a mean temperature of 30ºC and a slight breeze, the cladode strips were sufficiently dry within four to seven days to be ground through a hammer mill. Zeeman (2005) dried the *Opuntia* cladode strips in the sun by placing them next to each other in a single layer on wire mesh racks about 700 mm off the ground. Some space was allowed between strips to enhance air movement around it to promote faster drying.

Plate 1: A single-machete cutter to cut *Opuntia* cladodes lengthwise in strips.

Plate 2: *Opuntia* cladodes cut into 15 to 25 mm strips and drying in the sun on a corrugated zinc roof.

Plate 3: Sun-dried *Opuntia* cladode strips coarsely ground through a 20 mm sieve.

Figure 2.1 Illustrations of the single-machete cutter and processed *Opuntia* cladodes.

After a week of storage before being cut into strips, the cladodes were slightly dehydrated and dried faster in the sun (Zeeman, 2005). When the cladodes are stored for longer periods than a week, especially when stacked in a heap, the cladodes start rotting (the parts that were bruised started to rot very fast) and those parts have to be discarded.

After the partially dried *Opuntia* strips reached a DM content of between 700 to 850 g/kg, they were collected and ground in a hammer mill to pass through a 20 mm sieve (Figure 2.1; Plate 3). Several authors (De Kock, 1980, 2001; Nefzaoui & Ben Salem, 2001) proposed that the dried cladode strips should be ground through a 6 mm sieve. Experience showed that dried *Opuntia* strips tend to clog up the hammer mill during the grinding process. Even with the 20 mm sieve sticky juices were extruded. It is suspected that the mucilage in the *Opuntia* cladodes creates the sticky juice paste in the coarsely ground cladodes. This sticky juice required that the hammer mill be opened and cleaned regularly.

The coarsely ground and partially dried material was spread out again indoors on a dry, clean cement floor. The material was turned frequently to prevent moulding and help facilitate the drying process. The increased surface area of the coarsely ground cladodes promoted the drying process even more. Some of the *Opuntia* cladode strips passed unaffected through the 20 mm openings in the sieve of the hammer mill. These pieces were picked out by hand and ground again with a new batch to produce a more homogenous material (Zeeman, 2005). Overcast and rainy weather conditions prevailed during a short spell and the *Opuntia* cladodes affected at the time were dried within three to four days in a force draught oven at 65ºC.

2.2 Experimental diets

The treatments were designed according to the incremental inclusion of 0, 240 and 360 g/kg of sun-dried and coarsely ground *Opuntia* cladodes in three balanced diets designated T0, T24 and T36, respectively. The composition of the three treatment diets is presented in Table 2.1.

The rationale for omitting a fourth treatment, namely treatment diet T12 as used in the study by Zeeman (2005), was that 120 g/kg inclusion of *Opuntia* cladodes, in comparison with T0, did not have a significant affect on feed and water intake, apparent diet digestibility or live weight gain of the young Dorper wethers.

Table 2.1 Air-dry composition of the three treatment diets with incremental inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatment groups*		
Feed ingredient (kg)	T0	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%

Similar to the procedures followed by Zeeman (2005), the lucerne hay was also ground through the same 20 mm sieve. Yellow maize meal, molasses meal (Calori 3000) and feed grade urea were included in the physical form in which these feeds are commercially available. The yellow maize meal and molasses meal were included at constant levels in the three treatment diets (Table 2.1). As the *Opuntia* cladodes were incrementally increased from 0 to 360 g/kg in the experimental diets, lucerne hay was decreased from 660 to 285 g/kg as fed. The crude protein (CP) content was expected to decrease as *Opuntia* inclusion increased, because the CP content of *Opuntia* is less than that of lucerne hay (77 compared to 184 g CP/kg DM). Therefore, in accordance with the procedures set by Zeeman (2005), the CP content of the diets was balanced iso-nitrogenous by the inclusion of feed grade urea in the treatments that contained *Opuntia* cladodes.

The treatment diets were mixed indoors with a garden spade on a dry, clean cement floor. The coarsely ground lucerne hay was spread evenly, followed by coarsely ground *Opuntia* material, maize meal, molasses meal and lastly feed grade urea. Thorough mixing was ensured by spreading the larger quantities and coarser feed ingredients, namely the *Opuntia* material and lucerne hay, at the bottom and distributing the smaller quantities of finer feed ingredients, namely the feed grade urea, maize and molasses meal, evenly on top before mixing. After mixing, the three treatment diets were stored in clean bags.

2.3 Experimental sheep

Twenty-eight young Dorper wethers with a mean body weight of 33.90 ± 2.98 kg were used in the trial. The wethers were stratified according to body weight and then randomly allocated to the three treatments. Three weeks before the trial commenced the wethers were treated for internal parasites and vaccinated for Pulpy kidney.

2.4 Trial design

The trial commenced on 6 June 2006 and ended on 15 August 2006. The trial period consisted of one week of adaptation followed by three Cycles (Block A: Cycle 1 – week 2 to 4, Cycle 2 – week 5 to 7, Cycle 3 – week 8 to 10; Block B: Cycle 1 – week 1 to 3, Cycle 2 – week 4 to 6, Cycle 3 – week 7 to 9) that ran consecutively (Figure 2.2).

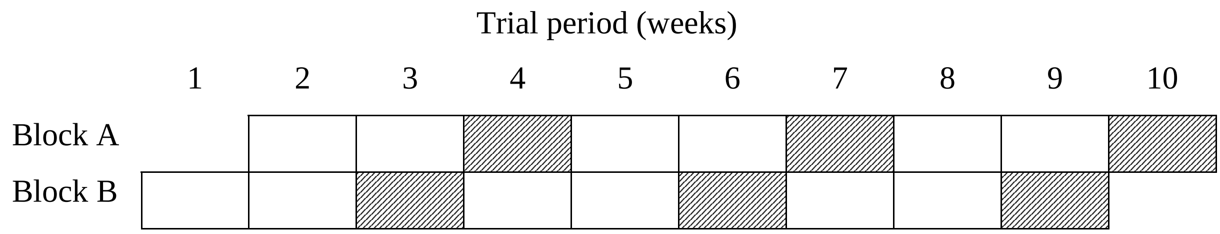

Figure 2.2 Schematic illustration of the Fully Randomized Block design.

The trial was designed as a Fully Randomized Block (Figure 2.2) with two identical blocks, each being a replica with all treatments present [2 Blocks (A and B) × 3 Treatments (T0, T24 and T36), respectively]. Each of the three Cycles within each block consisted of a 2-week production period (Figure 2.2: Block A – weeks 2 and 3, weeks 5 and 6, and weeks 8 and 9; Block B: weeks 1 and 2, weeks 4 and 5, and weeks 7 and 8) followed by a period when feed intake and digestibility were determined individually for every wether (Figure 2.2 shaded areas: Block A - weeks 4, 7 and 10; Block B - weeks 3, 6 and 9).

During the adaptation and production periods, the 28 Dorper wethers were housed in an open-sided roofed shed in their six groups according to treatments in the two Blocks. In order to reduce bias, the six different groups of wethers were also randomly allocated to each of the six kraals.

During the periods when feed intake and digestibility were determined, the wethers from the three treatment groups in a Block were moved indoors and housed individually in metabolism cages for a period of one week. This procedure was repeated alternately for three consecutive Cycles. During these periods the individual wethers from the three treatment groups within a replica (Block A or B) were randomly allocated to their respective metabolism cages.

Zeeman (2005) pointed to the rationale for the designs of the current series of trials, namely the use of two concurrent Blocks. It is customary to conduct feed intake and digestibility trials with a small number of animals. To reduce the strain on the facility, the animals and the human resources in the current study, the feed intake and digestibility period of Block B were run in a staggered fashion relative to Block A, namely it always commenced one week prior to that of Block A (see Figure 2.2). When large numbers of animals are involved, it is convenient to conduct feed intake and digestibility studies with this type of trial design. The design allows daily activities such as feeding and watering, collecting feed refusals, faeces and urine to be completed routinely in a relatively short period of time, thus limiting additional stress as far as possible and reducing the workload (Zeeman, 2005).

This experimental design was used to measure the voluntary feed intake and apparent diet digestibility successively in three Cycles as the trial progressed during a trial period of 70 days. It was assumed that a 70-day trial period was sufficient to determine if the inclusion of *Opuntia* in the treatment diets would have any significant effect on the voluntary feed intake, apparent diet digestibility, live weight gain or carcass characteristics of the Dorper wethers.

2.5 Trial procedures

2.5.1 Weighing of experimental sheep

The young Dorper wethers were weighed with an electronic scale without food or water being withheld at the start and at the end of the trial.

Once the trial commenced, all the wethers were weighed regularly every Tuesday at 12h00 in the same way. Therefore, the wethers were weighed before being moved indoors into individual metabolism cages. At the end of each period, in the metabolism cages, the wethers were weighed again when taken out.

2.5.2 Adaptation period

2.5.2.1 Feed intake

It was important to accustom the sheep to a disciplined feeding regime that would apply to the whole trial period. Therefore, the Dorper wethers were offered food at a 15% refusal level of intake for each group. The amount of feed offered and refused by the wethers was measured at 48-hour intervals, namely every second day starting at noon. The feed allocation per group was then calculated as the feed consumed during the preceding two days and multiplied by 1.15. The wethers were fed twice daily (12h00 and 07h30) about half of the total amount of feed weighed for each day. If a particular group of wethers ate more feed than that calculated and weighed for a 48-hour cycle, more feed was weighed, recorded and provided to the specific group.

The total feed refused by each group was collected and dried in a force draught oven at 100ºC for at least 16 hours. After weighing and thorough mixing, representative samples were taken from the pooled feed refusals of each kraal, ground to pass through a 1 mm sieve and stored in plastic jars with airtight screw tops pending chemical analyses. A composite feed sample from each treatment diet offered was collected on a daily basis. The samples were dried at 100ºC in a force draught oven, mixed thoroughly, ground to pass through a 1 mm sieve and stored in plastic jars with airtight screw tops pending chemical analyses.

2.5.2.2 Water intake

Plastic water buckets with a volume of 20 *l* were used to provide water for the wethers in each group. These buckets were placed in the same corner of each kraal opposite to the feeding trough and filled with water up to a calibrated mark of 16 *l*. Each day the buckets were refilled to the calibrated mark using a plastic 2 *l* measuring cylinder and the amount recorded to calculate the amount of water the wethers drunk. The buckets were emptied and cleaned as required. A similar water bucket (20 *l*) was used outdoors to measure daily water evaporation from the same quantity of water and surface area exposed to the air. This information was used to correct the water consumption by the groups of Dorper wethers.

2.5.3 Production period

2.5.3.1 Feeds and feed refusals

The procedures used for the feeding of the wethers in the different groups as well as the collecting of their feed refusals and the preparation of samples for chemical analysis were the same in the successive production period as described for the adaptation period (see 2.5.2.1).

2.5.3.2 Water

During the production period the wethers were provided water in the same way as described for the adaptation period (see 2.5.2.2).

2.5.4 Feed intake and digestibility period

The Dorper wethers were randomly allocated individually in the metabolism cages (see 2.4). These metabolism cages are designed specifically to separate and collect the faecal and urine excretion of male sheep with a minimum loss (De Waal, 1979). The sheep are prevented from turning around and they can only face towards the feed and water troughs, thus contamination of the feed or water with faeces were limited to a minimum (Zeeman, 2005).

2.5.4.1 Feeds and feed refusals

The Dorper wethers were offered food at a 15% refusal level of intake, calculated on a daily basis by using a 3-day moving average of feed intake of the preceding three days. The wethers were fed twice daily (12h30 and 08h00), half an hour later than those sheep in the production period (see 2.5.3.1 and 2.5.2.1). If a particular wether ate more feed than that presented for the 24-hour cycle, more feed was weighed, recorded and provided to that wether.

The total feed refused by each wether was collected and dried in a force draught oven at 100ºC for at least 16 hours. After weighing and thorough mixing, representative samples were taken from the pooled feed refusals of each individual animal, ground to pass through a 1 mm sieve and stored in plastic jars with airtight screw tops pending chemical analyses. A composite feed sample from each of the three treatment diets offered was collected on a daily basis. These samples were dried at 100ºC in a force draught oven for at least 16 hours, mixed thoroughly, ground to pass through a 1 mm sieve and stored in plastic jars with airtight screw tops pending chemical analyses.

2.5.4.2 Water

Plastic buckets with a volume of 5 *l* were used to provide water to the wethers in the metabolism cages. These buckets were filled with 4 *l* of water to a calibrated marker. The buckets were refilled to the calibrated marker as required using a plastic 2 *l* measuring cylinder. The quantity of water added was recorded and the amount of water drunk by the wethers calculated. The buckets were emptied and cleaned as required to prevent the feed that fell into the water from the wethers' eating, from fouling the water, making it unacceptable to the sheep. A similar water bucket (5 *l*) was used indoors to measure daily water evaporation in the building and the information used to correct the water consumption by the individual wethers.

2.5.4.3 Faeces collection

The faeces of each sheep was collected daily in separate large, brown paper bags, placed in a force draught oven and dried at 100ºC. The faeces resulting from treatment diets T24 and T36 took much longer to dry. The wetter faeces formed a crust once it started drying in the oven that impeded the drying process. The faeces had to be left in the oven for a longer period and the crusts broken regularly when noted before it was considered to be at the DM level.

After weighing and thorough mixing of the total dry faecal excretion from each individual sheep, a representative sample was taken and ground to pass through a 1 mm sieve and stored in plastic jars with airtight screw tops pending chemical analyses.

2.5.4.4 Urine collection

Urine was collected on a sheet metal shoot at the base of the metabolism cages and directed via urine collection plates into dark, brown glass bottles. A plastic funnel protected with a medium mesh sieve was inserted in each bottle to prevent faeces from falling into the urine collection bottles. However, due to the wet nature of some of the faeces, the urine of a number of the wethers was apparently more contaminated with faeces than would normally be expected, which could have affected, among others, the nitrogen content of the urine.

A preservation solution (4N H_2SO_4 with 9% $CuSO_4$) was added to each bottle with an inclusion level of 5% to prevent microbial activity (De Waal, 1979) and volatilization of ammonia from urine (AOAC, 2000). When a bottle was filled close to capacity with urine, the bottle was emptied into a plastic 2 *l* measuring cylinder, the urine volume recorded and the bottle placed back under the funnel with the sieve properly in place.

2.6 Chemical analyses

2.6.1 Dry matter (DM)

The total feed refusals and faeces of each wether collected were dried in a force draught oven at 100ºC and the DM weight recorded. The composite feed samples of the three treatment diets collected were weighed, dried in a force draught oven at 100ºC and weighed again.

The DM content of the composite feed samples was calculated as fallows:

$$\text{DM (g/kg)} = \frac{\text{Weight of sample after drying (g)}}{\text{Weight of sample before drying (g)}} \times 1\,000$$

2.6.2 Ash

Similar to the procedures followed by Zeeman (2005), samples of approximately 2 g were weighed accurately to determine the ash content according to the procedures described by the AOAC (2000).

The ash content of samples was calculated as follows:

$$\text{Ash (g/kg DM)} = \frac{\text{Weight of sample after ashing (g DM)}}{\text{Weight of sample before ashing (g DM)}} \times 1\,000$$

2.6.3 Organic matter (OM)

The OM content (g/kg) of samples was calculated by subtracting the ash content from 1 000.

2.6.4 Crude protein (CP)

Similar to the procedures followed by Zeeman (2005), samples of approximately 0.2 g were weighed accurately to determine the CP content by inserting it into a Leco Nitrogen analyzer (Leco, 2001) and the total N content determined on combustion in oxygen. A factor of 6.25 was used to convert the N content of the samples to CP content.

2.6.5 Ether extract (EE)

Similar to the procedures followed by Zeeman (2005), samples of approximately 2 g were weighed accurately to determine the EE content according to the procedures described by the AOAC (2000).

The EE fraction of samples was calculated as follows:

$$\text{EE (g/kg DM)} = \frac{\text{[Dry flask weight (g) + EE (g DM)]} - \text{[Dry flask weight (g)]}}{\text{Weight of sample (g DM)}} \times 1\,000$$

2.6.6 Acid-detergent fibre (ADF)

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

The ADF content of samples was calculated as follows:

$$\text{ADF (g/kg DM)} = \frac{\text{Sample weight after boiling (g DM)} - \text{Ash weight (g DM)}}{\text{Weight of sample (g DM)}} \times 1\,000$$

2.6.7 Neutral-detergent fibre (NDF)

Similar to the procedures followed by Zeeman (2005), samples of approximately 1 g were weighed accurately to determine the NDF content according to the procedures described by Goering and Van Soest (1970) and Robertson and Van Soest (1981). Sulfite and α-amylase were not used as reagents during NDF determination.

A challenge arose when a vacuum was applied to drain off the NDF solution from the sinter glass crucibles after boiling samples that contained *Opuntia*. Mucilage is a hydrocolloid and presents a great capacity to imbibe water (Sáenz *et* al., 2004) and made it very difficult to vacuum extract the NDF solution from the sinter glass crucibles. It took more than 40 minutes to extract; some crucibles were even totally clogged. Therefore, the procedures described by Goering and Van Soest (1970) and Robertson and Van Soest (1981) were modified slightly and the samples rinsed only with acetone and not also with boiling distilled water. This facilitated the vacuum procedure to be completed.

The NDF content of samples was calculated as follows:

$$\text{NDF (g/kg DM)} = \frac{\text{Sample weight after boiling (g DM)} - \text{Ash weight (g DM)}}{\text{Weight of sample (g DM)}} \times 1\,000$$

2.6.8 Gross energy (GE)

Similar to the procedures followed by Zeeman (2005), samples of approximately 0.3 to 0.5 g (according to sample density) were weighed accurately to determine the GE content according to the procedures described by the AOAC (2000).

2.6.9 Apparent digestibility coefficients

The apparent digestibility of feed or nutrients is best defined as the proportion of ingested feed or nutrients not excreted in the faeces and therefore assumed to be absorbed by the animal (McDonald *et al*., 2002).

The following formula was used to calculate apparent digestibility coefficients:

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

Note that in this study apparent digestibility is presented as a coefficient and not as a percentage.

2.7 Carcass evaluation

2.7.1 Carcass weight

The cold carcass weight of the wethers was recorded 24 hours after being slaughtered.

2.7.2 Fat thickness

The 9th through 12th rib (Figure 2.3) of each wether was removed from the left side of the carcass, the rack and the loin cuts were separated between the 12th and 13th rib (Figure 2.4; Plate 1) to measure the fat depth with a calliper at a distance of 35 and 110 mm (Figure 2.4; Plate 2 and Plate 3, respectively) from the mid dorsal line (Carson *et al*., 1999).

Figure 2.3 Left 9th through 12th rib removed from a carcass.

Plate 1: 12th rib dissected from a carcass; section between the 12th and 13th rib facing (separated at rack and loin).

Plate 2: Fat depth measured with calliper at a distance of 35 mm from mid dorsal line.

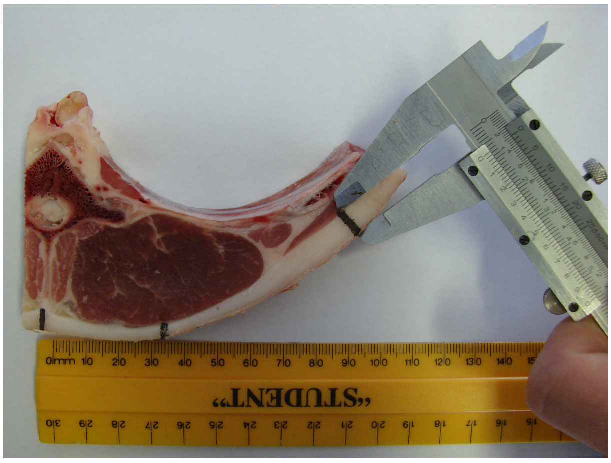

Plate 3: Fat depth measured with calliper at a distance of 110 mm from mid dorsal line.

Figure 2.4 Methods used to determine carcass characteristics based on rib sections.

2.7.3 Surface area of the *musculus longissimus dorsi*

The cross-sectional surface of the longissimus muscle (*musculus longissimus dorsi*) between the 12th and 13th rib was traced immediately after quartering it directly off onto transparent film (Figure 2.5) (Edwards *et al*., 1989). The traced outline was scanned with a scale bar and the eye muscle area (the rib-eye area; Kadim *et al*., 2003) subsequently measured using a video image analysis system (Soft Imaging System: analysis® 3.0). The video image analyzing system was calibrated with the scale bar.

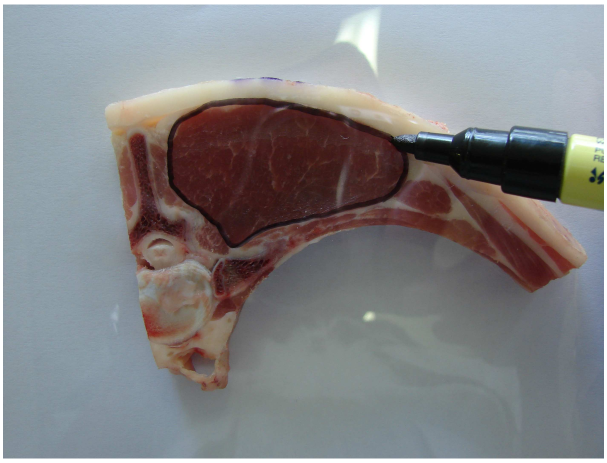

Figure 2.5 *Longissimus dorsi* muscle traced off onto transparent film.

2.7.4 Carcass tissue determination

The 9th through 11th rib sections that were dissected from the carcasses (after the 12th rib has been removed from the same cut in 2.7.2), were physically separated by dissection into bone, lean meat and fat with a sharp knife (Kirton *et al*., 1962). The relative contributions (coefficient) of bone, lean meat and fat to the whole rib sections were calculated.

2.8 Statistical analysis

The data was analyzed and tested for significant differences using the PROC ANOVA procedures of the SAS programme (SAS, 1999). When significant differences were found ($P<0.05$), further multiple comparisons using Tukey's higher studentized range (HSD) test was used to identify these differences.

3. Results and Discussion

3.1 Treatment Diets

3.1.1 Chemical composition of *Opuntia* cladodes

The chemical composition of freshly pruned *Opuntia ficus-indica* cladodes used in this study is presented in Table 3.1.

Table 3.1 Chemical composition of *Opuntia ficus-indica* var. Algerian cladodes

Chemical constituent	*Opuntia ficus-indica* var. Algerian
Dry matter (g DM/kg)	110.0
Organic matter (g OM/kg DM)	774.6
Crude protein (g CP/kg DM)	76.5
Ether extract (g EE/kg DM)	14.1
Acid-detergent fibre (g ADF/kg DM)	163.6
Neutral-detergent fibre (g NDF/kg DM)	254.5
Gross energy (MJ/kg DM)	14.035
Ash (g/kg DM)	225.4

The dry matter (DM) content of the freshly pruned cladodes was low (Table 3.1), but is in agreement with results published by Azócar (2001), López-García *et al*. (2001), Ben Salem *et al*. (2002a,c) and Tegegne *et al*. (2007). According to López-García *et al*. (2001) and Tegegne (2001), the water content of *Opuntia* species varies from a low of 700 g/kg to as high as 930 g/kg fresh cladodes, depending on season and age of the cladodes. As plants mature, there is a decrease in moisture content (Tegegne, 2001).

The organic matter (OM) content of cladodes (Table 3.1) is within the range provided by Ben Salem *et al*. (1996), Azócar (2001), Zeeman (2005) and Tegegne *et al*. (2007). According to López-García *et al*. (2001) the OM content of cladodes varies from 599 to 843 g/kg DM.

The crude protein (CP) content of cladodes (Table 3.1) was slightly higher than values reported in the literature. The values reported by Ben Salem *et al*. (2002a) and McMillan

(2002) were similar. The CP content of *Opuntia* can vary from 38 g/kg (Azócar, 2001) to 126 g/kg DM (Misra *et al*., 2006). This suggests that diets containing *Opuntia* cladodes must be supplemented with a protein or simple nitrogen (N) source (De Kock, 1980, 2001; McMillan, 2002; Misra *et al*., 2006).

There is little variation between most *Opuntia* species in the ether extract (EE) content with averages ranging from 5.7 to 20.6 g/kg DM (López-García *et al*., 2001). The EE content of cladodes (Table 3.1) was very similar to the 16.6 g/kg DM reported by Zeeman (2005).

The acid-detergent fibre (ADF) content of cladodes (Table 3.1) was in close agreement with values published by Ben Salem *et al*. (2004), Tegegne *et al*. (2005a,b; 2007) and Zeeman (2005). According to Nefzaoui and Ben Salem (2001), the ADF content of *Opuntia* cladodes may vary between 112.9 and 189.8 g/kg DM.

The neutral-detergent fibre (NDF) content of *Opuntia* cladodes ranges from 185 g/kg DM (Azócar, 2001) to as high as 466 g/kg DM (Misra *et al*., 2006). The NDF content (Table 3.1) was also consistent with the 244 g/kg DM obtained by Zeeman (2005).

According to López-García *et al*. (2001) the ash content of cladodes varies from 158 g/kg to 401 g/kg DM while Nefzaoui and Ben Salem (2001) reported an average content of 172 g ash/kg DM in certain species. According to Nefzaoui and Ben Salem (2001) this high ash content may be ascribed to the high Ca content. The ash content of cladodes in the present study (Table 3.1) is in close accordance with published values (Sirohi *et al.*, 1997; Tegegne *et al*., 2007).

The gross energy (GE) of cladodes (Table 3.1) is in close comparison with the 13.624 MJ/kg DM reported by Zeeman (2005). According to McDonald *et al*. (2002), most common foods contain about 18.5 MJ GE/kg DM. Minerals do not contribute to the calorific content of feeds (McDonald *et* al., 2002; Zeeman, 2005) and the low GE of *Opuntia* could be the result of the high mineral content or a low fibre content. According to Nefzaoui and Ben Salem (2001) the energy in cactus cladodes is derived mainly from the high soluble carbohydrate content.

According to Walters (1951) and Retamal *et al*. (1987), both as cited by Zeeman (2005), there is a seasonal variation in the chemical composition of *Opuntia* cladodes. The CP, EE, ash and crude fibre (CF) content of cactus pear plants increases on a DM basis in winter while the nitrogen-free extractive (NFE) content increases in the summer.

Spineless cacti cannot be regarded as a balanced fodder crop or the only feed provided to ruminants. It should be viewed as a good, cheap source of energy and be utilized as such (De Kock, 1980, 2001).

3.1.2 Chemical composition of lucerne hay (*Medicago sativa*)

Sun-dried and coarsely ground *Opuntia* cladodes were used to progressively replace coarsely ground lucerne hay (*Medicago sativa*) in treatment diets T24 and T36. Therefore, the chemical composition of lucerne used in the present study is presented in Table 3.2.

Table 3.2 Chemical composition of the lucerne hay (*Medicago sativa*) used in this study

Chemical constituent	Lucerne hay
Dry matter (g DM/kg)	888.3
Organic matter (g OM/kg DM)	912.7
Crude protein (g CP/kg DM)	184.0
Ether extract (g EE/kg DM)	13.2
Acid-detergent fibre (g ADF/kg DM)	317.6
Neutral-detergent fibre (g NDF/kg DM)	480.3
Gross energy (MJ/kg DM)	17.743
Ash (g/kg DM)	87.3

The OM, CP, ADF, NDF and GE content of lucerne hay (Table 3.2) is much higher than that of *Opuntia* cladodes (Table 3.1). Conversely, the ash content of *Opuntia* is much higher than that of lucerne hay while the EE content varies little between these two roughages.

It was assumed that differences in composition of *Opuntia* and lucerne hay would also effect the chemical composition of the treatment diets. Coarsely ground lucerne hay was used as the primary roughage in the diets because it is the most commonly used roughage source with a high CP and fibre content for ruminants in South Africa.

3.1.3 Chemical composition of the three treatment diets

The chemical composition of the three treatment diets (Figure 3.1) is presented in Table 3.3.

Table 3.3 Chemical composition of the three treatment diets with incremental inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes

	Treatments*		
Chemical constituent	T0	T24	T36
Dry matter (g DM/kg)	913	905	902
Organic matter (g OM/kg DM)	900	879	862
Crude protein (g CP/kg DM)	171	177	177
Ether extract (g EE/kg DM)	24	24	22
Acid-detergent fibre (g ADF/kg DM)	214	178	159
Neutral-detergent fibre (g NDF/kg DM)	413	363	313
Gross energy (MJ/kg DM)	17.340	16.727	15.480
Ash (g/kg DM)	100	121	138

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

The variation in the DM content of the three treatment diets was negligible and differs from the findings of Zeeman (2005) who suggested that the reason for the higher water content of T36 (118.3 g/kg) in comparison to T0 (94.5 g/kg) was due to the mucilage content. Thus, the ground *Opuntia* cladodes increased the water content of the treatment diets as inclusion level increased. In the present study, however, the *Opuntia* cladodes did not have any real effect on the DM content of diets (Table 3.3).

The OM, ADF, NDF and GE content of the three treatment diets decreased as the inclusion level of *Opuntia* cladodes increased (Table 3.3). This can be ascribed to the lower OM, ADF, NDF and GE content of *Opuntia* cladodes (Table 3.1) compared to lucerne hay (Table 3.2). The decreasing ADF and NDF content of the diets (Table 3.3) with incremental inclusion

Plate 1: Treatment diet T0.

Plate 2: Treatment diet T24.

Plate 3: Treatment diet T36.

Figure 3.1 Treatment diets with incremental levels of sun-dried and coarsely ground *Opuntia* cladodes.

levels reflected the diluting effects of the low fibre content of *Opuntia* cladodes. This corresponds with the findings of Zeeman (2005).

The CP content of the treatment diets decreased as *Opuntia* inclusion increased incrementally. Therefore, feed grade urea was used to maintain the final CP content of T24 and T36 (see 2.2). It was assumed that these CP levels will promote live body weight gains in the Dorper wethers.

The ash content of T24 and T36 increased as *Opuntia* cladodes were incrementally added to the treatment diets (Table 3.3). This can be ascribed to the higher ash content (Table 3.1) of the cladodes (Batista *et al*., 2003). Zeeman (2005) found similar results. According to Tegegne (2002a) sheep that were fed only *Opuntia* consumed more salt lick than any other group and this may suggest that *Opuntia* is deficient in some of the macro-minerals. Nefzaoui and Ben Salem (2001) explained that an excess of Ca is not problematic in itself, but an unbalanced Ca:P ratio (35:1) requires correction. It was not expected that the EE content of diets T24 and T36 would have been influenced by the incremental inclusion of *Opuntia* cladodes, due in part to the comparable EE content of *Opuntia* cladodes and lucerne hay (Table 3.1 and 3.2, respectively).

3.2 Animal live weight changes

A major objective of this study was to evaluate whether two treatment diets with incremental levels of sun-dried *Opuntia* cladodes substituting lucerne hay will have the same capacity as the control diet to promote growth in sheep.

The average daily gain (ADG) and the live body weight change of the young Dorper wethers are presented in Table 3.4. The average live body weight of the wethers at weekly intervals is illustrated in Figure 3.2.

The ADG of the Dorper wethers did not differ ($P>0.05$) between treatments with increasing inclusion levels of *Opuntia* (Table 3.4) over the total trial period of 70 days; although the ADG tended to decrease slightly. Similarly, changes in live body weight was not affected ($P>0.05$) by the treatment diets, with total live body weight gained tending to decrease with increasing levels of *Opuntia* cladodes inclusion. These results suggest that the overall effects of the diets on the wethers were small as suggested previously by Zeeman (2005) and that the diets have been utilized well by the young Dorper wethers.

Table 3.4 Average daily gain (ADG) and live body weight change of Dorper wethers as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*				
	T0	T24	T36	P	CV (%)
ADG (g/day)	118 ± 13.7[a]	116 ± 15.6[a]	96 ± 7.9[a]	0.3219	34.552
Live body weight change (kg)	7.422 ± 0.861[a]	7.333 ± 0.982[a]	6.020 ± 0.497[a]		

[a,b] Means in the same row followed by different superscripts differ significantly (P<0.05)

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

Atti *et al*. (2006) found differences in animal performance because, among others, the energy and fibre content of the various treatment diets differed as more *Opuntia* was included in the diets. In the absence of sufficient energy, the nitrogen supply cannot be utilized efficiently by ruminants and could have affected live weight gain (Atti *et al*., 2006; Ben Salem *et al*., 2004).

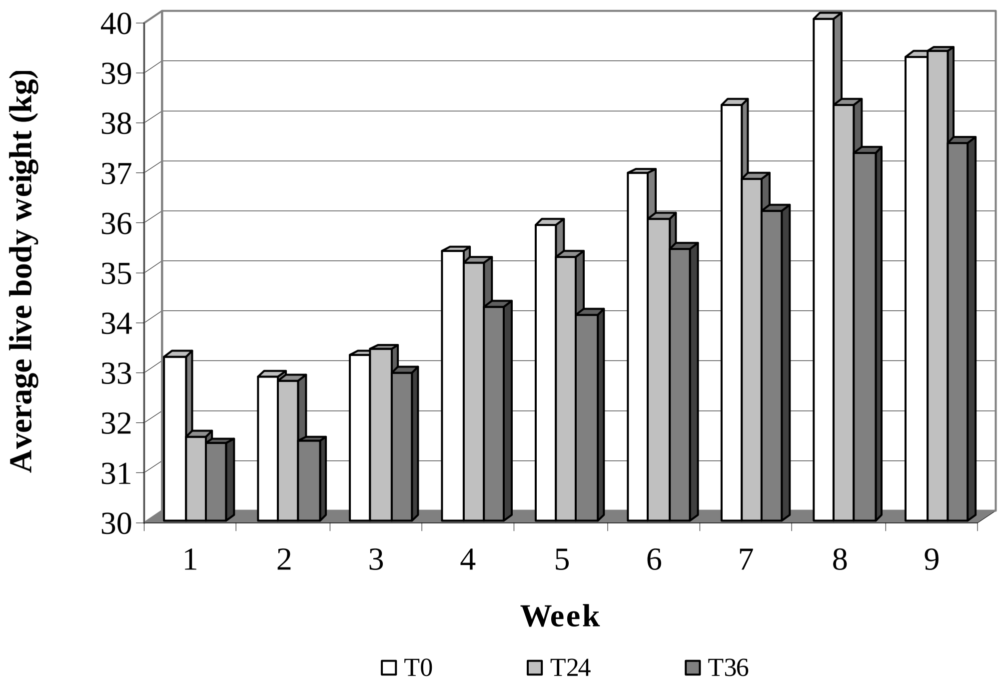

Figure 3.2 Average live body weight of Dorper wethers during the trial period.

Ben Salem *et al*. (2005) explained that when *Opuntia*-based diets are supplemented with protein and energy sources, nutrient deficiencies that may impact on rumen fermentation and consequently result in a decreased growth rate, may be overcome. Thus, the weight gains (Table 3.4) of the wethers were acceptable and could in part be ascribed to the maize meal and urea (Table 2.1) included in the respective diets.

According to Ben Salem *et al*. (2004) and McDonald *et al*. (2002), one adverse consequence of supplying the rumen with more than optimal concentrations of ammonia-N is the energetic inefficiency of rumen ammonia utilization by the microbes and hence, conversion of excess ammonia to urea in the liver and excreted via the urine. Thus, by providing adequate energy and protein usually leads to higher body weight gains.

Ben Salem *et al*. (2002a, 2004) explained that differences in the quality of the nitrogen in feeds may account for differences in animal performance when supplemented with *Opuntia*. Protein supplementation may be required in addition to feeding prickly pear (McMillan *et al*., 2002) and, according to Ben Salem *et al*. (2002c), a further improvement may be expected when by-pass proteins are used, supplying most of the essential amino acids.

In conclusion, the inclusion of sun-dried and coarsely ground *Opuntia* cladodes had no marked effect (P>0.05) on animal performance.

3.3 Feed and water intake, faeces and urine excreted, and digestibility of diets

3.3.1 Voluntary feed and nutrient intake

The average daily dry matter intake (DMI) of the Dorper wethers in the different treatment groups during the production periods (see 2.4) is presented in Table 3.5.

No significant difference (P>0.05) was observed between the treatment diets (Table 3.5), but the DMI increased slightly at a constant rate as the trial progressed from Cycle 1 to Cycle 3, irrespective of the dietary treatment. This might suggest that the wethers became more adapted to the feeds. The data in Table 3.5 suggest that there is a slight positive link between

DMI per day and ADG (Table 3.4), but a slightly negative relation with the inclusion level of sun-dried *Opuntia* cladodes in the diets.

Table 3.5 The average daily DMI of the Dorper wethers during the production periods as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*				
Feed intake	T0	T24	T36	P	CV (%)
Cycle 1 (g DM/day)	990 ± 93^{a}	945 ± 6^{a}	830 ± 119^{a}	0.2757	9.087
Cycle 2 (g DM/day)	1114 ± 88^{a}	1096 ± 14^{a}	1056 ± 119^{a}	0.5396	9.047
Cycle 3 (g DM/day)	1232 ± 55^{a}	1223 ± 52^{a}	1176 ± 114^{a}	0.8256	9.781

^{a,b} Means in the same row followed by different superscripts differ significantly (P<0.05)

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

The daily intake of DM and chemical constituents by the Dorper wethers during the feed intake and digestibility period of Cycle 3 are presented in Table 3.6. The data of the last Cycle of each Block (Block A week 10 and Block B week 9; see 2.4) was used.

Table 3.6 The average daily intake of DM and chemical constituents by the Dorper wethers determined during the feed intake and digestibility period of Cycle 3 as influenced by incremental inclusion levels of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*				
Chemical constituent	T0	T24	T36	P	CV (%)
Dry matter (g DM/day)	1368 ± 69^{a}	1345 ± 46^{a}	1317 ± 61^{a}	0.9039	13.858
Organic matter (g OM/day)	1235 ± 62^{a}	1198 ± 41^{a}	1152 ± 52^{a}	0.7405	13.704
Crude protein (g CP/day)	237 ± 12^{a}	249 ± 9^{a}	249 ± 10^{a}	0.8067	13.264
Acid-detergent fibre (g ADF/day)	266 ± 14^{a}	243 ± 12^{a,b}	208 ± 8^{b}	0.0105	14.700
Neutral-detergent fibre (g NDF/day)	551 ± 28^{a}	505 ± 26^{a}	419 ± 15^{b}	0.0006	13.481
Gross energy (MJ/day)	23.724 ± 1.199^{a}	22.804 ± 0.695^{a}	20.697 ± 0.916^{a}	0.1701	13.292
Ash (g/day)	133 ± 8^{a}	148 ± 5^{a,b}	165 ± 10^{b}	0.0061	15.288

^{a,b} Means in the same row followed by different superscripts differ significantly (P<0.05)

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

The attention of the reader is specifically drawn to the fact that only the data for the feed intake and digestibility period of Cycle 3 is shown in this text. It was assumed that the data relating to feed intake and digestibility, as well as water intake and urine excreted during this period would be representative of the first two Cycles. Hence, if any significant (P<0.05) differences of data were detected in Cycle 3, the data of Cycle 1 and 2 would have been analyzed as well.

No significant difference (P>0.05) was observed between the DM, OM, CP and GE intake of the Dorper wethers as *Opuntia* incrementally substituted lucerne hay in two of the treatment diets (Table 3.6).

The ADF and NDF intake decreased (P<0.05) as *Opuntia* incrementally increased and is attributed to the lower fibre content of *Opuntia* (see Table 3.1) in comparison to lucerne hay (see Table 3.2). In contrast, the ash intake increased (P<0.05) as *Opuntia* incrementally increased in the treatment diets. This was expected due to the high ash content of *Opuntia* cladodes.

Results reported by Zeeman (2005) and De Waal *et al*. (2006) are similar to the present study. During the feed intake and digestibility study, Zeeman (2005) stated that there were no differences (P>0.05) in feed intake of the Dorper wethers. There was a general tendency for DMI to decline slightly as the inclusion of *Opuntia* incrementally increased. According to Zeeman (2005), voluntary feed intake would probably have increased once the animals have adapted sufficiently to the coarsely ground sun-dried *Opuntia* cladodes in the diets. According to De Kock (1980) and Nefzaoui and Ben Salem (2002) spineless cactus material is ingested better in the form of a dried meal. Ben Salem *et al*. (2004) and Tegegne *et al*. (2005b, 2007) reported that the increased DMI of animals on *Opuntia* diets may be attributed to the high soluble fraction in cactus pear, as feeds rich in fermentable components could increase outflow rate.

According to McDonald *et al*. (2002), one of the factors affecting feed intake of ruminants is the fibre content of the feed. Tegegne *et al*. (2007) found that the increase in DMI following cactus pear supplementation up to 600 g/kg (on a fresh basis) was due to the low fibre content of cactus pear resulting also in a high passage rate.

According to Tegegne *et al*. (2002a, 2007) the high moisture content of cactus pear can contribute to the relatively low voluntary DMI of sheep with 800 g/kg freshly cut cactus pear inclusion in the diets. A similar effect was obtained by Gebremariam *et al*. (2006). There is some evidence that feeds with a particularly high content of water bound within plant tissues promote a lower DMI than comparable feeds of lower water content (McDonald *et al*., 2002; Gebremariam *et al*., 2006). This factor could not have played a role in the present study as the cladodes were sun-dried and coarsely ground.

According to Tegegne *et al*. (2007) the general nutrient imbalance (deficiency of P; Misra *et al*., 2006) of a diet containing cactus pear could effect appetite and contribute to a relatively low DMI of sheep. In the present study an effort was made to ensure that the diets were balanced at the macro level, leading to a comparable intake between treatment diets, irrespective of *Opuntia* inclusion.

These results suggest that incremental inclusion of sun-dried and coarsely ground *Opuntia* cladodes in experimental diets did not markedly change the acceptability or voluntary feed intake of the young Dorper wethers. The average daily DMI during the production periods (Table 3.5) as well as in the feed intake and digestibility period (Table 3.6) did not have any marked effect on the ADG of the Dorper wethers (Table 3.4). Thus, the observed trend in DM and chemical constituent intake (except that of ADF, NDF and ash) following *Opuntia* supplementation could be associated with animal performance.

3.3.2 Apparent digestibility of diets

The average apparent digestibility coefficients of the treatment diets during Cycle 3 are presented in Table 3.7. The data of the last Cycle (namely Cycle 3; see 2.4) of each Block (Block A week 10 and Block B week 9; see 2.4) was used. The reason for using only this data set was discussed in 3.3.1.

The apparent DM digestibility for diets T0 and T24 did not differ significantly ($P>0.05$), but both treatments differed ($P<0.05$) from T36 (Table 3.7). The apparent OM and CP digestibility increased significantly ($P<0.05$) as *Opuntia* inclusion increased. According to Tegegne *et al*. (2007) this could be ascribed to an increased DMI of cactus pear.

Table 3.7 Apparent digestibility coefficients for DM and chemical constituents during Cycle 3 as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*				
Chemical constituent	T0	T24	T36	P	CV (%)
Dry matter (DM)	0.714 ± 0.004[a]	0.732 ± 0.007[a]	0.756 ± 0.004[b]	<0.0001	2.055
Organic matter (OM)	0.734 ± 0.005[a]	0.757 ± 0.006[b]	0.783 ± 0.003[c]	<0.0001	1.878
Crude protein (CP)	0.724 ± 0.006[a]	0.775 ± 0.008[b]	0.806 ± 0.003[c]	<0.0001	2.185
Acid-detergent fibre (ADF)	0.438 ± 0.014[a]	0.497 ± 0.015[b]	0.541 ± 0.012[b]	<0.0001	8.052
Neutral-detergent fibre (NDF)	0.623 ± 0.008[a]	0.649 ± 0.008[a,b]	0.667 ± 0.010[b]	0.0003	3.631
Gross energy (DE)	0.710 ± 0.005[a]	0.738 ± 0.009[b]	0.758 ± 0.004[b]	<0.0001	2.579
Ash	0.528 ± 0.011[a]	0.529 ± 0.013[a]	0.562 ± 0.088[a]	0.0296	5.879

[a,b,c] Means in the same row followed by different superscripts differ significantly (P<0.05)

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

The apparent ADF digestibility of treatment diet T0 was significantly lower (P<0.05) than that of diets T24 and T36. The apparent digestibility of the NDF content of diet T0 differed significantly from diet T36 (P<0.05) (Table 3.7). In contrast, Zeeman (2005) obtained no significant differences (P>0.05) between the apparent digestibility of both the ADF and NDF content of all treatment diets. It was expected due to the fact that *Opuntia* is low in fibre (ADF and NDF) and that the fibre present is mainly contributed by lucerne hay and will therefore remain equally digestible. Ben Salem *et al*. (2002c) explained that this low fibre content of spineless cactus could negatively effect rumination and thus affect diet apparent DM digestibility.

The apparent GE digestibility of the treatment diets increased significantly (P<0.05) from diet T0 to diets T24 and T36. The apparent digestibility of ash did not differ (P>0.05) between the treatments, although it must be borne in mind that minerals are not digested but become soluble to be absorbed from the digestive tract. Therefore the results suggest that the minerals present in *Opuntia* were not soluble (in an absorbable form) and could not be absorbed effectively enough. This was not expected due to the large contribution of minerals made by *Opuntia*. The mineral requirements of the wethers could have been satisfied by the other feed ingredients.

Similar to results of the present study as shown in Table 3.7, Zeeman (2005) found that the apparent digestibility of most chemical constituents increased significantly ($P<0.05$) in line with increased *Opuntia* inclusion and that the low fibre content of *Opuntia* is positively correlated with DM digestibility. Hence, the DM digestibility increases with higher inclusion levels of *Opuntia* in the diets. Zeeman (2005) also ascribed the higher digestibility to the fact that *Opuntia* cladodes contain higher levels of easily digestible carbohydrates (Ben Salem *et al*., 1996, 2004; Batista *et al*., 2003). High mineral levels (Ben Salem *et al*., 1996; Misra *et al*., 2006) in cactus may limit microbial growth in the rumen which could affect apparent digestibility of nutrients, but was not the case in the present study.

Urea is utilized very quickly and virtually completely by the micro-organisms in the reticulo-rumen (McDonald *et al*., 2002), therefore, it was expected that the CP content of treatment diets containing urea (T24 and T36; Table 2.1) would have reflected a higher apparent digestibility (Zeeman, 2005). Ben Salem *et al*. (2002a,c,d) explained that by enhancing microbial activity with a soluble nitrogen source in the rumen (and P supplementation; Misra *et al*., 2006) encouraged microorganisms to degrade more fibre. This was probably the case in the present study. Ben Salem *et al*. (2002c) explained that a further improvement in apparent digestibility and animal performance may be expected when by-pass proteins are used in these diets. The resulting essential amino-acids and peptides may have a stimulatory effect on the growth of micro-organisms and will subsequently increase the nutrient digestibility, highlighting the importance of essential amino-acids in ruminant nutrition for favourable production (Misra *et al*., 2006).

According to Gebremariam *et al*. (2006), the tannin content of cactus could have affected CP digestibility negatively as the cactus inclusion is increased in diets. This is ascribed to the precipitation of the feed proteins into tannin protein complexes. According to Ben Salem *et al*. (2002b,c, 2005), the presence of oxalates in cladodes could also effect diet apparent digestibility by forming insoluble complexes with several minerals (Ben Salem *et al*., 2002c).

It may be hypothesized that there is a positive correlation between increased inclusion of sun-dried and coarsely ground *Opuntia* (up to 360 g/kg) in sheep diets and diet apparent digestibility ($P<0.05$). The increased digestibility was not reflected in DMI or sheep growth. Thus, the observed trend in diet apparent digestibility following cactus supplementation level could not be associated with animal performance.

3.3.3 Digestible nutrient intake

The average daily digestible DM and chemical constituent intake of the Dorper wethers during Cycle 3 are presented in Table 3.8. The combined data of the last Cycle (namely Cycle 3; see 2.4) of each Block (Block A week 10 and Block B week 9; see 2.4) was used. The reason for using only this data set was discussed in 3.3.1.

Table 3.8 The average daily digestible DM and chemical constituent intake by the Dorper wethers during Cycle 3 as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*				
Digestible chemical constituent	T0	T24	T36	P	CV (%)
Dry matter (g DM/day)	977 ± 51[a]	983 ± 29[a]	995 ± 44[a]	0.9414	13.421
Organic matter (g OM/day)	907 ± 48[a]	905 ± 28[a]	902 ± 40[a]	0.9934	13.502
Crude protein (g CP/day)	172 ± 9[a]	192 ± 6[a,b]	201 ± 8[b]	0.0782	12.888
Acid-detergent fibre (g ADF/day)	117 ± 8[a]	121 ± 8[a]	112 ± 4[a]	0.4577	17.962
Neutral-detergent fibre (g NDF/day)	344 ± 20[a]	328 ± 18[a,b]	279 ± 11[b]	0.0017	13.606
Digestible energy (MJ/day)	16.851 ± 0.897[a]	16.794 ± 0.440[a]	15.682 ± 0.682[a]	0.4897	13.075
Ash (g/day)	70 ± 5[a]	78 ± 2[a]	92 ± 5[b]	0.0001	13.319

[a,b] Means in the same row followed by different superscripts differ significantly (P<0.05)

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

No significant differences (P>0.05) were observed between the digestible DM, OM, ADF and energy intake by the Dorper wethers (Table 3.8). This was not expected as the apparent digestibility of DM and most chemical constituents differed (P<0.05), except that of ash (Table 3.7).

The digestible CP intake increased (P<0.05) from diet T0 to T36 as *Opuntia* inclusion increased, but the digestible NDF intake decreased (P<0.05). This could be due to the more soluble CP and lower fibre content of *Opuntia* cladodes than lucerne hay (Zeeman, 2005). The difference (P<0.05) in digestible ash intake could be ascribed to the difference in ash intake (Table 3.6; P<0.05), but is not commensurate with the ash digestibility (Table 3.7; P>0.05).

Tegegne *et al*. (2007) stated that the nutrient imbalance (as reflected by low fibre content, high passage rate, high moisture and ash content, lack of fermentable N, lack of lignified material to elicit adequate rumination, presence of oxalates and the wide Ca:P ratio) in cactus pear could be associated with unparallel nutrient (digestible nutrient) intake. Other researchers (Ben Salem *et al*., 1996; Tegegne, 2002a; Gebremariam *et al*., 2006; Misra *et al*., 2006) came to the same conclusion.

The digestible CP intake recommended by Misra *et al*. (2006) for maintenance requirement of adult sheep is 40 g/day. In the present study, the digestible CP intake within all treatments was well above this value.

According to De Waal *et al*. (1981) the maintenance energy requirement of sheep is estimated at 22 g digestible OM intake per kg $W^{0.75}$/day. Therefore, with a digestible OM intake of 57, 58 and 60 g/kg $W^{0.75}$/day for treatment T0, T24 and T36 (respectively), it would appear that the sheep consumed sufficient digestible OM to allow for both maintenance requirement and considerable growth.

3.3.4 Water intake and excreted in urine and faeces

The daily water intake of the Dorper wethers during the production periods (see 2.4) are presented in Table 3.9.

Table 3.9 The daily water intake of the Dorper wethers during the production periods as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*				
Water intake	T0	T24	T36	P	CV (%)
Cycle 1 (m*l*/day)	2004 ± 311^{a}	2360 ± 13^{a}	2134 ± 322^{a}	0.3805	12.437
Cycle 2 (m*l*/day)	2290 ± 297^{a}	2782 ± 172^{a}	3005 ± 260^{a}	0.4145	13.690
Cycle 3 (m*l*/day)	2758 ± 161^{a}	3196 ± 228^{a}	3559 ± 367^{a}	0.4662	13.481

^{a,b} Means in the same row followed by different superscripts differ significantly (P<0.05)

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

The reader is reminded that water intake during the production periods was determined on a group basis and not individually. No significant difference (P>0.05) was observed between the treatments in the production periods as *Opuntia* inclusion incrementally increased within Cycles 1, 2 and 3 (Table 3.9). Only a slight increase in water intake was observed, except the water intake of Cycle 1 from treatment T36 that was less than that of T24 in the same week. This could be due to the competition effect between the sheep within the groups. These results suggest that the overall effect of the treatments on the water intake within the groups were small in the production periods. Of interest is the fact that, as the production periods progressed from Cycle 1, to 2 and 3, the water intake of the Dorper wethers increased slightly, irrespective of dietary treatment. This might be the result of a higher environmental temperature or the higher DMI (see Table 3.5); as the wethers aged, more water was drunk according to their relative body weights.

The results of the daily water intake and urine excretion of the Dorper wethers during the feed intake and digestibility period of Cycle 3 are presented in Table 3.10 and illustrated in Figure 3.3. The data of the last Cycle of each Block was used as discussed in 3.3.1.

Table 3.10 The average daily water intake and urine excreted by the Dorper wethers as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes during the feed intake and digestibility period of Cycle 3 (Mean ± s.e.)

	Treatments*				
	T0	T24	T36	P	CV (%)
Water intake (m*l*/day)	3031 ± 273^{a}	$3597 \pm 206^{a,b}$	3927 ± 272^{b}	0.0683	21.748
Urine excreted (m*l*/day)	1147 ± 133^{a}	1254 ± 100^{a}	1301 ± 87^{a}	0.7188	26.936

[a,b] Means in the same row followed by different superscripts differ significantly (P<0.05)

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

A significant increase (P<0.05) in the voluntary water intake of the wethers was observed between treatment diets T0 and T36 (Table 3.10). In contrast, there were no significant differences (P>0.05) in the urine excretion. This was not expected given the considerable increase in water intake (P<0.05). With increased *Opuntia* inclusion in diets a proportionate amount of water was expected to be voided in the urine as *Opuntia* inclusion in the treatments increased (Zeeman, 2005).

These findings concur to a large extent with the results reported by Zeeman (2005). According to Zeeman (2005) the daily voluntary water intake of the wethers increased ($P<0.05$) with *Opuntia* inclusion level, but the differences in daily urine excretion were much smaller and not significantly ($P>0.05$) different.

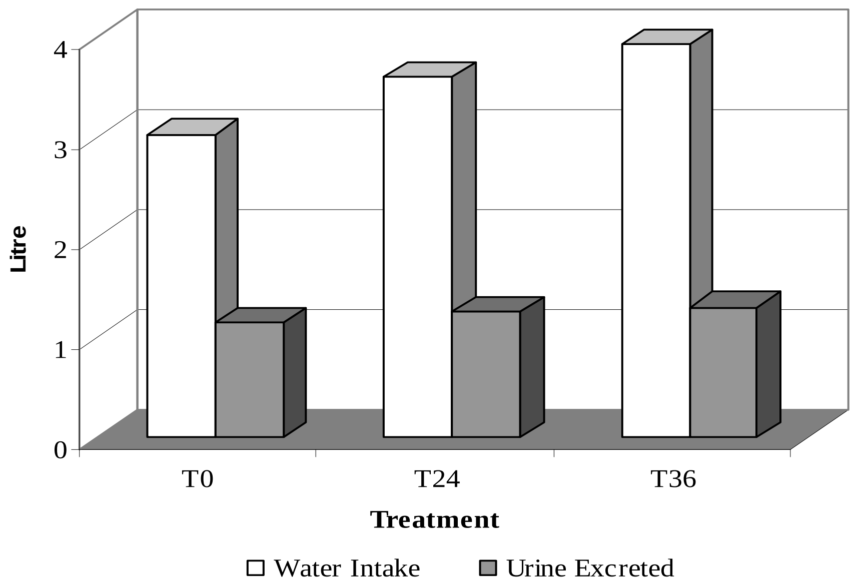

Figure 3.3 Average water intake and urine excreted by wethers in the feed intake and digestibility period of Cycle 3.

The increased water consumption by the sheep in the present study, following cactus supplementation, resulted in wetter faeces excreted by the wethers in the respective treatments (Figure 3.4). Zeeman (2005) postulated that the wetter faeces may be ascribed to the fact that *Opuntia* cladodes contain a complex carbohydrate, mucilage, with a great capacity to absorb water (Sudzuki Hills, 1995; Tegegne, 2002b; Sáenz *et* al., 2004). Since mucilage binds strongly to water, it is quite plausible that this may render some of the water in the digestive tract of the wethers unavailable for absorption (Zeeman, 2005; De Waal *et al*., 2006). Hence, the sheep may have needed to drink more water ($P<0.05$). Tegegne *et al.* (2007) stated that insensible water loss via faeces increased at higher cactus pear supplementation levels and it cannot be fully explained.

Plate 1: Sheep faeces from treatment diet T0.

Plate 2: Sheep faeces from treatment diet T24.

Plate 3: Sheep faeces from treatment diet T36.

Figure 3.4 Faeces excreted by the Dorper wethers as influenced by dietary treatment during Cycle 3.

Some authors ascribe this wet faeces to a laxative effect (Ben Salem *et al*., 2002d), or a result of diarrhoea (Ben Salem *et al*., 2002a; Le Houérou, 2002) (a chronic symptom of mineral imbalances and/or rapid fermentation; Tegegne *et al*., 2007).

According to Nefzaoui and Ben Salem (2001) the high amount of oxalates present in *Opuntia* cladodes may explain this laxative effect when fed to animals. But, according to Zeeman (2005) and De Waal *et al*. (2006), this wetter faeces (reminiscent of diarrhoea) could be ascribed to the water-binding capacity of mucilage. Other researchers (De Kock, 1980; Tegegne *et al*., 2007) reported that there was no indication of serious digestive disturbance in animals fed cactus pear; hence, it is not a disease symptom and has no detrimental effect on the animal.

De Kock (1980) and Ben Salem *et al*. (1996, 2002d) reported that supplementation of cactus-based diets with fibrous foods (straw and hay) (1% of live weight; Le Houérou, 2002) may prevent such digestive disturbance by improving microbial activity in the rumen. According to McDonald *et al*. (2002), mucilage, that is almost completely indigestible by non-ruminant animals, can be broken down by the microbial population of the rumen. Therefore, small amounts of mucilage could pass through the digestive tract and cause the wetter faeces.

Zeeman (2005) provided a dietary prophylactic of 0.7 g kaolin (hydrated aluminium silicate; Al_2O_3 $2SiO_n$ $2H_2O$) to all the wethers at every feeding to prevent the excretion of wet faeces. This measure had no visible effect in reducing the excretion of wet faeces. Hence, it was postulated that the wet faeces could not have been caused by diarrhoea. It is important to stress the fact that the wet faeces also lacked the customary foul smell associated with diarrhoea (De Waal *et al*., 2006).

3.4 Carcass characteristics

According to Atti *et al*. (2006) there is a paucity of references concerning the effect of spineless cactus as a dietary supplement on animal products, particularly meat quality.

3.4.1 Carcass weight

The mean carcass weight of the Dorper wethers is presented in Table 3.11.

Table 3.11 Carcass weight as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*				
	T0	T24	T36	P	CV (%)
Carcass weight (kg)	19.567 ± 0.734^a	19.111 ± 0.868^a	17.770 ± 0.729^a	0.4178	12.881

^{a,b} Means in the same row followed by different superscripts differ significantly (P<0.05)

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

No significant difference (P>0.05) was observed between the treatments as *Opuntia* inclusion incrementally increased from 0, 240 to 360 g/kg in the diets (Table 3.11). Only a slight decrease in carcass weight was noted.

According to Tien and Beynen (2005) the two groups of sheep supplemented with cactus pear in their study had a significant (P<0.025) higher carcass yield than the control group. This was not the case in the present study. According to Atti *et al*. (2006) the carcass weight of goat kids decreased significantly (P<0.05) with cactus supplementation.

To conclude, the average carcass weight did not differ significantly (P>0.05) between the treatments. Thus, the mean carcass weight cannot be associated with *Opuntia* inclusion.

3.4.2 Fat thickness

The fat thickness between the 12^{th} and 13^{th} rib on the left side of the Dorper wethers are presented in Table 3.12.

Table 3.12 Fat thickness between the 12^{th} and 13^{th} rib as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*				
Fat thickness measured	T0	T24	T36	P	CV (%)
35 mm from spinal cord (mm)	3.731 ± 0.475^a	3.502 ± 0.516^a	3.054 ± 0.559^a	0.8007	47.479
110 mm from spinal cord (mm)	6.102 ± 0.830^a	5.091 ± 0.695^a	5.540 ± 0.820^a	0.8437	44.015

[a,b] Means in the same row followed by different superscripts differ significantly (P<0.05)

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

No significant differences (P>0.05) were observed in the thickness of the fat layer between the 12^{th} and 13^{th} rib, as measured 35 and 110 mm from the centre of the spinal cord (Table 3.12). Only a slight decrease in fat thickness 35 mm from the centre of the spinal cord was observed as *Opuntia* inclusion incrementally increased in the experimental diets.

The average thickness of the fat layer between the left 12th and 13th rib, as measured at distances of 35 and 110 mm from the centre of the spinal cord was not affected and cannot be associated with *Opuntia* inclusion between the treatments.

3.4.3 Surface area of *musculus longissimus dorsi*

The cross-sectional surface area of the longissimus muscle (*m. longissimus dorsi*) between the 12th and 13th rib on the left side of the Dorper wethers is presented in Table 3.13.

Table 3.13 Surface area of the longissimus muscle (*m. longissimus dorsi*) as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

	Treatments*			P	CV (%)
	T0	T24	T36		
Area of eye muscle (mm^2)	1488 ± 54^a	1549 ± 131^a	1431 ± 87^a	0.6253	19.609

[a,b] Means in the same row followed by different superscripts differ significantly (P<0.05)

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

No significant difference (P>0.05) on the surface area of the eye muscle was observed between the treatments as *Opuntia* inclusion incrementally increased (Table 3.13).

Thus, the surface area of the eye muscle cannot be associated with the inclusion level of *Opuntia* in the experimental diets.

3.4.4 Carcass tissue determination

The carcass tissue coefficients (9th through 11th rib sections on the left side) of the Dorper wethers are presented in Table 3.14.

No significant difference (P>0.05) was observed in any of the dietary treatments on either the fat, meat or bone composition of the carcasses (Table 3.14).

Table 3.14 Carcass tissue coefficients as influenced by inclusion level of sun-dried and coarsely ground *Opuntia* cladodes (Mean ± s.e.)

Carcass fractions	Treatments*			P	CV (%)
	T0	T24	T36		
Fat	0.243 ± 0.023^a	0.202 ± 0.015^a	0.214 ± 0.023^a	0.3502	28.797
Meat	0.521 ± 0.016^a	0.545 ± 0.013^a	0.526 ± 0.014^a	0.0608	7.535
Bone	0.227 ± 0.018^a	0.243 ± 0.008^a	0.246 ± 0.015^a	0.7361	18.607

[a,b] Means in the same row followed by different superscripts differ significantly (P<0.05)

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

Tien and Beynen (2005) observed significant (P<0.025) differences between the percentage of carcass yield of sheep in the control group and those supplemented with cactus pear. The meat percentage of the control group (61.6%) was lower (P<0.025) than those supplemented with cactus pear (67.6 and 64.4%). In contrast, the bone percentage of the control group (38.4%) was higher (P<0.025) than those supplemented with cactus pear (33.1 and 35.8%). Cactus supplementation resulted in an increased percentage of meat at the expense of bone. This was not the case in the present study. Tien and Beynen (2005) concluded that supplementing diets with cactus pear not only increased weight gain, but also improved slaughter characteristics.

According to Atti *et al*. (2006) cactus supplementation increased (P<0.05) the bone percentage of goat male kids during a total trial period of 74 days. Goats receiving cactus pads *ad lib*. had a higher (P<0.05) bone percentage (26.9%) than those of the control group (22.9%). The fat percentage decreased (P<0.05) from 15.8% in the control group to 10.5% in the cactus supplemented group. Hence, cactus intake reduced carcass adiposity (Atti *et al*., 2006). Nevertheless, both the bone and fat percentages mentioned were not in accordance with the results obtained in the present study. Atti *et al*. (2006) noted no statistical difference (P>0.05) in the muscle percentage (mean of 59.4%) between the dietary treatments. This was also the case in the present study.

Muscle and fat depots depend on nutrient consumption and utilization (Atti *et al*., 2006). The DE intake of the Dorper wethers (Table 3.8) was very similar (P>0.05) and could not have effected the carcass composition of the sheep in the present study.

Atti *et al*. (2006) mentioned that due to treatment effects on slaughter body weight and hence, carcass weight, body muscle and fat weights were affected. This was not the case in the present study as live body weight change (Table 3.4) remained the same ($P>0.05$) between the treatment groups.

In conclusion, the average tissue coefficients of the Dorper wethers did not differ significantly ($P>0.05$) between the treatment diets as the inclusion level of *Opuntia* increased. Thus, the mean carcass composition coefficients of the Dorper wethers observed in this study cannot be associated with *Opuntia* inclusion.

4. Conclusions

The long-term goal of this research programme at the University of the Free State is to utilize and characterize *Opuntia ficus-indica* as a feed source when incorporated at substantial levels as a major ingredient in balanced diets for livestock.

The present study investigated to what extent sun-dried and coarsely ground *Opuntia* cladodes can be incorporated in balanced sheep diets without reducing sheep performance.

Opuntia ficus-indica is a high yielding plant that is well-adapted to a range of soils and climatic regions. When *Opuntia* plants are pruned to stimulate fruit production, large volumes of plant material (cladodes) are wasted and just left to dry and rot. In many countries these freshly pruned material is gathered and fed directly to ruminants. The need arose in South Africa to convert this 'waste material' with its high water content of about 890 g water/kg into an attractive feed that can be put to greater use in formulated diets. However, the high water content makes transport and storage of *Opuntia* difficult. Therefore, if sheep can maintain or better still gain live weight on *Opuntia*-based diets without deleterious effects, this "waste" material can be cut, dried, milled and stored as a feed and utilized during drought or fed directly to sheep as part of a total mixed diet (as for treatment diets T24 and T36 in the current study). By sun-drying and grinding cladodes, value is added to the product partly because it can be stored or transported over longer distances and incorporated in production diets.

Based on the experience from this study, as well as the previous study by Zeeman (2005), it is recommended to cut *Opuntia* cladodes into strips of about 15 to 25 mm wide and to dry it in the sun on a corrugated sink roof or wire mesh. The cladode strips must be turned frequently with an appropriate implement such as a hay fork or rake to facilitate air movement and prevent moulding or rotting of the cladode strips in those places where air circulation is restricted. Thereafter, the sun-dried cladode strips with its DM content of about 700 to 850 g/kg can be further processed by grinding it coarsely in a hammer mill to pass through a 20 mm sieve and store it before being used in diets. Although the cladodes were cut by hand and sun-dried in a very simple way for this trial, these processes can be mechanised.

When sheep is offered diets containing sun-dried *Opuntia*, it is recommended to allow for an adaptation period of one to two weeks which helps facilitate higher voluntary intake of dried cladodes as the wethers progressively become accustomed to it. It was also observed that sheep will select the other diet ingredients if the *Opuntia* fraction is discernibly coarser than the main coarse roughage component of the diets, namely lucerne hay. To reduce this selective feeding behaviour the dried cladodes can be ground finer than the proposed 20 mm [using a 6 mm sieve recommended by De Kock (1980, 2001) and Nefzaoui and Ben Salem (2001)] or by processing the diets into feed pellets. However, this would increase the cost of processing the *Opuntia* cladodes but ensure a more constant and non-selective feed intake. It would seem that particular attention must be paid to ensure uniformity in the coarseness of the roughage fractions.

As the inclusion of *Opuntia* in the experimental diets increased from 0, 240 to 360 g/kg, the DM content decreased due to the lower DM content of *Opuntia* cladodes compared to the roughage component it substituted, namely lucerne hay. The same was observed for OM, ADF, NDF and GE. In contrast, the ash content increased with *Opuntia* inclusion. The decreasing ADF and NDF content of diets T24 and T36 reflected the diluting effects of the low fibre content of *Opuntia* cladodes. The CP and EE content varied slightly because of the inclusion of feed grade urea and the low lipid content of both *Opuntia* cladodes and lucerne hay.

Dietary treatment had no effect ($P>0.05$) on sheep live weight gains. The moderate but satisfactory weight gain of the Dorper wethers could be the result of the supplemented maize meal and urea in the respective diets. This increased the energy and CP content, respectively. It should be noted that the control diet (T0) used in this study was similar to the formulation used by Zeeman (2005) and this diet was only designed to promote moderate growth. A slight decrease in ADG ($P>0.05$) was noted in the present study, suggesting that the overall effects of the diets on the wethers were small. Based on the data obtained in this study, it is recommended that *Opuntia*-based diets be supplemented with additional protein and energy feed sources. This would likely overcome any nutrient deficiency that could affect rumen fermentation and consequently prevent an increased growth rate.

Opuntia inclusion had no effect on DM feed intake. The intake of OM, CP and GE also remained the same between treatments and could explain why animal live weight gain was not affected by dietary treatment. The ADF and NDF intake decreased ($P<0.05$) and ash intake increased ($P<0.05$) following *Opuntia* inclusion in diets. This can be associated with the lower proportion of a fibrous feed source (lucerne hay) high in ADF and NDF in the diets or the high ash content of *Opuntia* cladodes.

Opuntia inclusion had a marked effect on the apparent digestibility of most chemical constituents, except for ash. It increased the apparent digestibility ($P<0.05$) of the diets when incorporated in the dried and ground form. This positive effect could be ascribed to the higher levels of easily digestible carbohydrates in the *Opuntia* and the addition of a source of non-protein nitrogen (NPN; feed grade urea) that is efficiently utilized by the rumen microbes and enhances digestion.

The digestible CP intake for all treatments was higher than the maintenance requirement of sheep and the Dorper wethers consumed sufficient digestible OM to allow for satisfactory live weight gain.

The voluntary water intake increased ($P<0.05$) with inclusion of sun-dried and coarsely ground *Opuntia* cladodes in diets during the feed intake and digestibility period. In contrast, the urine excreted by the sheep remained the same ($P>0.05$) in all treatments, but the faeces excreted was much wetter than the expected normal consistency of sheep pellets. It is suggested, as was also the case in a previous study by Zeeman (2005), that the mucilage present in the digestive tract of the wethers may render some of the water associated with the digesta unavailable for absorption. The precise mode in which the *Opuntia* interacts with water and prevents it from being extracted from the digesta or being absorbed from the colon is not known and is currently investigated in a follow-up trial. Nevertheless, the wethers were compelled to drink more water to compensate for this extra water loss in the faeces. The wet faeces typically produced by sheep on *Opuntia* diets were mostly assumed to be the result of diarrhoea, but the wet faeces lacked the customary foul smell associated with diarrhoea.

None of the carcass characteristics (carcass weight, area of eye muscle, tissue composition and subcutaneous fat layer) measured in this study was affected ($P>0.05$) by the inclusion of *Opuntia* in the experimental diets. These results suggest that the overall effect of *Opuntia* on the carcass weight and quality of the Dorper wethers were small.

From the results of the present study, it seems that, irrespective of the dietary treatment, adequate nutrients for maintenance and production of sheep were supplied by the treatment diets. Sun-dried and coarsely ground *Opuntia* cladodes is an alternative feed source that can be included successfully in sheep diets to meet requirements for maintenance or production diets without any detrimental effects on animal performance or carcass quality.

Treatment diet T0 was formulated as a basal diet to ensure moderate growth of sheep. The same objective was set in formulating treatment diets T24 and T36. It is recommended that research should focus on the formulation of *Opuntia*-based production diets with a high energy content to be used in feedlots.

The effect of mucilage on the wetter faeces excreted by sheep on *Opuntia*-based diets and what happens in the alimentary canal also needs to be further investigated. This is currently being done in a comparative slaughter trial with similar Dorper wethers. It is of particular interest to understand the precise mode of interaction between *Opuntia* and water in the alimentary tract. This improved understanding of the mode of interaction would enable the development of procedures to reduce the wet faeces produced by sheep, making *Opuntia* a more attractive feed source.

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Abstract

Incremental levels of sun-dried and coarsely ground cactus pear (*Opuntia ficus-indica* var. Algerian) cladodes were used to substitute part of the lucerne hay in balanced diets and fed to 28 Dorper wethers. The extent to which sun-dried and coarsely ground *Opuntia* cladodes can be incorporated in balanced sheep diets without effecting sheep performance was investigated over a period of 70 days. The three treatment diets (T0, T24 and T36) used in this study 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. The dry matter intake (DMI) varied little between diets but the apparent digestibility increased [$P<0.05$; 71.4% (T0) vs. 75.6% (T36)]. The average daily gain (ADG) of the wethers decreased slightly as *Opuntia* inclusion increased. This suggests that the overall effects of the diets on the performance of the wethers were small. As the inclusion level of *Opuntia* increased in the diets, the water intake of the wethers also increased ($P<0.05$; T0 vs. T36), while urine excretion showed little increase ($P>0.05$). The faeces DM excreted remained the same for all diets, but with the higher levels of *Opuntia* inclusion the DM content of the faeces excreted visibly decreased considerably. It is suggested that the mucilage ingested via the *Opuntia* and present in the digestive tract of the wethers may have interacted with the water fraction in the digesta, rendering some of the water unavailable for absorption. Hence, the wethers were compelled to drink more water to compensate for this extra water loss via the faeces. The wetter faeces were assumed to be the result of diarrhoea by some researchers, but the wet faeces lacked the customary foul smell associated with diarrhoea. *Opuntia* inclusion in the diets had no effect on carcass characteristics of the wethers (weight, fat thickness, surface area of *musculus longissimus dorsi* and relative tissue coefficients). This suggests that the effect of *Opuntia* in the treatment diets on the carcass weight and quality of the wethers were small. From these results, it seems that, irrespective of the dietary treatment, adequate nutrients for sheep maintenance and production was supplied by the diets. Sun-dried and ground *Opuntia* cladodes can be seen as an alternative feed supplement in semi-arid and arid regions of most countries that can be included in sheep maintenance or production diets without any detrimental effects on animal performance or carcass quality. It is recommended that research should focus on the formulation of *Opuntia*-based production diets with a high energy content, to be used in feedlots. The effect of mucilage on the wetter faeces excreted by sheep

on *Opuntia*-based diets and what happens in the alimentary canal also needs further investigation.

Key terms: carcass characteristics, digestibility, faeces, mucilage, *Opuntia*, urine, water intake

Opsomming

Toenemende vlakke van son-gedroogde en grof gemaalde turksvyblaaie (*Opuntia ficus-indica* var. Algerian) is gebruik om ‘n deel van lusernhooi in gebalanseerde diëte te vervang en is aan 28 jong Dorperhamels gevoer. Tydens ‘n totale proefperiode van 70 dae is ondersoek ingestel tot watter mate son-gedroogde en grof gemaalde *Opuntia* blaaie in gebalanseerde skaapdiëte ingesluit kan word sonder noemenswaardige invloed op die prestasie van die skape. Die drie behandelingsdiëte (T0, T24 en T36) het onderskeidelik (lugdroë basis) 0, 240 en 360 g/kg son-gedroogde, grof gemaalde *Opuntia*; 660, 410 en 285 g/kg grof gemaalde lusern hooi; 300 g/kg geel mieliemeel; 0, 10 en 15 g/kg voergraad ureum; en 40 g/kg molasse meel bevat. Die inname van droë materiaal (DM) het min tussen diëte verskil, maar die skynbare verteerbaarheid het toegeneem [$P<0.05$; 71.4% (T0) vs. 75.6% (T36)]. Die gemiddelde daaglikse toename (GDT) van die hamels het effens afgeneem soos *Opuntia* insluiting vermeerder het. Dit dui daarop dat die algemene effekte van die diëte op die prestasie van die hamels klein was. Soos die insluitingsvlak van *Opuntia* in die diëte verhoog het, het die waterinname van die hamels dienooreenkomstig verhoog ($P<0.05$; T0 vs. T36), terwyl uitskeiding van urine min toename getoon het ($P>0.05$). Uitskeiding van die mis DM was onveranderd vir alle diëte, maar met die hoër vlakke van *Opuntia* insluiting het die DM-inhoud van die mis uitgeskei sigbaar aansienlik afgeneem. Daar word vermoed dat die slymgom-inname via *Opuntia* in die verteringskanaal van die hamels op ’n onbekende wyse met water inmeng en ’n deel van die water nie vir absorpsie beskikbaar stel nie. Gevolglik het die hamels meer water gedrink om te kompenseer vir hierdie ekstra water wat in die mis uitgeskei is. Meeste navorsers skryf die nat mis toe aan diarree, maar die kenmerkende stank wat met diarree geassosieer word het in die nat mis ontbreek. Insluiting van *Opuntia* in die diëte het geen effek op karkaseienskappe van die hamels (massa, vetdikte, oppervlak van *musculus longissimus dorsi* en relatiewe weefselkoëffisiënte) gehad nie. Dit dui daarop dat die effek van *Opuntia* in die behandelingsdiëte op die karkasmassa en karkaskwaliteit van die hamels klein was. Hierdie resultate dui daarop dat, ongeag die dieet wat in die studie gebruik is, voldoende voedingstowwe vir onderhoud en produksie van skape deur die diëte voorsien is. Son-gedroogde en gemaalde *Opuntia* blaaie kan as ‘n alternatiewe voerbron in semi-ariede en ariede omgewings van meeste lande benut word as diëte vir die onderhoud en produksie van skape sonder noemenswaardige nadelige effek op diereprestasie of karkaskwaliteit. Dit word aanbeveel dat navorsing behoort te fokus op die formulering van *Opuntia*-gebaseerde

produksiediëte met ‘n hoë energie-inhoud vir gebruik in voerkrale. Die effek van slymgom op die natter mis wat deur skape op *Opuntia*-gebaseerde diëte uitgeskei word en veral wat in die verteringskanaal gebeur benodig verdere navorsing.

Sleutel terme: karkaseienskappe, mis, *Opuntia*, slymgom, urine, verteerbaarheid, water inname