

**Qualitative characteristics of selected
Atriplex nummularia (Hatfield Select)**

by

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Abbreviations

ADF	Acid Detergent Fibre
ADL	Acid Detergent Liquid
Al	Aluminum
Ca	Calcium
Cl	Chloride
cm	centimeters
CNS	Central Nervous Centre
CO ₂	Carbon Dioxide
CP	Crude Protein
Cu	Copper
DM	Dry Matter
DMI	Dry Matter Intake
DOM	Digestible Organic Matter
DOMI	Digestible Organic Matter Intake
DOMI/kgW ^{0.75}	Digestible Organic Matter Intake per Metabolic Liveweight
Fe	Iron
g	gram
HCl	Hydrochloric acid
IVDMD	<i>In Vitro</i> Digestible Dry Matter
IVDOM	<i>In Vitro</i> digestible Organic Matter
K	Potassium
kg	Kilogram
(LW) ^{0.75}	Metabolic Live Weight
M	Molar
m ²	Square meters
Mg	Magnesium
mg	milligram
MJ	Mega Joule
ml	milliliter

mm	millimeter
mmole	millimole
Mn	Manganese
N	Nitrogen
NaCl	Sodium Chloride
NAN	Non-Ammonia Nitrogen
NDF	Neutral Detergent Fibre
NH ₃ -N	Ammonia Nitrogen
°C	Degrees Celsius
OM	Organic Matter
OMI	Organic Matter Intake
P	Phosphorus
P-CDOMD	Pepsin-Cellulase Digestion of Organic Matter in Dry Matter
P-COMD	Pepsin-Cellulase Digestion of the Organic Matter
pH	H-ion concentration
ppm	parts per million
S	Sulphur
Si	Silica
VFA	Volatile Fatty Acids
Zn	Zinc
µm	micrometer

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Abstract

Qualitative characteristics of selected *Atriplex nummularia* (Hatfield Select)

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This study was conducted in two trials. The aim was firstly to identify the qualitative characteristics of *Atriplex nummularia* (Hatfield Select). Goats and sheep were used to identify three palatability groups of plants in the *A. nummularia* (Hatfield Select) paddock. These palatability groups were compared in terms of quality to one another. Secondly, qualitative and quantitative intakes of *A. nummularia* (Hatfield Select) by goats and sheep were determined. This was done in a grazing trial lasting five days. A comparison was conducted between goats and sheep as well as between the different days of the grazing period.

During the first trial, goats and sheep were used to identify the most-, medium- and least-palatable *A. nummularia* (Hatfield Select) plants. The regrowth on these plants were harvested and used for laboratory analysis to identify the qualitative differences between these three groups. These samples were also

used to determine and compare degradability between the three groups as well as between goats and sheep.

Goats and sheep preferred *A. nummularia* (Hatfield Select) plants with a significantly ($p = 0.05$) higher crude protein (CP), phosphorus (P) and magnesium (Mg) content. The most preferred plants also had higher neutral detergent fibre (NDF), Ca, K, Na, Cl^- and Cu content than the least preferred plants, but these were not significant ($p > 0.05$). *A. nummularia* (Hatfield Select) provides enough CP for maintenance and production in both goats and sheep. All mineral requirements for maintenance in goats and sheep can be satisfied on *A. nummularia* (Hatfield Select), except that of Cu. For production (growth and lactation) only P is deficient and needs to be supplemented. *A. nummularia* (Hatfield Select) makes an ideal drought fodder crop to support the natural veld during the dry season.

An overall higher DM, N and NDF rumen degradability of *Atriplex* was recorded with goats than with sheep. Goats exhibited a significantly ($p = 0.05$) higher DM and N degradation and although a higher NDF degradation was also recorded, this was not significant. The rate of DM, N and NDF rumen degradation was also higher in goats than in sheep. This means that goats have a more favorable rumen environment for the digestion of *A. nummularia* (Hatfield Select). DM and N degradation were also significantly ($p = 0.05$) higher in the most palatable group than the least palatable group. NDF degradability decreased with palatability. This means that the most palatable plants have a higher digestibility and quality than the least palatable plants.

In the second experiment, rumen and oesophageal fistulated sheep and goats were allowed to graze *A. nummularia* (Hatfield Select) for five days. Qualitative and quantitative intakes were determined. The quality and quantity of ingested material were compared between goats and sheep as well as between the different grazing days.

There was a significant decline in the quality and quantity of intake over the grazing period. Some parameters were significant, for example CP. The CP concentration declined from 18% to 3.91 % for goats and from 19.88% to 6.61% for sheep. The cell wall constituents (NDF) increased by about 10% from the start to the end of the grazing period. IVDOM decreased by 14% and intakes were almost halved from the start to the end of the grazing period. Other authors have also observed this decrease in quality and quantity of intake over time. The lower quality and quantity in intake was because of a decline in the availability of high quality edible material. At the end of the grazing period, there was very little edible material left which caused an extremely low quality and quantity of intake.

Rumen $\text{NH}_3\text{-N}$ concentrations also declined as the dietary CP declined, but it was still present in high enough concentrations to sustain the rumen micro flora population. Rumen VFA decreased over the grazing period. The acetic acid to propionic acid ratio increased towards the end of the grazing period. This caused a decline in the efficiency of utilization of ME for maintenance as acetic acid has an efficiency in utilization of ME of 59% and propionic acid of 86% (McDonald *et al.*, 1995). This means that energy will have to be supplemented to sustain maintenance.

Chapter 1

Literature Survey

1.1 Introduction

“The climate, as a major element of the physical environment, influences lifestyles and to a large extent determines agricultural production systems. Agriculture is basic to the survival of man. Profitable farming entails careful planning and management in order to exploit existing climatic advantage and to minimize climatic stress” (De Jager, 1993).

Dry conditions, which reduce the availability of grazing, exert possibly the greatest influence on livestock production. In South Africa the annual rainfall declines from a high of 800mm at the east coast to as little as < 50mm in the dry western regions. This low rainfall leads to aridity that affects grazing capacity. Aridity increases when moving from east to west. Production decreases correspondingly with a consequent increase in farm size. It is due to these arid conditions in the west that we need to establish plants to supplement and reinforce the natural veld during periodic and seasonal droughts.

The main constraint for range livestock is the shortage of feed from native rangelands because of poor grazing management, overstocking and drought, resulting in soil degradation. *Atriplex nummularia* is a drought fodder crop indigenous to Australia, and grows on various soil types. This crop can be used for soil rehabilitation and at the same time provide feed for browsing and grazing animals. It is well known for its adaptation to saline soils and drought stress and provides feed to animals under these conditions (Draz, 1983).

The palatability and nutritional composition of individual plants have an influence on intake from a pure *A. nummularia* pasture. By selecting plants of higher

palatability and nutritional value, the production of animals on these pastures can theoretically be increased.

1.2 *Atriplex nummularia*

A. nummularia is indigenous to Australia and has been planted in South Africa for more than 100 years. *A. nummularia* is a perennial woody fodder shrub from the family Chenopodiaceae. These plants are halophytes which means that they are highly salt tolerant. The leaves are single, blue-grey and covered with a layer of bladder like hairs called trigomes. These have an important physiological function by controlling the ion balance in the leaves. An osmotic adaptation exists in the leaves if the salt concentration in the tissue gets too high. Oxalic acid is formed and is transported to the trigomes where it is converted back to salt. The osmotic potential in the leaves stays relatively normal. The trigomes burst and salt crystals and cell wall contents stays on the leaf surface while new trigomes form. This leads to the accumulation of salt on the leaf surface which probably makes the leaves less palatable (Jones and Hodginson, 1969). Due to the high salt concentration in the plant's roots and leaves, it maintains a high osmotic value in its cellular fluid, which is a physiological adaptation to moisture stress and thus drought resistance (Hoon, 1991). *A. nummularia* further contains a C4-carbon metabolism, which means that photosynthesis is highly effective at high temperatures and light intensities (De Kock, 1980). This species also has a low moisture usage. It needs approximately 304kg water per kilogram DM produced (Hoon, 1991). De Kock (1980) found that this species needed only 250kg of water per kilogram of dry matter produced. These fodder shrubs are also adapted to a wide range of soil types and climatic conditions. It produces under relatively unfavourable conditions a relatively high yield of green forage material (De Kock, 1967). All the above considerations make *A. nummularia* an ideal fodder crop under the relatively unfavourable conditions in the dry and extreme conditions of the arid areas of South Africa.

Due to the high salt content of saltbush, it is important to have enough drinking water available to animals at all times. Brackish water may have a negative influence in the intake of saltbush. Hoon (1991) fed *A. nummularia* to Dorper sheep. The control group received rainwater while the treatment group received brackish water. As soon as the treatment group changed to brackish water, intakes were decreased by 40%. He also observed an improvement in intake as the animals became adapted to the brackish water. Hopkins and Nicholson (1999) reported that there was no effect of feeding *Atriplex* to lambs on tenderness or juiciness and overall panelists ranked meat samples similarly for acceptability.

Saltbush species have been reported to vary in nutritive value and to contain a range of compounds that may have anti-nutritional properties at high concentrations. These include oxalates, nitrates, sodium, potassium and chloride (Masters *et al.*, 2001).

Nutritional value:

Forage values of *A. nummularia* are generally considered to be high (Le Houérou, 1980), although quality is influenced by age and phenological stage at the time of harvest and by previous cutting and grazing management. This could be illustrated by the decrease in protein and ash contents and an increase in fibre content of *A. lentiformis* of the initial clippings and subsequent regrowth (Goodin, 1979).

The nutritional value of *A. nummularia* is relatively high. It satisfies the maintenance requirements of sheep and can even sustain some growth (Le Houerou, 1991). Several grazing studies conducted in Morocco have shown that the introduction of *A. nummularia* as a means of range improvement has increased live-weight gain of sheep and goats compared with those grazed on unimproved range (Chriyaa *et al.*, 1997). They also used *A. nummularia* as a protein supplement for sheep during gestation on a wheat straw diet and got a

higher lambing percentage and birth weight. In their work, alfalfa hay and saltbush foliage had the highest values for CP and IVDMD. The NDF value of saltbush foliage and blue wattle foliage was the lowest for all the feeds evaluated. Supplementing straw with saltbush showed the highest increase in DMI. The authors mentioned that the reason for this increase in DMI was that saltbush corrected the protein deficiency of the straw. Animals, which received saltbush foliage as a supplement, were the only ones that gained weight over the whole period of the trial. Table 1 presents the composition of the feeds used by Chriyaa *et al.* (1997). Of particular importance to this study is the composition of *A. nummularia*.

Table 1.1 Chemical composition and *in vitro* digestibility of forages used to supplement wheat straw in sheep feeding (Chriyaa *et al.*, 1997)

Item	Supplement				
	Wheat straw	Alfalfa hay	<i>A.nummularia</i>	Blue wattle	Medic pods
CP (g/kg)	52	136	137	109	108
NDF (g/kg)	703	466	348	342	557
Mg (g/kg)	1.3	2.6	2.1	5.3	2.9
Al (g/kg)	0.7	0.9	2.7	1.6	5.9
Si (g/kg)	30.0	5.2	5.2	4.4	17.0
P (g/kg)	1.0	2.0	0.5	0.7	2.2
S (g/kg)	1.9	2.7	4.3	7.1	1.8
Cl (g/kg)	8.7	7.5	56.6	7.4	3.6
K (g/kg)	7.4	19.5	11.1	4.6	6.0
Ca (g/kg)	5.5	14.8	6.9	30.1	18.8
Mn (mg/kg)	43.8	37.1	65.2	63.2	75.2
Fe (mg/kg)	783.7	540.9	602.1	432.9	-
Cu (mg/kg)	4.8	8.0	4.8	5.1	6.3
Zn (mg/kg)	12.6	22.4	27.8	19.8	106.9
IVDMD (g/kgDM)	447	586	622	488	507

Sheep feeding on fresh *A. nummularia* can have intakes of up to 1.5 kg/day (Steynberg and De Kock, 1987). Wilson (1977) fed dried leaves of four shrubs and four trees to merino wethers in metabolism crates. One of these shrubs was *A. nummularia*. A crude protein concentration of 20.6% and a neutral detergent fibre concentration of 46%, both on a DM basis, were reported. Digestibility's of 70.4% for NDF and 82.0% for N were found. The author determined the OMI as 432 g/day. Apparent digestibility of 68.8% was converted to a true digestibility of 86.3% with the equation $y = 14.5 + 1.042 x$ (Van Soest *et al.*, 1966).

Weston *et al.* (1970) measured the values of various parameters relating to digestion, eg. nutrient digestibilities, flow of digesta and their constituents through the rumen and abomasums and the concentrations of end products of digestion, of sheep fed *A. nummularia*. The chemical composition and digestibility of the saltbush were within the ranges reported in other literature for saltbush grown in semi-arid environments. The values of most parameters measured were within, or close to, the ranges observed with pasture grasses and legumes. However, with saltbush, the stomach played a less important role in the digestion of organic matter and fibre. It further appeared that the ruminal absorption of volatile fatty acids was impaired. The protein of the saltbush was extensively degraded to ammonia in the rumen and accordingly the protein value of the diet was much lower than indicated by its digestible crude protein content.

The saltbush as offered to the sheep, by Weston *et al.* (1970), contained 8% of water. The levels of crude protein, sodium and potassium on a DM basis were 19.8%, 4.0% and 3.4% respectively. The sheep showed a daily OMI of 510g. The authors found 60.8% of the organic matter to be digested. 72% of the dietary N intake left the rumen as NAN. The loss of dietary N during passage through the rumen was ascribed to microbial deamination of dietary nitrogenous substances. This was reflected in the presence of significant quantities of ammonia in the rumen. Ammonia levels in the rumen fluid were in the order of 27 ± 3 mg N per 100ml. The overall digestibility of dietary N was in the order of 75.8%. The level

of volatile fatty acids in the rumen fluid was 8,5mmol/100ml. The pH of the rumen fluid was found to be in the range of 6.9 to 7.1.

Ben Salem *et al.* (2004) used *A. nummularia* Lindeque foliage (atriplex) and *Opuntia ficus indica* f. *inermis* pads (cactus) as alternative N and energy supplements respectively. The author fed 24 Barbarine lambs, which were allotted into four homogeneous groups and housed in individual crates, barley straw *ad libitum* supplemented with either barley grains and soybean meal; or barley grain and atriplex; or cactus and soybean meal; or cactus and atriplex. By replacing soybean meal with *Atriplex*, no effect on DMI of straw was observed. The authors did find that sheep fed cactus had a lower straw DMI than those fed barley. Diets of barley and soybean (BS), barley and atriplex (BA) and cactus and soybean (CS) had the same OM and fibre (NDF and ADF) digestibilities, which were significantly lower than those for cactus and atriplex (CA). Daily gain of lambs averaged 119g, 180g, 81g, 59g respectively for diets CS, BS, CA and BA. The authors attributed the low growth levels with *Atriplex* diets to the high level of soluble N in *A. nummularia*. Table 1.2 shows the composition of the experimental feeds. The composition of *A. nummularia* is of particular relevance.

Table 1.2 Chemical composition of feeds on dry matter basis (Ben Salem *et al.* 2004)

	Barley straw	Barley grain	Soybean meal	<i>A.nummularia</i>	O.F.I <i>f. inermis</i> *
DM (g/kg)	868	859	883	286	177
OM (g/kg)	948	976	931	745	762
CP (g/kg)	34	141	465	178	46
NDF (g/kg)	764	289	370	445	338
Ca (g/kg)	4.4	0.8	3.1	13.6	52.1
P (g/kg)	1.2	2.2	7.1	1.8	1.0
Na (g/kg)	2.6	0.2	3.0	47.0	0.6
K (g/kg)	16.4	7.8	25.9	28.9	26.0
Mg (g/kg)	1.0	1.1	2.4	8.4	10.9
Cu (mg/kg)	6.1	2.4	17.8	13.0	6.5
Fe (mg/kg)	160.7	40.4	299.8	285.1	170.8
Mn (mg/kg)	36.7	11.6	26.9	56.5	248.9
Zn (mg/kg)	18.3	22.3	48.3	47.0	31.0

*O.F.I. *f. inermis* ; *Opuntia ficus indica f. inermis* (spineless cactus)

The stage of growth and maturity considerably affects the nutritive value, palatability and utilization of *Atriplex* species. Such plants are nutritious in the wet season, while they are relatively poor during the dry season (El Shaer *et al.*, 2000, as cited by Aganga *et al.*, 2003). In contrast, Aganga *et al.* (2003) stated that *Atriplex* species contains higher concentrations of nitrogen in winter, compared to summer, when it has high concentrations of sodium. As a supplementary fodder, *Atriplex* species should not make up more than 25-30% of a sheep's diet (Aganga *et al.*, 2003). Casson *et al.* (1996) suggested that the high salt content of saltland forage plants is likely to be the major determinant of palatability and that dilution of salt content through the availability of other feed resources would be necessary to improve intake and performance. Table 1.3 illustrates more nutritional values of *A. nummularia* as cited by Aganga *et al.*

(2003). From Table 1.3 it is clear that stage of growth and maturity influence the nutritional composition of *A. nummularia*.

Table 1.3 Chemical analysis of *Atriplex nummularia* (Watson and O’Leary, 1993 as cited by Aganga *et al.* 2003)

Content	Cut 1	Cut 2	Cut 3	Cut 4	Ave regrowth
Ash (g/kg)	181	247	220	223	230
CP (g/kg)	92	131	91	85	103
ADF (g/kg)	337	243	317	306	289
NDF (g/kg)	497	405	489	472	455
Lignin (g/kg)	104	92	93	84	90
Na (g/kg)	64.2	75.3	71.1	68.8	71.1
Ca (g/kg)	4.9	6.8	4.9	4.8	5.5
K (g/kg)	19.8	23.2	20.4	17.4	20.3
Mg (g/kg)	3.6	4.3	4.6	4.9	4.6
P (g/kg)	2.2	2.6	2.0	1.5	2.0
Na/K	5.5	5.5	5.9	6.7	6.0

This fodder has a low energy value (6.1MJ/kg) (Hobson *et al.*, 1986) but a relative high protein value (21%) (Jacobs and Smit, 1977; Verschoor, 1992). According to Wilson (1977) the fibre digestion of *A. nummularia* is relatively high and the N content and digestibility are above average. This is a fodder with enormous potential in the arid zones, but it needs some kind of energy supplementation. When supplemented with energy, it can sustain production when natural veld cannot (Steynberg and De Kock, 1987).

Table 1.4 Mean values for chemical factors for the most preferred and least preferred plants of river saltbush and old man saltbush
(Norman *et al.*, 2004)

Measurement	Old man Saltbush		River Saltbush	
	Most preferred	Least preferred	Most preferred	Least preferred
P-CDOMD %	59.06	60.62	50.04	53.83
P-COMD %	82.09	82.19	66.06	71.91
ADF %	17.11	17.85	26.80	24.71
NDF %	30.54	32.22	42.28	39.45
N %	2.46	2.03	1.62	1.55
N:S	5.60	4.42	4.34	3.89
S %	0.45	0.48	0.38	0.41
Total ash %	28.00	26.30	24.21	24.97
Soluble ash %	23.08	21.63	19.79	19.93
Na %	7.25	6.89	5.93	7.04
K%	3.63	3.83	2.67	2.66
Cl %	11.76	11.64	10.30	12.35
Ca %	0.77	0.73	0.82	0.85
Phosphate %	0.15	0.14	0.13	0.13
Mg %	0.77	0.78	1.00	1.17
Mn mg/kg	146.68	170.17	142.15	288.46
Zn mg/kg	18.84	19.61	18.76	21.67
Fe mg/kg	189.50	178.40	186.11	200.56
B mg/kg	113.77	109.77	70.09	81.97
Oxalate %	3.29	2.97	2.56	2.69
Nitrate mg/kg	249.27	94.74	110.49	80.35
Crude tannin%	0.14	0.09	0.12	0.09

Norman *et al.* (2004) examined the nutritive value and preference by sheep of two saltbush species, *A. amnicola* (river saltbush) and *A. nummularia* (old man saltbush). The sheep demonstrated a strong preference for river saltbush over old man saltbush, as estimated by the consumption of individual bushes.

Significant variation between old man and river saltbushes was found for many of the plant factors tested as illustrated in Table 1.4. River saltbush differed from old man saltbush in that it had lower pepsin-cellulase digestion of the organic matter (P-COMD) and pepsin-cellulase digestion of organic matter in dry matter (P-CDOMD), higher ADF and NDF, less N, S, K and B, a lower N:S ratio, lower total and soluble ash, more Mg and less nitrates. Within each species, different factors were found to be related to preference. Within river saltbush, greater preference was associated with, lower Na and Cl and higher tannins. For old man saltbush preference was related to higher N, nitrates and N:S ratio. Differences between species were greater than differences within species for these factors affecting preference and palatability. These results were not consistent with known preference and selection principles derived from a range of other publications (Forbes, 1999; Forbes and Mayes, 2002). Norman *et al.* (2004) therefore, concluded that selection within or between species of saltbush was not primarily associated with digestibility, fibre, CP, S, minerals, nitrate or oxalate.

1.3 Palatability

Palatability is a complex phenomenon determined by animal, plant and environmental variables. Evidence exists that sheep and cattle sometimes possess different degrees of sensitivity to palatability factors when a choice of feeds is offered. Individual animals differ in their preferences for plant species. Some forage species and even genotypes within a species may be unpalatable to grazing ruminants. This is possibly due to factors like alkaloids, which lower the palatability of the forage. Natural and induced environmental factors frequently influence selection by ruminants (Gorden, 1978). The features of a food material that are sensed before it is swallowed, of which an animal is consciously aware, are often collectively called the palatability of that food (Forbes, 1998). Palatability is often confused with acceptability or preference of a food. The palatability of a food is not only a function of the food, because the acceptability of the food depends on what the animal has previously learned of that food (Forbes, 1998). According to Grill and Berridge (1985) palatability is “a

response measure which is based on the outcome of the central nervous system's integration of taste and internal-state signals combined with cues arising from previous associations". Brobreck (1957) suggested that stimulation of the appetite centre, through a variety of stimuli, results in a neural motor outflow producing reflexes of attention, approach, examination, and incorporation or rejection of food. Final choice of food is thus determined by the responses elicited from the special senses to stimuli from the food. Gorden (1978) defined *Relative Forage Palatability* as: "A plant characteristic(s) eliciting a proportional choice among two or more forages conditioned by plant, animal and environmental factors which stimulate a selective intake response by the animal. This characteristic(s) may also be described in terms of acceptability, preference, selective grazing, and relish conditioned by sensory impulse." It is often thought that animals will have a higher intake on a more palatable food than a less palatable food. This may be true for short-term intake but not for long-term intake.

1.3.1 Factors that influence forage palatability

Animal factors:

The animal factors that influence palatability may be partitioned into five major categories: (1) the senses, (2) species or breeds, (3) individual variations, (4) previous experience or adaptation, and (5) physiological condition (Gorden, 1978).

The senses affecting the palatability of a food are touch, vision, olfactory, taste, and instinct. Without visual and taste cues animals cannot identify the appropriate diet. Animals become aware of food first by their senses, particularly vision and olfaction. They move towards the food and eat a small amount initially to be able to further characterize it by its taste and texture. Familiar food is eaten in greater quantities as long as the animal has learned that no major discomfort has followed previous meals of that food (Forbes, 1998).

Animals selectively remove the leaves from the stems with the sense of touch (Arnold, 1966). This is done by leaf plucking with the lips and is very common in the concentrate selectors such as goats.

Bazely and Ensor (1989) found that none of their sheep learnt to discriminate between green and yellow of the same brightness but could differentiate between different brightness' (41 to 77% reflectance). This does not mean that sheep do not have color vision, but brightness might be important for grass reflecting the amount of protein in the feed like ryegrass. The sight of food induces changes in the firing rate of some neurons in the lateral hypothalamus of the conscious sheep (Maddison and Baldwin, 1983), and sight may be more important than odor in food recognition in sheep and other ruminants. However, temporary covering of the eyes does not interfere with the preference for certain herbage species by grazing sheep (Arnold, 1966), suggesting that they use smell, taste and tactile stimuli to a great extent to discriminate between different species. Individual neurons in the lateral hypothalamus and *zona incerta* respond to the sight, but not the smell of the food, and then only palatable food, not food that sheep won't eat. Cells that formerly responded to food later respond to salt instead when the animal is made sodium-deficient (Forbes, 1998).

Olfactory ability varies between different species; carnivores are able to smell their prey over a long distance (Forbes, 1998), while poultry have no sense of smell. Herbivores, having a poor ability to smell, are surrounded by their food and the ability of smell is of little use in seeking food (Forbes, 1998). Arnold (1970) found that the smell of food was an important determinant of food choice by sheep, although Tribe (1949) thought that odor had little part to play in selection of plant species by grazing animals. Tribe (1949) found that young sheep, without olfactory lobes, discriminated less than intact sheep between stale or faeces-contaminated and fresh-cut herbage. When given a known food, sheep do not use odor to control intake (McLaughlin *et al.*, 1974) although it's odor may be used to differentiate between foods (Pfister *et al.*, 1990). Cattle deficient in

sodium have the ability to detect sodium bicarbonate at up to 20m by smell (Bell and Sly, 1983). Bell and Sly (1983) found that anosmic (animal of which the olfactory gland is removed) cattle took longer to identify salt solutions than the control, but they could still taste the salt. This shows that the senses of taste and olfactory are separate. Sheep showed a reduced intake from a container tainted with carnivore faeces and a higher intake (95%) from the uncontaminated container (Pfister *et al.*, 1990). The sheep went as far as possible away from the odoriferous containers.

Taste is a more proximate guide to food quality than vision and olfaction. The taste of a food is a powerful tool for the animal to associate the nutritional value of the food (Forbes, 1998). For example; a bitter taste is often associated with toxins in the food. Animals can adapt to a less tasteful food. When sheep were fed quinine-treated hay, they discriminated against it in the preliminary period. Thereafter they ate equal amounts of quinine-treated and untreated hay in a 5-day choice period (Jones and Forbes, 1984). This demonstrated adaptation as they learned that there were no harmful consequences to eating this unpalatable hay. Sheep and goats are sensitive to bitter, sour, salty and sweet solutions (Goatcher and Church, 1970). Preferences for taste can be blocked by including 5-50 ppm of monosodium glutamate in the solution. Sheep prefer the taste of butyrate to several other compounds. Arnold *et al.* (1980) tested 32 chemicals found in plants for food preference by sheep and found that butyric acid increased preference but not total intake. When foods containing 25 ml of 2M acetic acid kg⁻¹, 1g kg⁻¹ of quinine or 20g kg⁻¹ of sodium chloride were offered *ad libitum* to sheep, intake was less than the intake of untreated food (Baile and Martin, 1972).

Animal species differ in the forage plants selected. Marten (1973) showed a greater ability of sheep than cattle to differentiate between grazed clones of reed canarygrass. Both sheep and cattle selected reed canarygrass on the basis of alkaloids, both discriminating against high alkaloid content in the grass. As

mentioned above, Goatcher and Church (1970) found that cattle were more sensitive, than were sheep, to concentrations of solutions that differed in sweetness, saltiness, and sourness. Sheep were more sensitive than cattle to bitterness. Arnold (1970) reported differences in preference curves of four breeds of sheep for citric acid and acetic acid.

Previous experience also affects the preference for a specific plant species by an animal. When animals were previously exposed to a less palatable species, they will initially consume this species in almost equal amounts than an unknown, more palatable species. This was well demonstrated in a study by Marten and Jordan (1974). These authors found that for sheep preconditioned on less palatable reed canary grass, the preference for more palatable orchard grass was reduced to a non-statistically significant difference. In a study done by Marten (1978), lambs initially preferred a strip of alfalfa-grass to the birdsfoot trefoil. After exposing the lambs to only birdsfoot trefoil, however, the lambs consumed the birdsfoot trefoil as regularly as the strip of alfalfa-grass.

Plant Factors:

Plant factors that may influence forage palatability to animals are: (1) species, (2) intraspecific variation, (3) chemical composition, (4) morphology or physical traits, (5) succulence or maturation, (6) availability in non-controlled situations, and (7) form of forage controlled by mechanization (Gorden, 1978).

While some investigators (Tribe, 1949; Heady, 1964) emphasize that specific plant species and plant characteristics do not elicit standardized palatability responses by animals, certain forage plant species, genotypes within species, and plant characteristics do elicit very predictable palatability responses by grazing ruminants.

Numerous associations reported between plant characteristics and plant palatability to ruminant animals have proven to be highly situation-specific,

making them worthless as general selection criteria. Among these are concentrations of sugar or soluble carbohydrates, protein or nitrogen, fibre or cell walls, cellulose, ether extract or fat, individual minerals or total ash, carotene, vitamins, organic acids, tannin, and silica (Marten, 1969).

Environmental Factors:

Natural and induced environmental factors frequently influence plant selection by ruminant animals. Among these are (1) plant diseases, (2) soil fertility, (3) animal dung, (4) Feed additives, (5) climatic variation, and (6) seasonal or diurnal variations (Gorden, 1978).

In a study conducted by Gorden (1978) in Minnesota, the presence or absence of a plant disease on palatability of two forage species was apparent in a stall-feeding study. He fed freshly cut smooth brome grass infected with *Helminthosporium* leaf spot and reed canary grass to separate groups of dairy heifers. The reedcanary grass is less palatable than the brome grass. Although brome grass is more palatable, the intakes of the heifers on the infected brome grass were lower than on the reed canary grass. This implies that the infection with a disease can have a negative effect upon the palatability of that plant.

Animals will discriminate against plants contaminated with faeces or urine, as proven by Tribe (1949). This could be due to a decrease in palatability.

1.4 Intake

Feed intake is a behavioral activity representing the amount of food eaten by an animal in a given period of time. Voluntary intake is generally correlated with the amount of nutrients that can be extracted from a feed, for example the feed's digestibility (Illius, 1998). The digestibility of forages is largely determined by features of the plant. Due to interactions between feeds, or between the animal and a feed, the potential digestibility and potential intake may not be achieved. Feed intake is an important aspect of animal production systems because of its close relation to animal performance and profit margins (Gill *et al.*, 1986). The

more food the animal can consume, the better the chance of increasing its daily production. An increase in production that results from an increase in food intake is associated with a better efficiency of the production process, since maintenance costs decrease as the productivity increases (McDonald *et al.* 1995). Changes in feed intake have also been associated with the phenomenon of compensatory growth. Animals undergoing compensation, following a period of growth restriction, were observed to greatly increase their feed intake (Baker *et al.*, 1985; Gibb and Baker, 1991). Substantial research has been done to understand the factors that are involved in the regulation of feed intake, yet it is so complex that many of the involved mechanisms remain unclear.

To understand intake control, we need to ask ourselves why do animals eat and why do they stop eating. It is generally accepted that animals eat to supply tissues with the necessary nutrients for maintenance, growth, work and production. Animals stop eating to limit metabolic or physical discomfort and thus the animal has to decide at what point the disadvantage of deficiency or excess of some nutrients outweigh the advantages of trying to meet the animal's energy requirements, which are thought to be the animals main intake 'drives' (Emmans, 1997).

It has long been assumed that, for forage diets, it is the bulkiness of the forages that primarily limits intake. This is a combination of the volume and the time that the undigested food stays in the rumen. Intake is limited by gut fill up to a breakpoint in digestibility, beyond which the relationship between intake and digestibility become negative and controlled by the animal's energy balance (Conrad *et al.*, 1964).

Feed intake is not strictly governed by a single factor, rather it is influenced by an interplay of external and internal factors. External factors are the sum of environmental and dietary cues, conversely internal factors are derived from within the animal. The physiological state of the animal is believed to have an

important effect on intake. In ruminants, voluntary feed intake is largely determined by the physiological demands due to maintenance requirements and potential production (Hicks *et al.*, 1986).

There is consensus in the literature that the central nervous system (CNS) is the principal regulatory site of feed intake in animals. Regulatory mechanisms convey either hunger or satiety signals to the CNS, which increase or limit feed intake respectively. The hypothalamus is the portion of the brain that is responsible for feed intake regulation. The lateral hypothalamus responds to hunger signals and the ventromedial hypothalamus responds to satiety signals (Martin *et al.*, 1989).

The following factors affecting feed intake will be discussed: (1) forage factors, (2) animal factors and (3) interactions between feed components.

1.4.1 Forage factors that affect intake

Physical factors

Physical factors are factors that directly influence the initial gut volume occupied by the feed ingested and the rate at which this volume decreases due to digestion and onward passage. The content of fibrous cell walls contributes a large portion of this volume. The cell wall contents are less soluble and take up more space than the cell contents. From 35 to 80% of the organic material of forages is found in the cell wall. The structural carbohydrates in the cell wall; hemicelluloses, cellulose and pectin, are broken down by micro-organisms in the rumen, which enable ruminants to use this energy source, which is not available to non-ruminants. The ease with which the micro-organisms can break these molecules down depends on the distribution of the molecules within the plant (Jung and Allen, 1995). The physical characteristics of the cell wall or fibre particles such as tissue origin, shape, buoyancy and specific gravity, affect the rate at which the particles are broken down and the ease of passage (Wilson and Kennedy, 1996).

Resistance to reduction in particle size is positively related to fibre content; however, relationships between fibre measured using neutral detergent solution and DMI are not always consistent (Reid *et al.*, 1988). Reid *et al.* (1988) also indicated that the fill effect of NDF may vary with different forages. Minson (1990) observed that for groups of forages with similar DM digestibility, fibre content is greater in legumes compared with grasses, temperate compared to tropical grasses and leaf compared to stem. Wilson and Kennedy (1996) suggested that the greater digestibility of legumes compared with grasses may reflect leaf length. Grass particles are inherently long and buoyant, with a low functional specific gravity, and easily entangled, while chewed vascular particles are short and chunky with high functional specific gravity and thus escapes the rumen quicker. This demonstrates that the potential intake not only depends on the fibre content, but also on the structure and the way in which the plant material is broken down during digestion.

The dry matter content of feeds may also influence the space occupied within the gut. Pre-wilting of grass prior to ensiling has consistently been shown to give silages with up to 44% higher intakes compared with unwilted material from the same sward (Teller *et al.*, 1993). An explanation for this higher intake could be that the effectiveness of chewing during eating and the rate of particle breakdown was enhanced with the drier material. Wilting also causes breakdown of the cell walls, leading to easier digestion.

In grazing animals the structure of the sward can restrict intake not only in terms of the space taken up in the gut, but also by limiting the amount of herbage which the animal can actually harvest within a 24h period. Characteristics of the grazed sward, such as plant density and height, can influence intake through their effect on ease of prehension and thus bite size (Hodgson *et al.*, 1991). Stobbs (1973) concluded that the sward bulk density and leaf to stem ratio were the main factors affecting bite size and intake of cattle.

Forage Mass

Ruminants have no difficulty in satisfying their appetite when enough desired forage is available and given the fact that grazing is unrestricted. Under such circumstances they will take in large quantities of forage with each bite (Allden and Whittaker, 1970). Bite size on young uniform swards varies with the physical dimensions of the individual bite and the quantity of forage within the volume encompassed by the teeth (Hodgson, 1996). When too little forage is available, less than 2000kg DM/ha, there will be a reduction in bite size. The animal will try to keep intake constant at a specific level and will spent more time grazing (Allden and Whittaker, 1970).

1.4.2 Animal factors that affect intake

Animal size

As mentioned earlier, the energy requirement of an animal contributes to the amount of intake of an animal. Across species, size is the factor most closely correlated with intake. Larger animals consume greater quantities of food. The relationship is, however, not isometric but scales allometrically with body mass, and intake is commonly expressed on the basis of metabolic body weight, or live weight (LW)^{0.75} (Illius, 1998).

Physiological status of the animal

Physiological status affects energy requirements and hence intake. In lactating animals, where nutrient demand is high, the rapid removal of metabolites from the blood may reduce the degree of stimulation of chemo receptors from the same amount of absorbed nutrients, or rate of passage may be faster reducing the bulk effect (Forbes, 1995). Intakes are normally higher in lactating compared with dry or pregnant cows (Campling, 1966). Invartsen *et al.* (1992) observed a reduction in intake due to pregnancy. He concluded that this reduction in intake was due to hormonal regulation and a physical decrease in space in the rumen due to the increase in size of the foetus.

Grazing animals

Intake of grazing animals is dependant both on intake rate and time spent grazing (Allden and Whittaker, 1970). Bite mass and bite rate are not independent. Newman *et al.* (1994) point out that for a given forage requiring a given time of mastication, an increase in bite mass will cause an increase in time of mastication, decreasing bite rate and resulting in intake rates that are similar. Animals will increase intake rate when time allowed grazing is restricted, once they learn that they are only allowed a restricted grazing period (Romney *et al.*, 1996).

Where sward structure limits bite mass and therefore intake rate, grazing time can be altered to compensate for decreased bite size. There appears to be an upper limit to the amount of time a ruminant will spend grazing (Forbes, 1995). Forbes (1995) suggests that ruminants are unwilling to eat for more than 12h per day. Thus, if bite size falls below a certain limit, animals will not be able to achieve maximum intake capacity. This occurs as a result of an upper limit to oral processing time, which encompasses prehension, mastication and rumination (Illius, 1998).

1.4.3 Interaction between dietary components

Supplementation can be considered as a means of increasing nutrient supply to animals that are unable to consume sufficient nutrients as forage. Supplementation tends to have an overall positive effect on dry matter intake, but may have positive or negative effects on intake of the basal forage (Forbes, 1995).

Supplements that are high in readily fermentable carbohydrate may have a greater effect on inhibition of fibre intake than more slowly fermentable supplements, through depression of digestion of the roughage fraction. Rapid

fermentation results in an inhibition of cellulolysis due to a low pH (Terry *et al.*, 1969).

Supplementation can be used to increase intake of poor quality feed by supplying a limiting nutrient. The rate of microbial fermentation of forage diets are depressed if ruminal ammonia concentration drops below 50mg nitrogen per liter (Wilson and Kennedy, 1996). Minson (1990) suggested that for feeds with a crude protein content of less than 62 g crude protein per kg of dry matter, fibre digestion is inhibited. He reported on a number of trials in which the intake of forages were increased by 14-77% following provision of supplementary protein. Where ammonia nitrogen concentration limits microbial fermentation, supply of nitrogen to the micro-organisms increase organic matter digestion in the rumen. This increases breakdown and rate of passage of poor quality forage, thereby removing the physical constraint and allowing the animal to consume more feed (Romney *et al.*, 1996).

1.5 Nutrition of goats and sheep

Gentry (1978) (cited by Van Soest, 1982) classified goats as “intermediate browsers” and sheep as “grazers”. Lu (1988) has described goats as “mixed-feeding opportunists”. Both goats and sheep are considered more capable of selective feeding than cattle because of their cleft upper lips (Hafez, 1975). Goats, however, are notoriously selective and adaptive feeders, as judged by grazing/browsing studies (French, 1970). Goats have a markedly different grazing behavior than other livestock. They harvest material from a wide range of plant species and at the same time exhibit marked preferences as regards the parts of any particular species which they select. Given the opportunity they will graze trees and shrubs to a greater extent than will sheep, and their preferential selection of what is commonly regarded as weed species in modern agricultural systems has led to their use in the manipulation and improvement of both indigenous and sown pasture (Russel *et al.*, 1983; Grant *et al.*, 1984). Levels of herbage intake and performance appear to be more sensitive to herbage mass

and sward height than is the case with sheep. As herbage mass declines the DM intakes of goats declines at a faster rate than that observed in sheep, and goats appear to stop grazing at a herbage mass of about 1000 kg DM/ha (Collins and Nicol, 1986).

Well-replicated experiments involving a range of feeds and levels of feeding with pelleted dried grass, medium- and low digestibility grass hay (Ndosa, 1980) and pelleted dried lucerne (Mohamed and Owen, 1982) found no differences between the apparent digestibility's of OM in sheep and goats. Alam *et al.* (1983) showed that the values for sheep may decline over time (after about 10 weeks), relative to those of goats, when given low quality roughages without supplementation. In a study by Domingue *et al.* (1991), unsupplemented prairie straw was better digested by goats than by sheep.

Studies by Domingue *et al.* (1991) have shown that goats have higher rumen ammonia concentrations than sheep when fed on low quality roughage. Alam *et al.* (1983) concluded that this was why goats had a higher DOMI when offered forages with OM digestibilities of less than 60%. Tan *et al.* (1987) noted that the higher intake of DOM and the higher rumen ammonia concentration in goats were not associated with a higher rate of digestion in the rumen when fed unsupplemented barley straw to sheep and goats. The 24- and 48-hour DM rumen degradation of straw was lower for goats than for sheep. Ndosa (1980) found the rate of passage of feed particles to be slower in goats than in sheep while Huston (1978) found the opposite. The results obtained by Ndosa (1980) were against their expectations because they had observed a higher DMI by goats than by sheep. Domingue *et al.* (1991) showed rumen fluid volume in relation to live weight to be higher in goats than in sheep when fed on a low quality straw. This could explain why goats seem able to consume more DOM than sheep, without having higher rates of passage or faster rates of digestion. Goats had, on the average, intakes 17% higher than sheep when fed on forages

and hays of various qualities. Other studies showed this difference in intake to be as much as 29% (Ndosa, 1980).

Table 1.5. illustrates a comparison of the nutrient requirements between goats and sheep.

Table 1.5 Nutrient Requirements of goats and sheep (DM basis) (NRC, 1985; NRC, 1981; AFRC, 1998)

Component	Goat	Sheep
CP (%)	10-15	9.5-15
Na (g/kg)	Not available	0.9-1.8
Ca (g/kg)	1.38	2.0
P (g/kg)	1.6-2.8	1.6-3.8
Mg (g/kg)	1.5	1.2-1.8
K (g/kg)	5-8	5-8
Cu (mg/kg)	10-20	7-11
Mn (mg/kg)	20-25	20-40
Zn (mg/kg)	50	20-33

The aim of this study was to identify the nutritional differences between the different palatability groups of *A. nummularia* (Hatfield Select F1). This will help in selecting more palatable plants, which can then be used for seed production. We need to select plants that will produce dry material in the extreme conditions (saline soils, dry and hot conditions) in which the current *A. nummularia* does, but it should have a higher palatability and acceptability and have a nutritional value to maintain animals in a time of food scarcity. This is especially important in the dry arid northwestern and western parts of South Africa where *A. nummularia* plays an important role in animal production systems. This study will also help us understand which nutritional factors in *A. nummularia* affects the palatability of this species.

We also want to identify some differences in the quantity and nutritional quality of the plant material selected between sheep and goats. This will help us to know which type of plants each of these two species prefer and thus what we should select for propagation for each of these animal species.

Chapter 2

A Comparison of the Nutritive Value of Diets Selected by Sheep and Goats Grazing *Atriplex nummularia* (Hatfield Select).

2.1 Introduction

The aim of this study was to determine the differences in nutritive value between the most- medium- and least-palatable *A. nummularia* (Hatfield Select) plants. It is believed that certain nutritional components of a plant influence the palatability of that plant.

The hypotheses are that:

- ? there is a difference in the nutritional composition, of the most-, medium- and least-palatable *A. nummularia* (Hatfield Select) plants, as identified by sheep and goats and that palatability will increase with an increase in CP and P and a decrease in NaCl;
- ? degradability will have an effect on the palatability of *A. nummularia* (Hatfield Select) with higher degradabilities associated with an increase in palatability;
- ? and goats will have a higher rumen degradability of DM, CP and NDF than sheep.

2.2 Materials and Methods

2.2.1 Location

These trials were carried out on the Hatfield Experimental Farm of the University of Pretoria, Pretoria, South Africa (28°15'30"E, 25°44'30"S) at an altitude of 1360m. This is a summer rainfall area with November, December and January as the principal rain period. The mean annual rainfall for the Hatfield Experimental Farm, as provided by the Hatfield Experimental Farm's weather station for the period 2001 to 2004, was 613.28mm. Table 2.1 illustrates the monthly rainfall for this period.

Table 2.1 Monthly rainfall (mm) for the Hatfield Experimental Farm for the period 2001 to 2004

Month	2001	2002	2003	2004
January	29.1	122.2	134.5	64.2
February	126.1	81.4	110.8	160.7
March	23.4	46.5	68.7	168.3
April	28.6	18.8	0.4	59.8
May	63.1	6.1	0	47
June	0	35	8.6	9.1
July	0	0	0	3.1
August	0	22.1	0.3	0
September	6.1	2.4	2.6	0
October	43.5	57.8	61.1	22.1
November	131.5	19.6	100.1	114.2
December	99.8	121.2	53.1	180.2
Total	551.1	533.1	540.2	828.7

2.2.2 Animals and Housing

During the identification of the different palatable groups of *A. nummularia*, three Boer-goat castrates with an average mass of 37kg and three SA Mutton Merino x Dohne Merino wethers with an average mass of 60.2kg were used. The animals were housed in a pen. At 07:00 each day the animals were transported with a vehicle to the experimental plot and at 19:00 they were transported back to the small stock section to overnight in a communal pen.

During the degradability study, four Boer-goat castrates with an average weight of 36kg, and four SA Mutton Merino x Dohne Merino wethers, with an average weight of 71kg were used. The goats were fitted with rumen canulae with a 50mm internal diameter and the sheep with rumen canulae of 80mm internal

diameter. The animals were originally placed in metabolic crates during the adaptation period. This led to some problems. There was a drastic drop in intake of these animals. This low intake proceeded for four days and the animals lost condition. The drop in intake could have been a result of their weight and large body size. The animals (sheep) were too big to lie down in the crates, which caused pain in the hoofs and serious stress. These animals were treated with phenyl butazone 12% because of inflammation.

Due to the design of the rumen fistulas and the fact that goats did not have wool to keep the fistulas tight, the fistulas were easily pulled out by catching on the metabolic crates. This disturbed the rumen environment and was not ideal for rumen degradability studies. All the animals were, therefore, individually placed in semi-indoor pens of approximately 7m² to recover and were then adapted to the feed and environment for five days. These pens were then used for the rumen degradability study. During this study the animals were fed *ad libitum* with a medium quality, fine milled alfalfa (*Medicago sativa*) hay. Feeding times were at 08:00 and 17:00 to ensure a constant rumen environment.

2.2.3 Preparation of experimental animals

2.2.3.1 Rumen fistulation technique

Rumen fistulas have a wide range of applications. They can be used for the collection of animal selected material (Lesperance *et al.*, 1960), rumen degradability studies (Orskov and McDonald, 1979) and for the determination of rumen NH₃-N and volatile fatty acids (VFA) in rumen fermentation studies.

The four goats were fitted with rumen cannulae by a veterinarian using the technique described by De Waal *et al.* (1983). The sheep used were already fitted with rumen cannulae. During the post operation period the animals were fed a mixture of fresh chopped triticale and a balanced pelleted diet. From the second week after the operation the animals were allowed to graze on a kikuyu pasture during the day supplemented with a balanced pelleted diet at night.

2.2.4 *Atriplex nummularia* (Hatfield Select) paddock

From previous studies, the Elite cultivar of *A. nummularia*, had been identified (Malan, 2000). *A. nummularia* plants from the study of Malan (2000) were then vegetative reproduced and used to produce seed for the establishment in Feb 2002 in a camp of 1020 m². 370 Plants were established with an area of 2.75m² per plant. In February 2003 and again in June 2003, these plants were browsed by sheep. All plants were pruned to a height of 40cm on the 9th of September 2003. Fertilization was applied as top dressing on the 18th of September 2003. Overhead irrigation was applied once a week for four hours from the day of fertilization until the starting point of the trial when all irrigation was stopped.

The paddock was divided into four equal units. The first two units were used in the palatability study as will be discussed below. The third and fourth units were used for a grazing study as discussed in Chapter 3.

Camp 1	Camp 2	Camp3	Camp4
Adaptation and grazing	Palatability and Plant samples	Rumen fluid and oesophageal collection	Grazing

Figure 2.1 Illustration of the *A. nummularia* paddock

2.2.5 Identification of palatable plants

All oesophageal fistulated animals browsed *A. nummularia* for three days to adapt to the conditions. According to Langlands (1975) animals, with oesophageal fistulas used for sampling material, should be adapted to that pasture for as long as possible. During this trial only three days adaptation to the saltbush pasture was possible due to a lack of plant material. As already mentioned above, the *Atriplex* paddock was divided into four units. The first unit

(adaptation camp) was used to adapt the animals to a saltbush diet. This camp was also used for grazing during the trial period between observations in camp two (observation camp). During the trial period the six animals were allowed to browse the observation camp for periods of one hour three times a day. The rest of the day the animals spent browsing the adaptation camp. In the mornings, before the animals were introduced to the observation camp, they were allowed to browse the adaptation camp for one hour. This was done to prevent the identification of unpalatable plants as palatable plants because of a hunger sensation of the animals after the fasting night. This hunger sensation will interfere with the degree of selectivity by the animals to palatability (Forbes, 1998). The first hour of observation in the trial camp was between 08:00 and 09:00 when the animals were still actively browsing after being fasted the night before. The second hour was between 12:30 and 13:30 when browsing was less active, and the third hour between 18:00 and 19:00 when the animals were again in a state of active browsing. During each of these times, all the animals were observed and notes were made of the number of times each plant was visited and the time spent at that plant. At the end of each day, each plant was subjectively evaluated for the amount of browsing (disappearance) that had taken place.

The following assumptions were made:

- ? the animals will spend more time at the most-palatable plants than the less palatable plants
- ? the animals will visit the most-palatable plants more often than the less palatable plants
- ? and the most-palatable plants will be browsed to the highest degree.

Using the above assumptions and observations, the most-palatable plants were identified each day and covered with black 20% shade net to stop any further browsing to these plants. This was done for five days, the most-palatable plants were identified on days two and three (during day one the animals were still

learning their way around the camp) and the medium-palatable plants were identified on days four and five. It was assumed that at the end of this five-day browsing period that all un-grazed plants were the least-palatable plants.

2.2.6 Collection of plant samples

2.2.6.1 Harvesting of plant material

After identification of the “most-palatable”, “medium-palatable” and “least-palatable” plants, nine plants were randomly selected from each group. All new growth with a stem thickness of 3mm and less was harvested and oven dried immediately to prevent any further cell respiration. The dried material was ground through a 2mm mesh after which the nine samples in each palatable treatment were divided into three samples consisting of three plants each.

The three plant samples of each palatable sample were mixed in equal amounts and used for further analysis.

2.2.7 Determination of disappearance rate and degradability in the rumen

Bags (140 x 90 mm) made of polyester cloth, with an average pore size of 53µm, were used. The bags had rounded corners for easy removal of material from the bags.

After the plant material collected, as described above, was dried (AOAC, 2000) and ground through a 2mm sieve, equal amounts of each plant in each treatment were mixed. This gave one representative sample for each group treatment (palatable treatment). Approximately 5g of dry sample were weighed into the oven dried bags which were then tied off with a 100% polyester string. The bags were attached to a stainless steel disc (140g, 45mm diameter, 11mm thick and ten holes around the edge) using 100% polyester string. The disc was in turn tied to a 40cm nylon string secured to the cork plug of the rumen cannula.

A 3x3 factorial experimental lay-out was used. This is illustrated in Table 2.2.

Table 2.2 Experimental lay-out

Period	Treatment A	Treatment B	Treatment C
1	Sa, Ga	Sb, Gb	Sc, Gc
2	Sc, Gc	Sa, Ga	Sb, Gb
3	Sb, Gb	Sc, Gc	Sa, Ga

*G = Goat; S = Sheep; a ,b and c = animal identification

The bags were all placed into the rumen at once and removed one by one on the sequential withdrawal method. Bags were withdrawn at 2, 4, 6, 8, 12, 24, 48, 72 hours respectively. After each incubation time, one bag per animal was removed from the rumen, immediately dipped in ice water and then placed on ice to inhibit further microbial activity until all the bags of that incubation time have been removed. Each bag was then rinsed and lightly squeezed repeatedly for two minutes under slow running cold water to remove all the rumen microbes and degraded material smaller than the bag pores. The bags were then frozen until the 72-hour bags have been removed and washed.

After all bags had been washed, they were dried in a forced draught oven at 60°C. The bags with their contents were then weighed. This procedure was repeated twice to give six replications for each treatment per animal treatment (sheep vs. goats).

Six additional bags of each treatment were washed and dried using the same procedure and used as the 0 hour bags.

2.2.8 Chemical analyses

Dry matter and ash

The DM and ash content of the nine plant samples as well as the *in sacco* samples were determined. DM was determined by weighing 1g of sample, in

duplicate, into a porcelain crucible of known dry mass and drying it in an oven at 100°C for 24h. The crucibles plus dry samples were then weighed after cooling in a desiccator. The crucibles plus sample were then placed in an ashing oven and ashed at 600°C for 4h. The crucibles plus ash were then weighed after cooling in a desiccator (AOAC, 2000).

$$\%DM = (\text{Mass of oven dry sample} / \text{Mass of air dry sample}) \times 100$$

$$\%Ash = (\text{Mass of Ash} / \text{Mass of air dry sample}) \times 100$$

$$\%OM = 100 - \%Ash \text{ (DM-basis)}$$

Crude protein

CP was determined on the nine plant samples and the *in sacco* samples.

It was determined on the Dumas method (AOAC, 2000). The principle of nitrogen determination is as follows: “N₂, freed by pyrolysis and subsequent combustion, is swept by CO₂ carrier into nitrometer. CO₂ is absorbed in KOH and the volume of residual N₂ is measured and converted to equivalent protein by numerical factor” (AOAC, 2000).

After the samples were dried and milled, 0.2g was weighed into a foil cup. The sample was then placed in a tray of the nitrogen analyzer and the weight entered into the computerized program. Nitrogen was determined as described above and a conversion factor of 6.25 was used to convert nitrogen to crude protein.

The analysis of the *in sacco* material was done in single runs because of the shortage in material.

Neutral Detergent Fibre

The NDF gives an indication of the amount of hemicelluloses, cellulose, lignin and cutin content of samples (Van Soest, 1984). It is also a measure for the total

cell wall content of samples, and is highly correlated with feed intake (Van Soest, 1984). Neutral detergent fibre was determined for the nine plant samples and the *in sacco* samples. Analysis was done on the Dosi fibre system (Robertson and Van Soest, 1981).

Because of a shortage in *in sacco* sample material, one correction was made to this method; instead of 1g sample, only 0.5g of sample was used per analysis. The analysis was not done in duplicate but in single runs due to a shortage in sample material.

NDF was calculated as follows:

$$\%NDF = [(dry\ mass\ of\ NDS\ extracted\ sample\ (g) - mass\ of\ ash\ (g)) / sample\ mass\ (g)] * 100$$

Minerals

The following minerals were determined for the nine plant samples:

Chloride was determined on the Volhard method (Vogel, 1961). This is an indirect method for chloride, in which a measured volume of standard silver nitrate solution is added in excess of the amount of chloride in the solution. The excess silver ion is back titrated with standard potassium thiocyanate solution, using ferric alum indicator.

Ca, Mg, N, K, Cu, Zn and Mn were all analyzed by atomic absorption spectrophotometer (AOAC, 2000). The samples were first ashed (AOAC, 2000). They were then diluted with 10ml of four molar HCl solutions and made up to 100ml with distilled water. Further dilutions were made with 0.1 M HCl to give dilutions within the range of the apparatus. Lanthanum was added to the dilution to give a 1% Lanthanum in the final dilution. These diluted samples were then analyzed for the various minerals by means of an atomic absorption spectrophotometer.

P was determined on an Auto Analyzer (AOAC, 2000). The same dilutions used for the above minerals were used.

Salt (NaCl) was determined assuming that all the chloride and Na were in the form of NaCl. NaCl as determined on the first limiting factor concept.

2.2.9 Statistical analysis

An analysis of variance with the GLM model (Statistical Analysis System, 1994) was used to determine the significance between different treatment, period and animal effects for the balanced data. Means and standard deviation (SD) were determined. Significance of difference (5%) between means was determined by the Bonferoni test (Samuels, 1989).

2.3 Results and discussion

2.3.1 Chemical composition

The chemical composition of the edible material will be discussed in this section. The three palatable groups were compared to determine the effect of chemical composition on palatability.

2.3.1.1 Crude protein

Table 2.3 illustrates the CP and NDF concentrations of the three different palatability groups of *A. nummularia* (Hatfield Select), as identified by sheep and goats.

Table 2.3 Crude protein and neutral detergent fibre concentration of the edible component of *A. nummularia* (Hatfield Select) (DM basis)

	CP (%)	NDF (%)
Most-palatable	24.38 ^a (± 0.40)	41.62 ^a (±1.96)
Medium-palatable	22.23 ^b (±0.96)	44.21 ^a (± 0.85)
Least-palatable	21.53 ^b (±0.59)	45.51 ^a (±2.02)

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Values in brackets represent the standard deviation

From Table 2.3 a significant difference in CP can be noticed with palatability. The most-palatable group has the highest CP concentration (24.38%) while the least-palatable treatment has the lowest CP concentration (21.53%) with the medium-palatable treatment intermediate (22.23%). The most-palatable group differs significantly from the medium- and least-palatable groups, which partly supports the hypothesis that there is a difference in chemical composition between the palatable groups and that the most-palatable treatment will have the highest CP concentration. This is partly in contrast with results obtained by Norman *et al.* (2004) who found that sheep significantly preferred river saltbush, with a lower N concentration, to old man saltbush. On the other hand, in the same trial sheep significantly preferred *A. nummularia* with a higher N concentration (2.46% N (15.38% CP)) to *A. nummularia* with a lower N concentration (2.03% N (12.69% CP)). Jacobs and Smit (1977) also conducted a study on the preference of four *Atriplex* species. In the preference study with *A. nummularia*, the 20 most preferred plants and 20 least preferred plants was identified during grazing. No significant differences between the most- and least preferred plants were reported for N. N concentrations reported were 3.68% (23% CP) and 3.48% (21.75% CP) respectively for the most- and least preferred plants. A higher, though non-significant, CP concentration was thus recorded in the most preferred plants.

Ben Salem *et al.* (2004) fed *A. nummularia* as a protein supplement to barley straw and Spineless cactus or barley grain. The CP concentration of *A. nummularia* was 17.8%. This value is much lower than the values obtained in the current study. The study of Ben Salem *et al.* (2004) was executed in a semi-arid environment with a mean annual rainfall of 390mm in central Tunisia. This difference in climatic and environmental conditions could possibly explain the differences between the two studies.

Weston *et al.* (1970) reported a CP value of 19.8% for *A. nummularia* west of Sydney, Australia. This value was for leaves only and should have a CP content higher than the leaf and fine stem material of the current study. The material used in the current study is from very young regrowth and the stem material included should not have had a significant effect on the CP value. Growing and environmental conditions could also contribute to the difference in CP values between the two studies.

Wilson (1977) reported an N value of 3.3% for *A. nummularia* available on the shrub-steppe areas of western New South Wales. Using a conversion factor of 6.25, this represents a CP value of 20.6%. This is for leaves only and compares to the value of 20.53% for the least-palatable treatment in the current study. Again the values of the most- and medium-palatable groups of the current study are higher than the values reported by Wilson (1977).

Watson *et al.* (1987) clipped *A. nummularia* plants on four harvest dates to a height of 15-20cm. In the first clipping, 12 weeks after transplantation, a CP value of 20.8% was reported. CP concentration decreased to 10.1% at the date of the last clipping, 30 weeks after transplantation. This decrease in CP concentration was due to an increase in the amount of stem material, which had a lower CP value than young plant material consisting of leaves and young stem material (Sparks, 2003). Comparing this study with the current study, the lower CP concentration of 20.8% and 10.1% to the higher values of the current study of

21,53% to 24.38% can definitely be ascribed to the higher proportion of stem material in the study of Watson *et al.* (1987).

Chriyaa *et al.* (1997) reported a CP value for *A. nummularia* in Morocco of 13.7%. This value was more or less the same as that of alfalfa (13.6%), and compares well with the value reported by Watson and O'Leary (1993) of 13.1%. In literature as cited by Aganga *et al.* (2003), EL Aich (1987) reported CP values for *A. nummularia* of 18.2 and 22.7%. Wilson (1966) also reported CP values for *A. nummularia* of 21.7%. The last two values were comparable with those medium- and least-palatable *A. nummularia* (Hatfield Select) groups of the current study.

It is clear from the above that there is large variation in the CP concentration of *A. nummularia* between, and even sometimes within, different studies. This variation can be ascribed to different environmental and climatic conditions, such as the soil composition, annual and seasonal rainfall, minimum and maximum temperatures and the location of each study. Van Niekerk *et al.* (2004b) conducted a study of the difference in composition of four drought tolerant fodder shrubs at two different locations. The one site was on the farm Lovedale in the arid zone of South Africa near Pofadder with low annual rainfall and high day temperatures, while the other site was on the Hatfield Experimental Farm in Pretoria, South Africa with a relatively high annual rainfall and moderate day temperatures. There was a significant difference in the CP values reported for *A. nummularia* between the two sites. Saltbush at Lovedale had a CP value of 19.8%, while at Hatfield it had a CP value of 17.6%.

Another possible reason for the high CP concentrations, obtained in the current study, could be a higher N content in the soil. The *A. nummularia* plot was fertilized with 50kg N per ha eight weeks before the plant material was harvested. By fertilizing the plants, more N becomes available to the plant which allows the plant to produce more plant proteins and nitrogenous compounds leading to a

higher N composition of the plant. Welch and Monsen (1981) stated that genetic variation plays an important role in the level of protein in *Atriplex* species. This could explain the significantly higher CP concentration in the most-palatable group than in the least-palatable group.

The plants used in this study were propagated from plants identified as palatable in previous studies (Verschoor, 1992; Malan, 2000). This increases the probability of a higher nutritional value in these plants and makes a possible contribution to the higher CP value.

From the NRC (1981), the daily CP requirement of goats is $2.03 \text{ g CP/kgw}^{0.75}$. For a free grazing animal with a body weight of 50 kg, the daily requirement would be 100gCP/day. Assuming an intake of 2% of body weight (1kg DM), the CP requirement would be satisfied by a feed consisting of 10%CP. All the treatments in the current study provide more than enough CP for maintenance of a free grazing goat. The CP requirement for a free grazing 50kg sheep is in the range of 9.5% (NRC, 1985). From this, the CP in the current study will also be sufficient for maintenance. *A. nummularia* (Hatfield Select) can also provide enough CP for growing lambs (16.9%) and lactating ewes (15%) in both goats and sheep (NRC, 1985).

2.3.1.2 Neutral Detergent Fibre

It could be expected that animals would prefer a diet with a low fibre concentration. In Table 2.3 it is evident that animals do select feed or plants with a lower fibre concentration. There is a tendency for palatability to decrease with an increase in NDF concentration. The most-palatable group had a lower NDF concentration (41.62%) while the least-palatable group had the highest NDF concentration (45.51%) and the medium-palatable group was intermediate (44.21%). These differences in NDF concentration were, however, not significant, although they do illustrate the tendency of animals to select a diet with lower NDF, if possible. A significant difference could have been reported if more

samples per palatability group had been used to decrease the variation within the treatments.

Norman *et al.* (2004) found that sheep significantly preferred *A. amnicola*, with a higher NDF concentration (42.28%), to *A. nummularia* with a lower NDF concentration (30.54%). This is in contrast with the results illustrated in Table 2.3 of the current study, where animals preferred a lower NDF concentration within the same plant species. Norman *et al.* (2004), however, also found that sheep preferred a lower NDF concentration (30.54%) than the NDF concentration (31.22%) of the least preferred plants within *A. nummularia*, although these differences were not significant.

In the study by Watson *et al.* (1987), the nutritive value of *A. nummularia* and *A. lentiformis* was evaluated over time with the nutritive value being determined at three different growth stages. The NDF concentration of *A. nummularia* for 12, 22 and 30 weeks after transplantation was 33.5%, 43.4% and 46.9% respectively. The increase in NDF concentration over time was due to an increase in the proportion of stem material (physiological maturity of the plant). The amount of stem material included in an edible plant sample that is cut by hand has an influence on the NDF value of that sample. The values in Table 2.3 are from plants harvested 2 months after the plants were pruned back to a height of 50cm. Only edible material with a stem diameter less than 3mm was sampled while Watson *et al.* (1987) used all plant material above a height of 20cm. The values of the medium and least-palatable plants compared well to the 22 and 30-week values of Watson *et al.* (1987).

Values reported by Ben Salem *et al.* (2004), of 44.5%, compared well with the medium-palatable plants, while values reported by Wilson (1977) of 46% and Watson and O' Leary (1993), as cited by Aganga *et al.* (2003), of an average value of 45.5%, compared well with the least-palatable plants of the current study. Abou El Nasr *et al.* (1996) reported NDF values of 59.4% for fresh *A.*

nummularia and 63.3% for *A. nummularia* hay. Chriyaa *et al.* (1997), on the other hand, reported a NDF value of 34.8 % for *A. nummularia*, while in the same study a NDF value for alfalfa of 46.6% was recorded. All the above studies were done for *A. nummularia*.

Sparks (2003) and Van Niekerk *et al.* (2004b) determined the nutritional value of four drought resistant fodder shrubs at two locations as described in the section on CP. Leaf material of *A. nummularia* had a NDF concentration of 40.7% and 33.2% at Hatfield and Lovedale respectively. Stem material for the same locations had a NDF concentration of 62.0% and 61.1% respectively. The NDF concentration of the palatable plants in Table 2.3 compares to the NDF value of the leaf material at Hatfield. These values cannot, however, be compared to the values of Table 2.3 because the plant material had been separated into leaf and stem fractions. It is also unknown what part of the plant was sampled.

The age (physiological stage) of plant material and the amount of leaf to stem in a sample have a large effect on the NDF value of a sample. Large variations are the order of the day between different studies, because of different methods and different parts of plant material that were sampled (Malan, 2000). Each study must, therefore, be evaluated within its own circumstances.

2.3.1.3 Macro minerals

Table 2.4 illustrates the macro-mineral concentrations of *A. nummularia* (Hatfield Select), as well as the Na:K, Ca:P and K:P ratios. The Na:K and K:P ratios are known to negatively influence the palatability of a plant while the Ca : P ratio is important for optimal utilization of both these minerals (Underwood and Suttle, 1999).

Calcium

The presence of high levels of oxalate in a diet have a negative influence on the absorbability of Ca by the animal. This is due to the formation of calcium oxalates that are relatively poorly absorbed in the animal (Underwood and Suttle, 1999). Since *A. nummularia* contains high levels of oxalic acid (3.26%) (Sparks, 2003) or 5.8% (Wilson, 1966), the Ca absorbability in animals grazing on these plants can be low. There is, however, some metabolism of oxalate by rumen microorganisms, particularly when there has been time to adapt to high-oxalate diets (Underwood and Suttle, 1999). Vitamin D₃ also affects the utilization of Ca in the animal body. It is, therefore, advised that the animals utilizing *A. nummularia* be exposed to enough sunlight (Underwood and Suttle, 1999).

There were no significant differences between the three palatability groups, although, there was a tendency for the Ca concentration to decrease with a decrease in palatability. The most-palatable group had a Ca concentration of 11.72%. This treatment had a higher Ca concentration than the medium-palatable groups with a Ca concentration of 9.13%. The least-palatable group had the lowest Ca concentration (8.54%). From Table 2.4 it is noticeable that there was not a large variation within each palatability group.

Table 2.4 Macro mineral concentration of the edible component of *A. nummularia* (Hatfield Select) plants (DM basis)

	Ca (g/kg)	P (g/kg)	Mg (g/kg)	Na (g/kg)	K (g/kg)	Cl ⁻ (g/kg)	NaCl (g/kg)	Na:K	K:P	Ca:P
Most-Palatable	11.72 ^a (± 1.34)	2.51 ^a (± 0.11)	7.73 ^a (± 0.26)	24.26 ^a (± 1.99)	18.99 ^a (± 0.44)	24.00 ^a (± 2.65)	39.56 ^a (±4.36)	1.3 : 1	7.6:1	4.7 : 1
Medium-Palatable	9.13 ^a (± 1.70)	2.23 ^b (± 0.03)	6.85 ^{ab} (± 0.61)	26.30 ^a (± 2.98)	18.33 ^a (± 2.45)	24.00 ^a (± 2.00)	39.56 ^a (±3.30)	1.4 : 1	8.2:1	4.1 : 1
Least-Palatable	8.54 ^a (± 0.70)	2.04 ^b (± 0.15)	6.59 ^b (± 0.35)	22.46 ^a (±0.81)	17.26 ^a (± 3.26)	18.33 ^a (± 4.51)	30.22 ^a (±7.43)	1.3 : 1	8.4:1	4.2 : 1

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Values in brackets represents the standard deviation

Norman *et al.* (2004) also reported no significant differences in the Ca concentration within or between the most preferred and least preferred species or plants. This author also reported a tendency for the Ca concentration to increase with palatability. Ca concentrations of 7.7 g/kg and 7.3 g/kg were respectively reported for the most- and least preferred *A. nummularia* plants. The same tendency was reported between the most preferred *A. amnicola* and the least preferred *A. nummularia*.

Jacobs and Smit (1977) also reported no significant differences between the most- and least preferred *A. nummularia* plants. Ca concentrations of 11.4 g/kg and 12.0 g/kg were reported for the most- and least preferred plants which compares to the most-palatable treatment illustrated in Table 2.4.

Watson and O'Leary (1993) as cited by Aganga *et al.* (2003) reported an average Ca concentration for *A. nummularia* of 5.5 g/kg. Chriyaa *et al.* (1997) reported a slightly higher value of 6.9 g/kg. In the study of Watson *et al.* (1987), as described earlier, values of 11.3 g/kg, 9.2 g/kg and 6.3 g/kg were reported for plants harvested to a height of 20 cm at 12 , 22 and 30 weeks after transplantation respectively. Hoon *et al.* (1991) reported Ca levels of 11.5 g/kg. Ben Salem *et al.* (2004) analyzed the chemical composition of the edible component (leaves and twigs) to investigate the potential of *A. nummularia* as a protein supplement. A calcium value of 13.6 g/kg was reported by Ben Salem *et al.* (2004). Sparks (2003) and Van Niekerk *et al.* (2004a) reported Ca levels of, 15.6 g/kg and 10.9 g/kg for *A. nummularia* leaf material at Hatfield and Lovedale respectively and 10.3 g/kg and 10.4 g/kg respectively for stem material at the same locations.

Calcium levels reported by Chriyaa *et al.* (1996) and Watson and O'Leary (1993) as cited by Aganga *et al.* (2003), are much lower than the levels obtained in the current study. Ben Salem *et al.* (2004) reported Ca levels much higher than any of the three palatable groups. There are numerous factors that have an influence

on the mineral composition of a plant, such as soil composition and interactions between minerals that may affect the absorption or uptake of certain minerals. These factors could explain these lower or higher levels of Ca.

Calcium levels reported by Hoon *et al.* (1991) of 11.5 g/kg compared well with the level of 11.72 of the most-palatable treatment in the current study. The 12 week value of Watson *et al.* (1987) of 11.3 g/kg also compared to the most-palatable group while the 22 week level of 9.2 g/kg compared to the medium-palatable group of 9.13 g/kg.

The Ca concentrations in *A. nummularia* (Hatfield Select) are higher than the maintenance requirements of goats (4 g/kg) (NRC, 1981), (1.6 g/kg) (AFRC, 1998) and sheep (2 g/kg) (NRC, 1985). From Table 2.4, it appears that even growth (8.1 g/kg) (AFRC, 1998) and lactation (6.7 g/kg) (AFRC, 1998) can be sustained in goats and sheep. It can thus be assumed that *A. nummularia* (Hatfield Select) can provide all the Ca needs of goats and sheep, depending on the availability of the Ca.

Phosphorus

The P status of forages varies widely and is influenced by the P status of the soil, the stage of maturity of the plant and the climate (Underwood and Suttle, 1999). Temperate forages usually contain more P than tropical forages (3.5 vs. 2.3 g P /kgDM) and legumes slightly more than grasses (3.2 vs. 2.7 g P / kgDM) (Minson, 1990), but there are exceptions. Distribution of P between leaf and stem is relatively uniform, but there is a reduction in whole plant P concentration as the plant matures, particularly during the dry season (Underwood and Suttle, 1999).

A higher P concentration in *Atriplex* species is positively correlated to a higher acceptability by grazing animals (Jacobs and Smit, 1977). From Table 2.4 it is noticeable that the most-palatable plants of *A. nummularia* (Hatfield Select) had a significantly higher P concentration than the medium- and least-palatable plants.

There was no significant difference between the medium- and least-palatable plants, although the medium-palatable group had a higher P concentration than the least-palatable group.

Jacobs and Smit (1977) reported a significant difference in P concentrations between the most preferred (6.0 g/kg) and the least preferred (4.1 g/kg) *A. nummularia* plants. This data together with the data from Table 2.4 confirms the importance of the P concentration in the palatability and preference of plants, within a species.

Chriyaa *et al.* (1996) and Hoon *et al.* (1991) both reported P concentrations of 0.5 g/kg which is much lower than any of the palatability groups in the current study. In the study by Watson *et al.* (1987), the P concentrations of *A. nummularia* at 12, 22 and 30 weeks after transplantation were 1.3, 1.3 and 0.1 g/kg respectively. This study by Watson *et al.* (1987) illustrates the decrease in P concentration with maturity, since there was a significant difference between the 12 and 22-week vs. the 30-week P concentrations. Ben Salem *et al.* (2004) reported a P concentration of 1.8 g/kg which is still lower than the P concentrations from Table 2.4, while Watson and O'Leary (1993), as cited by Aganga *et al.* (2003), reported a P concentration of 2.0 g/kg which compares to the P concentration (2.04 g/kg) of the least-palatable groups in Table 2.4.

Van Niekerk *et al.* (2004a) reported P concentrations of 2.47 g/kg and 1.63 g/kg for *A. nummularia* leaf material at Hatfield and Lovedale respectively. P concentrations of stem material of 2.1 g/kg and 1.19 g/kg were reported for the same respective locations (Sparks, 2003). From these results it seems that there is a slight variation between leaf and stem P concentrations. The results of Sparks (2003), at the Hatfield site, compared well with the most- and medium-palatable groups in the current study.

The variation within results between the different studies can be ascribed to differences in soil composition, plant maturity and climate of the different experimental sites (Underwood and Suttle, 1999).

The P levels of *A. nummularia* (Hatfield Select) in the current study are well above the 2.0 g/kg DM maintenance requirement of sheep (NRC, 1985). It is also much higher than 1.6 g/kg DM (AFRC, 1998) but lower than 2.8 g/kg DM (NRC, 1981) considered adequate for the maintenance of goats. Phosphorus levels were too low for growing (3.3 g/kg) (AFRC, 1998) and lactating (4.0 g/kg) (AFRC, 1998) goats. They were also too low for growing (3.8 g/kg) (NRC, 1985) lambs and lactating (2.9 g/kg) (NRC, 1985) ewes. On the basis of this, P supplementation should be considered for producing animals.

Magnesium

The Mg concentration of herbage plants varies with the species, the soil and climatic conditions in which the plant grows (Underwood and Suttle, 1999). Seasonal variation in Mg concentration in herbage is, however, relatively small (Minson, 1990). It is known that N and K fertilization of pastures lowers the absorption of Mg from the pasture. This is often the cause of grass tetany due to a shortage of Mg in the pasture (Underwood and Suttle, 1999). The only site of Mg absorption in the ruminant is in the rumen. By feeding forages high in K and/or Na, the Mg absorption in the rumen decreases and a Mg deficiency is likely to occur (Underwood and Suttle, 1999). This is especially important in the utilization of *Atriplex* species that contain high sodium concentrations. It is also important to note that the rumen pH is important, because it dramatically influences the solubility and, therefore, the absorption of Mg in the rumen (Underwood and Suttle, 1999). Rumen solubility of Mg decreases from 80% to 20% when the rumen pH increases from pH 5 to pH 7 (Dalley *et al.*, 1997). High levels of ammonia in the rumen also depresses the absorption of Mg. Johnson *et al.* (1988) reported that the transfer of ruminants from diets of hay and

concentrate to a grass diet, will almost invariably raise rumen ammonia concentrations, as well as pH, leading to hypomagnesemia and tetany.

Jacobs and Smit (1977) reported that the higher acceptability of *Atriplex* species is due to the higher Mg and P concentrations. From Table 2.4 it is noticeable that the most-palatable plants had the highest Mg concentration (7.73 g/kg), while the least-palatable plants have the lowest Mg concentration (6.59 g/kg) and the medium-palatable plants intermediate (6.85 g/kg). Of importance is that the most-palatable group differed significantly from the least-palatable group. The medium-palatable group did not, however, differ significantly from either the most or least-palatable groups.

Jacobs and Smit, (1977) reported a significant difference in Mg concentrations of 14.8 g/kg and 13.1 g/kg for the most- and least preferred *A. nummularia* plants respectively. Norman *et al.* (2004), however, did not report any significant difference in Mg concentration between the most preferred (7.7 g/kg) and least preferred (7.8 g/kg) *A. nummularia* plants. This author did, however, report a significant difference between the most preferred *A. amnicola* (10 g/kg) and the least preferred *A. nummularia* (7.7g/kg). The results of the above two authors, as well as of the current study, emphasizes the importance of Mg in diet preference and palatability by the free grazing animal.

The Mg concentrations reported by Chriyaa *et al.* (1997) and Watson and O'Leary (1993) as cited by Aganga *et al.* (2003) of 2.1 g/kg and 4.6 g/kg respectively, were much lower than the values reported in Table 2.4. These low levels of Mg probably could be due to soil conditions such as high N or K concentrations in the soil. It is thus not of any significance to compare plants that grow in different environments, in terms of mineral composition.

Hoon *et al.* (1991) reported a Mg concentration of 7.1 g/kg for *A. nummularia*. This Mg concentration compares well to the Mg concentrations of the most-

and medium-palatable groups in Table 2.4. Ben Salem *et al.* (2004) reported a Mg concentration of 8.4 g/kg which is a little higher than the Mg concentration of the most-palatable treatment, but does compare with this treatment.

Sparks (2003) and Van Niekerk *et al.* (2004^a) reported Mg concentrations for *A. nummularia* leaf material of 9.7 g/kg and 3.0 g/kg for Hatfield and Lovedale respectively. Mg concentrations of stem material were reported as 2.0 g/kg and 0.8 g/kg for Hatfield and Lovedale respectively (Sparks, 2003). From the study by Sparks (2003), it is evident that soil, climate, environment and plant part have a huge influence on the Mg concentration of that plant. The Mg concentrations reported by Sparks (2003) are much lower than the concentrations illustrated in Table 2.3 for *A. nummularia* (Hatfield Select) except for the leaf material selected at Hatfield, which was 2 g Mg/kg higher than the plant material reported in Table 2.4.

The Mg levels of the *A. nummularia* (Hatfield Select) in the current study were well above the 1.5 g/kg (AFRC, 1998) Mg requirements of goats. It was also above the 1.2-1.8 g/kg (NRC, 1985) range required by sheep. It would thus not be necessary to supplement Mg on these pastures.

Potassium

The K concentrations in plant material are influenced by the K status of the soil, the plant species and its state of maturity (Underwood and Suttle, 1999). Cool-season grass species maintain a higher K concentration than warm-season grass species while temperate legumes have lower K concentrations than tropical legumes (Underwood and Suttle, 1999). Jacobs and Smit (1977) reported that K has a large influence on the acceptability of a plant with a higher acceptability as the K concentration decreases. These authors reported K concentrations of 25.7 g/kg for the most preferred *A. nummularia* plants and 36.4 g/kg for the least preferred plants.

There were no significant differences between the K concentrations of the three palatability groups of *A. nummularia* (Hatfield Select) in Table 2.4. although there was a tendency for the K concentration to increase with palatability. This is, in contrast to the finding of Jacobs and Smit (1977), who reported a decrease in K concentration with an increase in palatability. The most-palatable plants in this study had the highest K concentration of 18.99 g/kg, while the least-palatable plants the lowest K concentration of 17.26 g/kg and the medium-palatable plants were intermediate with a K concentration of 18.33 g/kg.

As with the Mg concentration, Chriyaa *et al.* (1997) reported a K concentration of 11.1 g/kg, which is much lower than illustrated in Table 2.4. Ben Salem *et al.* (2004), on the other hand, reported a K concentration of 28.9 g/kg, which is much higher than any of the K concentrations in Table 2.4. Hoon *et al.* (1991) also reported a higher K concentration of 23.2 g/kg for *A. nummularia*. All the above concentrations are for *A. nummularia*. None of the concentrations in the above studies compares to the K concentrations as reported in Table 2.4. The most probable explanation for this is the variety in study sites leading to different climatic conditions and most important, different soil compositions that affects the K concentration in these plants.

Sparks (2003) reported K concentrations of 33.0 g/kg and 38.0 g/kg for *A. nummularia* leaf material at Hatfield and Lovedale respectively. K concentrations of 18.5 g/kg and 23.6 g/kg were reported for stem material of *A. nummularia* at Hatfield and Lovedale respectively. The stem material of the samples taken at Hatfield had more or less the same concentrations as the most and medium-palatable groups in Table 2.4.

A. nummularia (Hatfield Select) provides the K requirements of both growth (5 g/kg) and lactation (8 g/kg) (NRC, 1981; NFRC, 1998) of goats. The K levels of these treatments also provides more than enough K for the 5-8 g/kg (NRC, 1985)

required by sheep. It would thus not be necessary to supplement K for animals on these pastures.

Sodium

Pasture Na concentrations are influenced by the application of K and N. Nitrogen increases pasture Na in a dose-dependant manner, but the concurrent application of K limits the N response, particularly at high application rates (Underwood and Suttle, 1999). This means that if the soil N content is high, more sodium will be found in the plant if enough Na is available. High K contents in the soil will, however, decrease the availability of Na to the plant. Du Toit (2001) noted that the acceptability of *Atriplex* species decreased after sufficient rains. This was probably because of an increase in the salt content, especially Na, which is most evident in *A. nummularia*.

There were no significant differences among the palatability groups in the Na concentrations of *A. nummularia* (Hatfield Select), as indicated in Table 2.4. The most- and medium-palatable groups, with Na concentrations of 24.26 g/kg and 26.30 g/kg respectively, were higher than the least-palatable group, with Na concentration of 22.46 g/kg. The most-palatable plants had a lower Na concentration than the medium-palatable plants. It is clear, from the above, that the sheep and goats used to identify the palatable plants, did not select according to Na concentration in the current study.

Norman *et al.* (2004) reported a significant difference in the Na concentration between the most preferred (59.3 g/kg) and least preferred (70.4 g/kg) plants of *A. amnicola*, but not for *A. nummularia*. Norman *et al.* (2004) also reported a tendency for the Na concentration to increase with palatability for *A. nummularia* which is in contrast to the statement of Du Toit (2001) that palatability decreases with an increase in Na concentration.

Ben Salem *et al.* (2004) reported a Na concentration of 47.0 g/kg. This is more than twice the Na concentrations illustrated in Table 2.4. Hoon *et al.* (1991) reported an even higher Na concentration of 50.8 g/kg while Watson and O'Leary (1993), as cited by Aganga *et al.* (2003), reported an even higher Na concentration of 71.7 g/kg. This illustrates the ability of *A. nummularia* to accumulate salt (NaCl) on the leaves (Jones and Hodginson, 1969).

Sparks (2003) reported Na concentrations of 25.36 g/kg and 34.78 g/kg of *A. nummularia* leaf material at Hatfield and Lovedale respectively. This author also reported Na concentrations of 4.29 g/kg and 6.91 g/kg for stem material at Hatfield and Lovedale respectively. The Na status of the soil was much higher at Lovedale (179 mg/kg) than at Hatfield (40 mg/kg). This is the reason for the higher Na concentrations in *A. nummularia* at Lovedale than Hatfield. The Na concentration of leaf material at Hatfield compares to the Na concentration of the most- and medium-palatable groups of *A. nummularia* (Hatfield Select) as illustrated in Table 2.4.

The low Na concentration illustrated in Table 2.4 could be explained by either low Na in the soil which is most likely the case, or high K concentrations in the soil which may have caused a low Na absorption by the plant. The latter explanation is, however, unlikely as the soils at Hatfield tended to have marginal levels of K

The Na levels of the treatments in the current study were well above the requirements of sheep (0.9-1.8 g/kg) (NRC, 1985). No requirements of Na are available for goats in either the NRC or AFRC.

Chlorine

From Table 2.4 it can be seen that there were no significant differences between the three palatability groups. The most- and medium-palatable groups both had a Cl concentration of 24.0 g/kg. This is in contrast to our expectation for the most-palatable treatment to have a lower Cl concentration than the least-palatable

treatment, which had a Cl concentration of 18.33 g/kg. By comparing these Cl concentrations to the Cl concentrations of other studies on *A. nummularia*, we can conclude that the Cl concentrations, in these three palatability groups, were too low to influence palatability.

Jacobs and Smit, 1977) stated that the Cl concentration of *A. nummularia* also had an influence on the preference for that plant. These authors reported a significant difference in the Cl concentrations, between the most preferred (46.5 g/kg) and the least preferred (58.4 g/kg) plants. From this we can conclude that a lower Cl concentration increases the preference for that plant. These results are in contrast to the results illustrated in Table 2.4 where the most-palatable plants had higher Cl concentrations than the least-palatable plants. Hoon *et al.* (1991) reported a Cl concentration for *A. nummularia* of 62.3 g/kg. This value is more than three times higher than the Cl concentrations presented in Table 2.4.

Sodium chloride (salt)

The presence of salt in a feed can contribute to the palatability of that feed (Grofum and Chapman, 1988; as cited by Underwood and Suttle, 1999), whereas the addition of salt to a feed with a high sodium content can lower feed intake (Wilson, 1966). The salt content, especially Na and Cl, of *Atriplex* is the main determinant of palatability in this species (Jones and Hodginson, 1969; Hoon *et al.*, 1991). Casson *et al.* (1996) suggested that the high salt content of saltland forage plants is likely to be the major determinant of palatability and that the dilution of salt content through the availability of other feed resources would be necessary to improve intake and performance. The high salt concentration in a diet increases the digestibility (Aganga *et al.*, 2003).

Due to large variations, there were no significant differences in NaCl concentration between any of the palatability groups as reported in Table 2.4. Respectively, NaCl concentrations of 39.56 g/kg, 39.56 g/kg and 30.22 g/kg were obtained for the most-, medium- and least-palatable groups of *A. nummularia*

(Hatfield Select). Surprisingly the least-palatable treatment had the lowest NaCl concentration. This is against the theory of Jones and Hodginson, (1969); Hoon *et al.* (1991) and Casson *et al.* (1996) that a high salt content relates negatively to palatability. The lower NaCl concentration in the least-palatable treatment must be an indication that the animals did not select for or against salt content, but for other parameters such as CP, P and Mg. A possible explanation for the animals not selecting according to salt content may be that the salt (NaCl) content of these plants was very low, due to low soil Na and Cl concentrations. The animals could also have had a slight salt hunger that caused them to select plants with a higher salt content.

The AFRC (1998) and NRC (1981) suggest that a diet for goats should contain at least 5 g NaCl/kg DM. The treatments in the current study provided much more NaCl than is required. It would not, therefore, be advised to give any salt supplementation, as this could depress the intake of *A. nummularia*.

Na:K, K:P and Ca:P ratios

Du Toit (2001) stated that sheep would prefer *Atriplex* species with a low Na:K ratio. The Na:K ratios of *Atriplex nummularia* (Hatfield Select) in Table 2.4 were similar to one another. The most- and least-palatable plants both had a Na:K ratio of 1.3:1 while the medium-palatable group had a Na:K ratio of 1.4:1. This indicates that the sheep and goats, used to identify the palatable plants at the Hatfield Experimental Farm, did not select according to Na:K ratios in the plants. Thus, according to the theory of Du Toit (2001), there should be no difference in palatability in *A. nummularias* (Hatfield Select) at the Hatfield Experimental Farm, due to Na:K ratios. This does not mean that Na:K does not have an influence on palatability, only that the effect of Na:K on palatability will depend on the status of the soil and environmental conditions.

A dietary Ca:P ratio between 1:1 and 2:1 is assumed to be ideal for growth and bone formation in all species, the upper limit approximating the ratio of the two minerals in bone. However, most livestock can radically change extreme ratios of dietary Ca:P by homeostatic control to acceptable ratios of absorbed and retained Ca:P unless and until phytate sets a ceiling on their absorption. A diet deficient in both Ca and P can have an apparently 'ideal' Ca:P ratio. The Ca:P ratio, therefore, has little or no place in defining requirements for P or Ca, each should be formulated independently. This is not to say that Ca never adversely affects the utilization of P and *vice versa*, rather that these interactions only have a nutritional significance when the supply of one element is limiting and the other is excessive. Ruminants can tolerate a wide range of Ca:P ratios when their vitamin D status is adequate and the dietary supply of each mineral is adequate (Underwood and Suttle, 1999).

Ca:P ratios of the three palatability groups of *A. nummularia* (Hatfield Select) are illustrated in Table 2.4. The most-palatable treatment had a Ca:P of 4.7:1 which is larger than that for the medium- and least-palatable groups with Ca:P ratios of 4.1:1 and 4.2:1 respectively. These ratios are above the norm, but can be tolerated by sheep and goats. To correct this ratio in the diet, animals grazing on these plants should be supplemented with a P source. There was, however, no significant difference between the Ca:P ratios between the palatable groups.

Jacobs and Smit (1977) stated that acceptability of plant material decreases with an increase in K content and a decrease in P content. This will thus result in a decrease in acceptability with an increase in the K:P content. This is evident in Table 2.4 with a K:P ratio of 7.6:1 for the most palatable group and 8.4:1 for the least palatable group. The current study, on *A. nummularia*, thus also tend to decrease in acceptability with an increase in the K:P content of selected *A. nummularia* plant material.

2.3.1.4 Trace minerals

The trace mineral composition of *A. nummularia* (Hatfield Select) is illustrated in Table 2.5.

Copper

The ability of a feed to meet the copper requirements of ruminants, or pose a risk of copper poisoning, depends more on the absorbability than the concentration of copper that it contains. Feed sources differ widely in Cu absorbability, for reasons that are not completely understood (Underwood and Suttle, 1999). The variation in Cu absorbability within and between feedstuffs for ruminants is determined largely by events in the rumen, notably the synchronicity of release of Cu and its potential antagonists, (molybdate, sulphide and Iron (Fe^{2+})) from the diet (Underwood and Suttle, 1999).

There were no significant differences in the Cu concentration of the three different palatability groups of *A. nummularia* (Hatfield Select). The most-palatable treatment had the highest Cu concentration of 8.46 mg/kg, the medium-palatable treatment the lowest (7.68 mg/kg) and the least-palatable treatment was intermediate (7.73 mg/kg). From these results we can assume that the Cu concentration did not affect the palatability of plants in this study.

Chriyaa *et al.* (1997) reported a Cu concentration for *A. nummularia* of 4.8 mg/kg while Ben Salem *et al.* (2004) reported a Cu concentration of 13.0 mg/kg. The Cu concentrations illustrated for the three different palatability groups of *A. nummularia* (Hatfield Select) were intermediate to the Cu concentrations reported by the above two authors. No definite reason can be given for this variation in Cu concentration. Possible reasons could be, different Cu status in soil, or other mineral interactions as mentioned above, within the different experiments.

Sparks (2003) reported Cu concentrations for *A. nummularia* leaf material of 27 mg/kg for both the Hatfield and Lovedale sites. This author also reported Cu

concentrations for stem material of 11 mg/kg and 9 mg/kg for the Hatfield and Lovedale sites respectively. These Cu concentrations are much higher than the values obtained in the current study.

The Cu levels of *A. nummularia* (Hatfield Select) in the current study are within the requirements of sheep (7-11 mg/kg) (NRC, 1985), but do not supply enough Cu to free grazing goats, which needs 10-20 mg/kg (AFRC, 1998). *A. nummularia* (Hatfield Select) may just provide enough Cu for maintenance for sheep, but should be supplemented to goats and producing sheep.

Table 2.5 Trace mineral composition of *Atriplex nummularia* (Hatfield Select) plants on the Hatfield Experimental Farm (DM basis)

	Cu (mg/kg)	Mn (mg/kg)	Zn (mg/kg)
Most-palatable	8.46 ^a (± 0.92)	46.25 ^a (± 3.63)	54.91 ^a (± 3.08)
Medium-palatable	7.68 ^a (±0.85)	51.36 ^a (± 7.54)	88.08 ^a (± 18.52)
Least-palatable	7.73 ^a (± 1.23)	57.73 ^a (±19.1)	103.82 ^a (± 55.79)

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Values in brackets represent the standard deviation

Manganese

The Mn concentrations in plant material depends largely on soil and environmental factors. One factor is the acidity of the soil, which markedly affects the uptake of Mn by the plant. With an increase in acidity (lower pH) of the soil, the Mn content of the plant will increase (Underwood and Suttle, 1999). In contrast high levels of Ca and P can lower the absorption of Mn by the animal.

From Table 2.5 it can be seen that there were no significant differences in Mn concentration between the three palatability groups. The Mn concentration did, however, tended to decrease with an increase in palatability. The most-palatable

plants had a Mn concentration of 46.25 mg/kg, which was lower than the medium- and least-palatable plants. The least-palatable group (57.73 mg/kg) had the highest Mn concentration and the medium-palatable group (51.36 mg/kg) was intermediate. There was, however, a too large variation to obtain any significant differences.

Norman *et al.* (2004) also did not find any significant difference between the most- and least preferred plants within, or between, *A. nummularia* and *A. amnicola*. Respectively, Mn concentrations of 146.68 mg/kg and 170.17 mg/kg were reported for the most- and least preferred *A. nummularia* plants. This was much higher than the values reported in Table 2.5.

Ben Salem *et al.* (2004) reported a Mn concentration of 56.5 mg/kg for *A. nummularia*. This value compares to the least-palatable treatment with a Mn concentration of 57.73 mg/kg. Chriyaa *et al.* (1997) reported a Mn concentration of 65.2 mg/kg which is much higher than any of the palatable groups. This could have been due to either a higher Mn concentration in the soil or a higher soil pH in the study of Chriyaa *et al.* (1997).

Sparks (2003) and Van Niekerk *et al.* (2004a) reported Mn concentrations in leaf material of *A. nummularia* of 153 mg/kg and 62 mg/kg for the Hatfield and Lovedale sites respectively. The value from Lovedale compares more or less to the least-palatable group, but the Mn concentration of Hatfield is much higher than any of the palatability groups. The Mn concentration of *A. nummularia* stem material was 35 mg/kg and 22 mg/kg for Hatfield and Lovedale respectively (Sparks, 2003). These Mn concentrations of the stem material are much lower than the palatable groups in Table 2.5.

According to the AFRC (1998), the Mn requirements of goats are between 60 and 120 g/kg. The Mn levels in the current study were lower than this requirement, and Mn supplementation would be necessary, especially for the

most palatable group. These levels of Mn have taken the interactions of other minerals into account. The ARC (1980) suggested a dietary concentration of 20 to 25 mg/kg for goats. The Mn levels in the current study were higher than this, and if there is no mineral interaction interfering with the utilization of Mn, no Mn needs to be supplemented. The NRC (1985) suggested a 20 to 40 mg/kg range for sheep. Thus, the material evaluated in the current study also provided enough Mn for sheep.

Zinc

The mean Zn concentration in pastures is 36 mg/kg DM. Values vary widely (range 7 to 100 mg/kg), but a high proportion lie between 25 and 50 mg/kg (Minson, 1990). Differences between species contribute little to reported variation in forage Zn (Minson, 1990). The state of maturity is more important, concentrations falling by almost 50%, irrespective of level of Zn fertilizer used, for successive cuts in one study (Underwood and Suttle, 1999).

Due to the large variation within and between palatability groups, there were no significant differences between the three palatability groups of *A. nummularia* (Hatfield Select). There was, however, a tendency for the Zn concentration to decrease with palatability. The most-palatable plants had the lowest Zn concentration of 54.91 mg/kg while the least-palatable plants had the highest Zn concentration of 103.82 mg/kg. The medium-palatable plants were intermediate, with a Zn concentration of 88.08 mg/kg.

Chriyaa *et al.* (1997) reported a Zn concentration of 27.8 mg/kg for *A. nummularia*, which is much lower than those illustrated in Table 2.5. Ben Salem *et al.* (2004) reported a Zn concentration for *A. nummularia* of 47.0 mg/kg which can be compared to the Zn concentration of the most-palatable group. Sparks (2003) and Van Niekerk *et al.* (2004a) reported Zn concentrations of 60 mg/kg and 14 mg/kg for *A. nummularia* leaf material at Hatfield and Lovedale

respectively. The Zn concentration of the Hatfield experiment falls between the most- and medium-palatable groups, while the Lovedale trial gave a Zn concentration much lower than any of the Zn concentrations illustrated in Table 2.5.

The AFRC (1998) recommended a dietary Zn concentration of 50 mg/kg for goats, and possibly up to 80 mg/kg for breeding females, or in the presence of dietary Zn antagonists. In the current study, the most-palatable plants provided enough Zn for goats in the absence of Zn antagonists, but should be supplemented for breeding females. The medium- and least-palatable plants provided enough Zn for all circumstances. The requirements of sheep (20-30 mg/kg) (NRC, 1985) will also be satisfied by all three palatability groups.

2.3.2 Rumen degradability of *A. nummularia* (Hatfield Select)

The degradability of a feed is that portion which breaks down in the rumen as a result of microbial fermentation (McDonald *et al.*, 1995). Rumen degradability is measured by means of *in situ* digestion, which includes the use of rumen cannulated animals to estimate the disappearance of DM, NDF and N (CP) from the rumen.

In the current study, both sheep and goats were fed on the same milled *M. sativa* hay and the same plant material was incubated in the rumens of goats and sheep. This means that no selection could have taken place and that a difference in degradability between goats and sheep will be because of inter species variation and not due to a difference in plant composition. This does not mean that there will not be a difference in degradability between treatments. Since the same plant material within each treatment was incubated in the rumens of goats and sheep, a difference in degradability between palatability groups would be because of plant factors.

2.3.2.1 Dry matter degradability

Table 2.6 illustrates the percentage of effective degradable DM of *A. nummularia* (Hatfield Select). It also compares the three palatability groups with each other as well as between goats and sheep.

Table 2.6 The % effective degradable dry matter of the edible component of *A. nummularia* (Hatfield Select)

	Goats	Sheep
Most-palatable	76.24 ^a ₁ (± 1.37)	74.10 ^a ₂ (± 1.82)
Medium-palatable	75.39 ^{ab} ₁ (± 1.07)	73.82 ^a ₂ (± 0.54)
Least-palatable	74.57 ^b ₁ (± 1.52)	73.61 ^a ₁ (± 1.25)

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Different subscript numbers within rows indicates significant difference between goats and sheep (P=0.05)

*Values in brackets represent the standard deviation

Goats had a significantly higher % of effective degradable DM of *A. nummularia* (Hatfield Select), for the most- and medium-palatability groups, than sheep. For the least-palatable plants there was no significant difference in the % of effective degradable DM between goats and sheep, although the goats tended to have a higher % of effective degradable DM than sheep for this treatment. This higher % of effective degradable DM for goats could possibly be ascribed to the higher cellulolytic activity in the rumen of goats (Van Soest, 1982). The rumen environment in goats was more favourable for the DM degradation of *A. nummularia* (Hatfield Select) than was that of sheep.

Within goats, there was a significant difference between the palatability groups. The most-palatable plants had a non-significant higher % of effective degradable DM than the medium-palatable plants. The medium-palatable plants again had a non-significant higher % of effective degradable DM than the least-palatable plants, but the most-palatable group was significantly higher than the least-palatable group. It appears that with goats, the percentage of effective degradable DM increased with palatability. Within sheep, however, there was no

significant difference in the percentage of effective degradable DM, between the different treatments groups. The percentage of effective degradable DM did, however, tend to increase with palatability. A possible reason for this increase in percentage of effective degradable DM from the least- to the most-palatable groups, within both sheep and goats, could possibly be because of the decline in NDF concentration as the palatability increases. This decline of NDF concentration with palatability is illustrated in Table 2.3.

The extent of DM degradability in Table 2.6 is extremely high. Comparing this to the *in vitro* digestibility of Chapter 3, DM degradability was higher in the rumen than IVDOM in the *in vitro* digestibility study. In both studies the experimental animals were fed on the same milled *M. sativa* hay, which means that the rumen fluid and rumen environment should have been approximately the same. The only difference that could have had an influence on *in vitro* digestibility is that only two sheep were used to collect rumen fluid while four sheep and four goats were used for the degradability study. This could have caused variation within and between animal species. Another reason for the lower IVDOM than degradability could be that the plant material used for IVDOM was collected via oesophageal fistulated animals. This plant material was exposed to the chewing action of animals, which breaks the cell walls of fresh material. This leads to the loss of highly digestible cell constituents and thus increases the proportion of cell wall constituents. The increase in the proportional cell wall constituents (NDF) leads to a lower digestibility and thus a possible reason for the lower IVDOM than DM degradability.

Chriyaa *et al.* (1997) reported 65.8% DM degradability for *A. nummularia* incubated for 72 h in the rumen of sheep. The DM degradability of the current study is 8-10% units higher than that reported by Chriyaa *et al.* (1997), even though the current study had NDF concentrations of 5-10% units higher than the study of Chriyaa *et al.* (1997). This cannot be explained since a higher cell wall content (NDF) should have resulted in lower DM degradabilities (Chriyaa *et al.*,

1997). This author also reported DM degradabilities of 53.3% and 49.3% for alfalfa hay and blue wattle foliage respectively.

In Table 2.7 the rate of degradation of DM is illustrated for *A. nummularia* (Hatfield Select). In this Table, goats are compared to sheep and the three treatments (most-, medium- and least-palatable groups) are compared to each other.

Table 2.7 The rate of dry matter degradation (% h⁻¹) of the edible component of *A. nummularia* (Hatfield Select).

	Goats	Sheep
Most-palatable	0.175 ^a ₁ (± 0.036)	0.147 ^a ₁ (± 0.034)
Medium-palatable	0.134 ^a ₁ (± 0.019)	0.120 ^a ₁ (± 0.012)
Least-palatable	0.142 ^a ₁ (± 0.031)	0.138 ^a ₁ (± 0.037)

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Different subscript numbers within rows indicates significant difference between goats and sheep (P=0.05)

*Values in brackets represent the standard deviation

There were no significant differences in the rate of DM degradation between sheep and goats. Goats did however tend to have a higher rate of DM degradation than sheep. This apparent higher rate of DM degradation for goats is possibly due to the higher cellulolytic activity in the rumens of goats, than in sheep (Van Soest, 1982). This higher rate of DM degradation for goats could also result in a higher DMI for goats, because of a lower retention time of feed particles in the rumen.

Within both animal species, there were no significant differences in rate of DM degradation between the three groups, although there was a tendency for the rate of DM degradation to be at it's highest in the most-palatable plants. The medium-palatable plants had a lower rate of DM degradation than the least-palatable plants. In terms of the effective DM degradability, the medium-palatable group should have had a higher rate of DM degradation than the least-palatable

group. This lower rate of DM degradation for the medium-palatable group is possibly due to too large a variation between animals in this treatment. This large variation could also have been caused by experimental errors during the trial.

The rate of DM degradation was on the high side. Rates of DM degradation for *A. nummularia* reported by Chriyaa *et al.* (1997) were in the range of 0.105 h^{-1} . This author ranked *A. nummularia*, with the highest rate of DM degradation, with *M. sativa* hay and medic pods second (0.061 h^{-1}). The rate of DM degradation in the current study was higher than any of the above-mentioned DM degradation rates.

2.3.2.2 Degradability of the nitrogen fraction

“Nitrogen fractions within the diet will vary in their susceptibility to breakdown, from immediately degraded to undegradable. Degradability will depend upon such factors as the surface area available for microbial attack, the physical and chemical nature of the protein and the protective action of other constituents. It is therefore a characteristic of the protein itself and should be measurable. It has been suggested that a major factor affecting degradability is the amino acid sequence within the protein molecule (McDonald, 1995)”.

Table 2.8 illustrates the % of effective degradable N of *A. nummularia* (Hatfield Select). This Table also compares the % of effective degradable N between goats and sheep as well as between the three treatments (most-, medium- and least-palatable).

Table 2.8 % Effective degradable nitrogen of the edible component of *A. nummularia* (Hatfield Select) plants

	Goats	Sheep
Most-palatable	88.49 ^a ₁ (± 1.37)	86.17 ^a ₂ (± 1.45)
Medium-palatable	86.17 ^b ₁ (± 0.88)	84.62 ^a ₂ (± 0.63)
Least-palatable	86.00 ^b ₁ (± 1.36)	85.15 ^a ₁ (± 0.71)

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Different subscript numbers within rows indicates significant difference between goats and sheep (P=0.05)

*Values in brackets represent the standard deviation

For the most- and medium-palatable groups, goats had a significantly higher % of effective degradable N, than sheep. This means that the rumen micro-organisms in the rumen of sheep were better able to utilize the diet N. Within the least-palatable treatment, goats tended to have a non-significant higher % of effective degradable N, than sheep. It appears, therefore, that goats have a higher capability to degrade N in *A. nummularia* (Hatfield Select). Whether this is true for goats that graze on *A. nummularia* (Hatfield Select) pasture, we cannot tell. This is because the rumen environment will be different on an *A. nummularia* (Hatfield Select) pasture than on the milled *M. sativa* hay used to keep a constant rumen environment.

Within goats, there was a significant decline in the % of effective degradable N from the most- to the medium-palatable groups. There was no significant difference between the medium- and least-palatable plants, although the % of effective degradable N did tend to decline from the medium- to the least-palatable groups. The least-palatable plants also had a significantly lower % of effective degradable N than the most-palatable plants. This means that the least-palatable plant's N was less available to micro-organisms in the rumen than that of the most-palatable plants. Within sheep, there were no significant differences in the % of effective degradable N between any of the three groups. The % of effective degradable N in sheep tended to decline from the most- to the medium-

palatable groups, but then increased from the medium- to the least-palatable group. The least-palatable group still had a lower % of effective degradable N than the most-palatable group. This higher % of effective degradable N for the least-palatable group of sheep cannot be explained. It could be due to an experimental error during the trial.

The % of effective degradable N in *A. nummularia* (Hatfield Select), as illustrated in Table 2.8, is extremely high. By comparing these values to values obtained by Chriyaa *et al.* (1997), the current study's % of effective degradable N is approximately 12% higher. This author ranked *A. nummularia* with the highest CP degradability of 74.40%. *M. sativa* had a CP degradability of 63.90% and medic pods of 69.11%. It should also be mentioned that the *A. nummularia* used in the study of Chriyaa *et al.* (1997), contained only 13.4% CP and had an apparent CP digestibility of 57.7%. The CP concentration of the current study was between 24.38% for the most-palatable plants and 21.53% for the least-palatable plants. This difference in CP concentration could have had a possible effect on the difference in N degradability between the two studies since Lindberg (1988) stated that it is possible to relate ($R^2 = 0.72$) the effective protein degradability values to the CP concentration of a feed sample. This author also stated that there is a high correlation between CP and DM effective degradability. These two statements could also explain some of the highly effective degradable DM and N in the current study.

In the study of Mathis *et al.* (2001), *in situ* degradabilities of 79.4, 79.4, 82.5 and 83.2 % have been reported for Alfalfa hay with a CP value of 18% and a NDF value of 49.6 %. These authors also found a high CP degradability with a high CP concentration and a high NDF concentration. These authors also reported an ADF value of 34.4 %, which should have lowered the degradability.

Rittner and Reed (1992) reported that the protein degradability in browse species was negatively correlated with the phenolic compounds and lignin. Ahn *et al.*

(1989) emphasized that species which had no tannin content exhibited high N degradabilities. None of the above three chemical components were tested for, but it could explain some of the extremely high N degradabilities in the current study. It is advised to determine the above chemical components in a degradability study, as this could provide a better explanation for these results.

Table 2.9 illustrates the rate of N degradation (% h⁻¹) for *A. nummularia* (Hatfield Select). It also compares the rate of N degradation of the three groups (most-, medium- and least-palatable) and that between goats and sheep.

Table 2.9 The rate of nitrogen degradation of selected edible material of *A. nummularia* (Hatfield Select)

	Goats	Sheep
Most-palatable	0.169 ^a ₁ (± 0.038)	0.141 ^a ₁ (± 0.034)
Medium-palatable	0.121 ^b ₁ (± 0.018)	0.114 ^a ₁ (± 0.014)
Least-palatable	0.129 ^b ₁ (± 0.016)	0.127 ^a ₁ (± 0.031)

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Different subscript numbers within rows indicates significant difference between goats and sheep (P=0.05)

*Values in brackets represent the standard deviation

There were no significant differences in the rate of N degradation between goats and sheep. Goats did, however, tend to have a higher rate of N degradation for all the treatments. The difference in the rate of N degradation was higher for the most-palatable treatment and decreased towards the least-palatable treatment. Since the same plant material was incubated in goats and sheep, this difference could not be due to any characteristics of the plants, it must be due to animal factors between the two species. A higher rate of degradation is most likely due to a more favourable rumen environment. This means that the microbe populations in the rumens of goats were better able to digest the CP of *A. nummularia* (Hatfield Select) than those of sheep. This could possibly be due to a larger microbe population in goats (Hadjipanayiotou and Antoniou, 1983) or due

to a larger surface area of the forage available for microbial attack. The latter explanation, however, is not relevant in the current trial, because the animal could not chew or ruminate the material in the *in sacco* bags.

Within goats, the rate of N degradation of the most-palatable plants differed significantly from the medium- and least-palatable plants. There was no significant difference between the latter two groups. The rate of N degradation increased slightly from the medium- to the least-palatable treatment. This increase was also noticed for sheep and it is thus not a function of the animals, but a function of the forage. There were no significant differences between the treatments within sheep. Within sheep, the rate of N degradation declined from the most-palatable treatment to the medium-palatable treatment. As mentioned, the rate of N degradation increased again in the least-palatable treatment, although, within both goats and sheep, the least-palatable groups had a much lower rate of N degradation than the most-palatable groups. The rate of N degradation decreased towards the medium and least-palatable groups probably due to the protective action of other substances such as NDF (McDonald *et al.*, 1995). This can be explained by the increase in NDF concentrations in the least-palatable treatment.

The extent of the rate of N degradation for *A. nummularia* (Hatfield Select) in the current study was high. Chriyaa *et al.* (1997) reported a rate of N degradation of 0.069 for *A. nummularia* in sheep. These authors also reported a rate of N degradation for *M. sativa* hay of 0.151 and for medic pods of 0.061.

2.3.2.3 Degradability of the neutral detergent fibre fraction

The digestibility of a food is closely related to its chemical composition. The fibre fraction of a food has the greatest influence on its digestibility (degradability), and both the amount and chemical composition of the fibre are important. Fibre can be divided into NDF and ADF. The NDF fraction is the whole fibre constituent of the cell wall and is divided into three fractions. These fractions are the more

digestible hemicelluloses and the less digestible cellulose and lignin fractions. The ADF fraction consists of the cellulose and lignin fractions. It is not only the chemical composition of fibre that affects the cell wall digestibility, but also the structure of the cell wall. For instance, stem material contains more vascular bundles and thus more lignin, which reduces its digestibility (McDonald *et al.*, 1995).

Table 2.10 illustrates the percentage of effective degradable NDF of *A. nummularia* (Hatfield Select) between goats and sheep. It also illustrates the difference in the % of effective degradable NDF between the three treatments (most-, medium- and least-palatable plants).

Table 2.10 The % effective degradable neutral detergent fibre of the edible component of *A. nummularia* (Hatfield Select) plants

	Goats	Sheep
Most-palatable	60.41 ^a ₁ (± 1.15)	59.78 ^a ₁ (± 0.90)
Medium-palatable	61.34 ^a ₁ (± 1.84)	60.11 ^a ₁ (± 1.15)
Least-palatable	61.13 ^a ₁ (± 2.06)	60.98 ^a ₁ (± 0.90)

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Different subscript numbers within rows indicates significant difference between goats and sheep (P=0.05)

*Values in brackets represent the standard deviation

There were no significant differences in the percentage of effective degradable NDF between goats and sheep, although goats did tend to have a slightly higher percentage of effective degradable NDF. This indicates that the NDF degradability between goats and sheep were equal, and we can assume that both animal species made similar use of the fibre fraction of *A. nummularia* (Hatfield Select).

From Table 2.10, it appears that the percentage of effective degradable NDF increased from the most-palatable group to the least-palatable group. There

were, however, no significant differences in the percentage of effective degradable NDF between any of these groups. Within goats, the percentage of effective degradable NDF increased from the most- to the medium-palatable plants and then decreased again towards the least-palatable group. The least-palatable plants still had a % of effective degradable NDF higher than that of the most-palatable plants. Within sheep, the percentage of effective degradable NDF increased from the most- to the medium-palatable groups and increased still further in the least-palatable group. This increase in the degradability of NDF could be due to a higher concentration of NDF in the least-palatable treatment, but is unlikely because degradability is known to decrease with an increase in NDF. This, however, depends on which fraction makes out most of the NDF, if hemicelluloses makes out the larger proportion, it could be true that the increase in NDF degradability is due to the increase in NDF concentration. If, however, the ADF fraction (cellulose and lignin) makes out the larger proportion of NDF, then it would not be able for the higher NDF degradability to be due to a higher NDF concentration. This is because the ADF fraction is almost indigestible.

Table 2.11 illustrates the rate of degradation of NDF for *A. nummularia* (Hatfield Select). This Table also illustrates the rate of degradation of NDF of the three different treatments (most-, medium- and least-palatable plants) between goats and sheep.

Table 2.11 The rate of degradation of neutral detergent fibre of selected edible material of *A. nummularia* (Hatfield Select)

	Goats	Sheep
Most-palatable	0.179 ^a ₁ (± 0.032)	0.140 ^a ₂ (± 0.029)
Medium-palatable	0.148 ^{ab} ₁ (± 0.019)	0.125 ^a ₂ (± 0.010)
Least-palatable	0.138 ^b ₁ (± 0.027)	0.123 ^a ₁ (± 0.028)

*Different superscript letters within a column indicates significant difference between treatments (P=0.05)

*Different between goats and sheep subscript numbers within rows indicates significant difference (P=0.05)

*Values in brackets represent the standard deviation

From Table 2.11, goats had a significantly higher rate of NDF degradation, for the most- and medium-palatable plants, than sheep. For the least-palatable group goats tended to have a higher rate of NDF degradation than sheep, but this was not significant because of the high standard deviation. The higher rate of degradation in goats than in sheep, fed on the same feed and with the same feed samples incubated in both species, could be because of a more favourable rumen microbe population in goats (Hadjipanayiotou and Antoniou, 1983). Van Soest (1982) stated that goats have a higher rumen cellulolytic activity than sheep. This could explain part of the higher NDF degradation and rate of NDF degradation in goats.

Within goats, there was a significant decrease in the rate of NDF degradation from the most- to the least-palatable groups. The most-palatable plants also had a non-significant higher rate of NDF degradation than the medium-palatable plants. The rate of NDF degradation in the medium-palatable plants was also non-significantly higher than that of the least-palatable plants. It may, therefore, be concluded that goats tend to have a higher rate of NDF degradation with an increase in palatability. This higher rate of NDF degradation is because the NDF concentration declines as palatability increases (Table 2.3). Within sheep, there was a non-significant increase in the rate of NDF degradation from the most- to the medium- to the least-palatable groups, though the difference between the medium- and least-palatable groups was very small. This decrease in the rate of NDF degradation of sheep could also be attributed to the increase in the NDF concentrations with a decrease in palatability.

2.3.2.4 Possible explanations for the high rumen degradation of *A. nummularia* (Hatfield Select)

It is well known that the fibre content of a diet influences the degradability of that diet. Acid detergent fibre is the component of NDF which has the largest influence on degradability of which lignin in ADF causes most of the indigestibility (McDonald *et al.*, 1995; Chriyaa *et al.* 1997). In the current study, only NDF was

determined. Although NDF values were high for *A. nummularia* (Hatfield Select), high effective degradabilities of DM, N and NDF were obtained. Since no analyses were done for ADF or lignin, it can be assumed that these chemical components occupied a relatively small proportion of the NDF. Chriyaa *et al.* (1997) reported that only 7.6% of the NDF was in the form of ADL and that 14.4 % was in the form of ADF. This low lignin concentration would make the cell walls more “approachable” for the micro-organisms in the rumen and thus would result in a higher degradability. In future studies, it would be advisable to determine the ADF and lignin fractions as well. This would facilitate explanation of the results.

The high degradability in the current study could also be due to rumen conditions. Unfavourable conditions in the rumen result in low and ineffective rumen microbial populations. It is known that the degradation of a feed is directly correlated to the rumen microbial population (McDonald *et al.*, 1995). When the rumen environment is in a favorable condition (optimum pH, optimum NH₃-N and correct microbial population composition), degradability will increase.

The high rumen degradabilities and rates of degradation of DM and N can be partly explained by the high soluble DM and N. The DM had a soluble fraction of between 26 and 30% while the N had a soluble fraction of between 36 and 40% within and between animal species and treatment. This high soluble fraction increases the degradability and is the most probable reason for the high degradabilities obtained in the current study. The high solubilities could be due to the high mineral concentration of *A. nummularia*. Another possible reason could be that the samples were too finely milled and that more plant material was washed from the bags than the true soluble fraction.

Chapter 3

Summary, Conclusions and Recommendations

The aim of this study was to identify three palatability classes, or groups, within *A. nummularia* cv. Hatfield Select and to identify the differences in chemical composition of these three groups. The factors most likely to influence the palatability were identified. The differences in rumen degradability of these three groups were determined as was the degradability between goats and sheep. From these studies the factors identified as influencing palatability, as well as the nutritive value of the treatments, can be used to select a cultivar that will be palatable to grazing animals and that can be utilized by these animals for maximum production.

Goats and sheep were used to identify the most-palatable or preferred *A. nummularia* cv. Hatfield Select plants during a grazing period. Young tender edible plant material was then harvested by hand and used to determine the chemical composition of these three palatability groups. These three palatability groups were also used to determine the degradability of the plant components, as well as to compare the degradability of the treatments by goats and sheep.

There were significant differences in the CP concentration between the most- and least-palatable groups. The most-palatable plants had a CP concentration of 24.38%, which was higher than the least-palatable group (21.53% CP). This is supported by the results obtained by Norman *et al.* (2004), who found that *A. nummularia* had a significantly higher CP concentration in the most preferred plants. According to Welch and Monsen (1981), the higher CP concentration in the most-palatable plants could be of genetic origin. This will make it possible to select palatable *A. nummularia* cv. Hatfield Select plants with a high CP level. From these high CP concentrations, more than enough CP should be provided for animal production and certain levels of growth, pregnancy and lactation for both sheep and goats (NRC, 1981; NRC, 1985 and EAAP, 1991).

The most-palatable plants had a non-significant lower NDF concentration (41.62%) than the least-palatable plants (45.51%). It can thus be concluded that the cell wall fraction increases with a decrease in palatability. The high cell wall fraction should, in future, also be analyzed for the less digestible fibre fractions (ADF and ADL). These fractions will give a complete assessment of the true influence of the cell wall fraction on digestibility.

The most-palatable plants also had higher concentrations of all the macro minerals determined (Ca, P, Mg, K, Na and Cl) than the least-palatable plants. Only P and Mg, however, had significantly higher concentrations in the most-palatable than the least-palatable plants. The most-palatable group had a P concentration of 2.51 g/kg and the least-palatable group 2.04 g/kg. This positively correlated influence of P on palatability was also reported by Jacobs and Smit (1977). The Mg concentration in the most-palatable plants was 7.73 g/kg while that in the least-palatable plants was 6.59 g/kg. This significantly higher concentration of Mg in the most-palatable plants than the least-palatable plants was also reported by Jacobs and Smit (1977). The salt content, especially NaCl, of *Atriplex* is generally this plant's main determinant of palatability (Jones and Hodginson, 1969; Hoon *et al*, 1991). This was not true for the current study, as the NaCl concentrations were very low and had no significant effect on palatability. The NaCl concentrations in the current study were in contrast to the statements of Jones and Hodginson, (1969); Hoon *et al*, (1991) and Casson *et al*. (1996) that a high salt content relates negatively to palatability. Within the trace elements determined (Cu, Mn and Zn), Cu had a non-significant decrease in concentration while Mn and Zn concentrations increased non-significantly with palatability. To summarise, the factors that significantly influenced palatability, were increases in the CP, P and Mg concentrations.

A. nummularia cv. Hatfield Select provides enough CP for production in both sheep and goats. Production can also be sustained for goats and sheep, provided that P, Cu and Zn are supplemented. Maintenance requirements of all

the minerals can be provided except for Cu. From the results it would be advisable to supplement animals grazing *A. nummularia* cv. Hatfield Select with Cu, but it would depend on soil conditions.

Goats had a significantly higher percentage of effective degradable DM, of *A. nummularia* cv. Hatfield Select, in the most- and medium-palatable plants, than sheep. The rate of DM degradation was also non-significantly higher in goats than in sheep. In the most- and medium-palatable groups, goats had a significantly higher percentage of effective degradable N, than sheep. Goats had a non-significant higher rate of N degradation than sheep. There was no significant difference in the % of effective degradable NDF between goats and sheep but goats did tend to have a slightly higher % of effective degradable NDF. Goats had a significant higher rate of NDF degradation, in the most- and medium-palatable plants, than sheep. This higher extent and rate of DM, N and NDF degradation is an indication that goats are better able to digest *A. nummularia* cv. Hatfield Select in the rumen than goats. The higher N degradation will result in a higher rumen $\text{NH}_3\text{-N}$ concentration and possibly higher microbial protein synthesis in goats. This will give a better utilization of dietary N by goats than by sheep. The non-significant higher NDF degradation by goats indicates a higher digestion of the fibre component of the diet by these animals. This higher digestion of the cell wall component will result in the production of higher levels of acetic and propionic acids in the rumen. If enough propionic acid is produced from hemicelluloses and the cell contents, these VFA will be able to provide enough energy to the animal for production. *A. nummularia* is known as a maintenance forage with a small production potential (Le Houerou, 1991). This is because of a shortage in metabolisable energy. In a subsequent chapter, low VFA concentrations will illustrate the shortage in energy.

Within goats, there was a significant lower percentage of effective DM degradability in the least-palatable (74.57%) than the most-palatable (76.24%) plants. This was not noted with sheep, which had small differences in the

percentage of effective degradable DM. Within goats and sheep, there was a non-significant lower rate of DM degradation in the least-palatable than the most-palatable groups. There was a significantly higher percentage of N degradability in the most-palatable than the least-palatable plants with goats. In sheep, this difference was, however, non-significant. Goats also had a significantly, and sheep a non-significant, higher rate of N degradation in the most-palatable than the least-palatable plants. Within goats there was a non-significant increase in the NDF degradation with increasing palatability. For sheep, just the opposite was true. Goats did, however, exhibit a significantly, and sheep a non-significant, higher rate of NDF degradation with an increase in palatability. With enough energy and high enough intakes, this fodder has enormous potential for animal production. These overall higher DM, N and NDF effective degradabilities and rates of degradability for the most-palatable plants than the least-palatable plants within goats and sheep, indicate a potentially better utilisation of the most-palatable plants than the least-palatable plants. There could thus be selected for a more palatable and higher potential *A. nummularia* cultivar from this population. The higher N degradability of the most-palatable plants indicates a higher microbial population and thus a higher utilization of the dietary material by the ruminant. The higher DM degradability indicates that the most-palatable group would have a higher over-all digestibility than the least-palatable group. The most-palatable treatment would also have a better utilisation of the potential energy of the plant. This is because of the higher NDF degradability of the most-palatable group than the least-palatable group, resulting in a higher production of VFA by the rumen micro flora.

From the above, it appears that there can be selected for a highly palatable cultivar which will also increase the nutritional value of *A. nummularia* for both goats and sheep. This more palatable cultivar will also have a better utilisation by animals. This fodder crop can be used as a maintenance diet and if it does not contain too high a salt concentration which is linked to local soil conditions, it will be relatively palatable.

Chapter 4

Qualitative and Quantitative Intake of *Atriplex nummularia* (Hatfield Select) by Sheep and Goats

4.1 Introduction

In this study the qualitative and quantitative intake of sheep and goats were compared in three periods of grazing. Certain rumen parameters (NH₃-N and VFA) between goats and sheep during a five-day grazing period, were also examined.

The hypotheses were:

- ? that there is a difference in qualitative and quantitative intake between sheep and goats and goats will select for a higher quality diet;
- ? that over time the qualitative and quantitative intake will decrease as the availability of edible material decreases;
- ? that there is a difference in the rumen VFA concentrations between goats and sheep and
- ? that there is a change in the VFA composition over time, with rumen acetic- and butyric acid concentrations increasing and rumen propionic acid concentration decreasing.

4.2 Materials and methods

4.2.1 Location

These trials were carried out on the Hatfield Experimental Farm of the University of Pretoria, Pretoria, South Africa (28°15'30"E, 25°44'30"S). This experimental farm has an altitude of 1360m. This is a summer rainfall area with November, December and January as the principal rain period. The mean annual rainfall for the Hatfield Experimental Farm, as provided by the Hatfield Experimental Farm's

weather station for the period 2001 to 2004, was 613.28mm. Table 2.1 illustrates the monthly rainfall for this period.

4.2.2 Atriplex population

The same *A. nummularia* population as discussed in Section 2.2.4 and figure 2.1, was used. The fourth unit was used as a transition camp between the trial discussed in Chapter 2 and the trial discussed in this chapter. This unit was also used to ensure that the faeces excreted by the animals during the first day of faecal collection originated from a high quality plant material. Animals utilized this camp for three days only. Unit three was used to take plant material samples selected by the animals. These samples were collected via oesophageal fistulas. These were used to determine the *in vitro* digestibility and intake of the different days on sampling. Rumen fluid was also collected from animals grazing this unit. The rumen fluid was used to determine rumen pH, rumen volatile fatty acid concentrations and rumen ammonia nitrogen concentration as described later.

4.2.3 Animals and housing

All animals were treated with 1ml of Ivomec (Ivermectin)(Bayer) as a precaution against external and internal parasites. The animals were also vaccinated against tetanus and pulpy kidney. Three Dohné Merino x SA Mutton Merino wethers (average mass 60kg) and three castrated Boer goats (average mass 37 kg) were fitted with oesophageal fistulas. Four of each animal type (average mass 72kg and 35kg separately) were fitted with rumen canulae. The goats were fitted with rumen canulae in mid-September 2003 and the sheep for previous studies. All the animals were kept in a pen overnight because of security reasons. The animals were taken to the experimental unit at dawn (05:00) and brought back to the pen at dusk (19:00). They were transported with a vehicle to ensure that the animals did not consume other plant material.

4.2.4 Logistical procedures

The animals were fitted with harnesses, faecal collection bags and oesophageal collection bags a week before the start of the trial. This allowed them enough time to become accustomed to this equipment while grazing on pasture. The animals spent three days in camp four, which allowed them to fill the gastro intestinal tract with high quality plant material and for one day they were allowed to graze camp three, thereby learning the camp and plants. Oesophageal fistula samples were collected from 05:20 to 06:00 on Days 1, 3 and 5. Rumen fluid samples were collected at 06:30, 13:00 and 19:00 on Days 1, 3 and 5. The first rumen fluid samples were collected one hour after the start of browsing. Faeces were collected every day at 04:45 and again at 20:00. Weighing of the animals commenced at 04:30 on the first morning and again on the morning after the last collection of samples.

4.2.5 Preparing experimental animals

4.2.5.1 Oesophageal fistulation technique

A number of systems have been developed to determine the quantity and quality of a grazing or browsing animal's diet. Sampling by the animal is the best way to get a representative sample of the diet selected by the animal (Lesperance *et al.*, 1960). Sampling by the animal was accomplished by the technique as developed by Torrel (1954) with a successful establishment of an oesophageal fistula in a sheep.

For the purposes of this study, four oesophageal fistulated goats and two sheep were prepared. Two of the four sheep used, already had oesophageal fistulas. The technique used for establishment of the fistulated animals is described by Torrel (1954), Cook *et al.* (1958) and Lesperance *et al.* (1960).

For the first week after the operation the wounds were cleaned and disinfected on a daily basis to prevent infection. During this period the animals were fed green chopped Triticale. Intakes were very low and the animals lost weight and

body condition. From the second week the wounds were cleaned every three days and the animals were allowed to graze on a kikuyu pasture. This reduced stress tremendously and intakes increased. They were supplemented with a fully balanced pelleted ration in the pen where they overnight. The animals were allowed 6 weeks for recovery. One of the goats died due to Tetanus (*Clostridium tetani*). The rest of the animals were immediately vaccinated against this bacterium. This forced the use of only three oesophageal fistulated animals of each species.

4.2.5.2 Rumen-fistulation technique

Rumen canulae have a wide range of applications. They can be used for collection of animal selected material (Lesperance *et al.*, 1960), rumen degradability studies (Orskov and McDonald, 1979) and for the determination of rumen NH₃-N and volatile fatty acids (VFA) in rumen fermentation studies.

Four goats were fitted with rumen cannulae, using the technique described by De Waal *et al.* (1983). The sheep used were already fitted with rumen cannulae. During the post-operation period the animals were fed a balanced pelleted diet. They were also allowed to graze a kikuyu pasture during the day from the second week after the operation.

4.2.6 Collecting samples

4.2.6.1 Collecting and preparing oesophageal samples

Samples of material selected by the animals were collected on days one, three and five. These samples were collected by removing the fistula and fitting the animals with collection bags attached around the neck. The fistulae were removed during the morning at 05:20 for 30 minutes to allow enough time for the animal to collect a large enough sample but the time span short enough to prevent the opening in the esophagus to shrink. The bags were then removed and the fistulae refitted to the oesophagus.

Plant material collected in such a manner is contaminated with saliva. The saliva increases the mineral and N concentration (Bath *et al.*, 1956) of the samples and, according to Engels *et al.* (1981), drying the samples with the saliva will lead to large variations in *in vitro* digestibility. The samples were collected and filtered through four layers of cheesecloth (Engels *et al.*, 1981) and the fluid was discarded. This results in the loss of some soluble nutrients but reduces the variation in *in vitro* digestibility and N content. Samples were dried for 48h at 50°C in a forced draught oven, milled and stored for chemical analysis.

4.2.6.2 Collecting rumen fluid

Rumen fluid was collected three times a day at 06:30, 13:00 and 19:00 on days one, three and five. Rumen contents were collected with the aid of a 60ml syringe connected to a flexible plastic tube. Contents were drawn up from a few locations in the rumen into the tube by the suction caused by the syringe. Approximately 150ml of rumen contents per animal were collected during each sampling period and placed in 250ml plastic bottles in a container filled with ice. The samples were stored like this and immediately after all the samples were collected they were taken to the laboratory where they were filtered through four layers of cheesecloth. The solids were discarded and the rumen fluid preserved as follows:

- a) 30ml of the rumen fluid was preserved after each sampling with 5ml of 0.5 M H_2SO_4 and frozen to determine the rumen fluid ammonia nitrogen ($\text{NH}_3\text{-N}$) concentration with an auto-analyzer at a later stage;
- b) 20ml of the rumen fluid were preserved after each sampling with 1ml of 10% NaOH and frozen to determine the rumen fluid VFA concentration with a gas chromatograph (GC) at a later stage.

Samples from each animal were preserved and analyzed separately, but the three samples of each day were frozen in the same container.

4.2.7 Determination of bodyweight

All the animals were weighed separately on the morning that the trial started at 04:30 and again on the morning after the trial has finished at 04:30. The animals were fasted over night before weighing. The water supply was emptied the night before weighing. This was done to ensure a more reliable empty body mass.

4.2.8 Determination of faecal excretion

For the determination of feed intake it is important to determine the total faecal excretion. It is thus important that all the faeces are collected and that there are no losses. According to Arnold (1962) the total collection of faeces by means of a harness and collection bag is quicker and more accurate than estimating faecal output by means of inert markers such as chromic oxide.

The requirements of such a harness are as follows: it should (a) enable complete collection of all faeces voided, (b) be simple and speedy to operate, (c) cause minimum distress to the animal, so that the animal accustomed to the harness and collection bag behaves normally (Arnold, 1962; Burns *et al.*, 1994).

Faeces were collected twice a day during the five-day grazing period. The faeces were weighed and a representative sample of 10% was taken. The samples were then dried for 48h at 100°C in a forced draught oven, milled and stored to determine the organic matter content.

4.2.9 Determination of digestibility

Digestibility can be determined by a wide range of methods. The two-stage *in vitro* bioassay is the method of choice for estimating diet quality and has the broadest application (Burns *et al.*, 1994). The process of sampling material with oesophageal fistulated animals, however, results in large variation in the *in vitro* digestibility of a feed. The digestibility was determined using the method as described by Tilley and Terry (1963) and modified by Engels *et al.*, 1981. This method will be discussed in section 4.2.12.

4.2.10 Determination of voluntary intake

Pasture intake was estimated from the ratio of faecal OM voided in the collection bags (Langlands, 1975) and the indigestibility of oesophageal samples by converting the *in vitro* digestibility to *in vivo* digestibility, according to Engels *et al.*, 1981.

$$\text{OMI (g/day)} = \frac{100}{(100\% - \text{indigestible OM})} \times \frac{\text{daily OM-excretion}}{1}$$

4.2.11 Chemical analysis

Dry matter and ash

The DM and ash content were determined for faeces and oesophageal fistula samples. This was done with the same method described in Section 2.2.8.

Crude protein

The CP was determined on the oesophageal fistula samples. This was done using the Dumas method (AOAC, 2000), as described in Section 2.2.8.

Neutral detergent fibre

The NDF was determined on the oesophageal fistula samples using the Dosi Fibre system (AOAC, 2000), as described in Section 2.2.8.

In vitro digestibility

The *in vitro* digestibility for the oesophageal fistula samples was determined using the method prescribed by Tilley and Terry (1963). This method consists of an incubation phase in rumen inoculums followed by a digestibility phase in acid pepsin. This method was adapted by Engels and Van der Merwe (1967) by the addition of 20mg nitrogen to the rumen inoculums. With this addition of nitrogen it was found that the origin of the rumen inoculums did not have an effect. The *in*

in vivo digestibility was determined with the regression equation suggested by Engels *et al.* (1981) for oesophageal fistula samples:

$$Y = 16.4205 + 0.7892X \quad (r = 0.962; S_{y,x} = \pm 2.0930 ; n = 6)$$

Where Y equals the *in vivo* digestibility of organic matter, determined with sheep, and X equals the *in vitro* organic matter digestibility (IVOMD) of oesophageal fistula extrusa of sheep, dried at 50°C.

Rumen NH₃-N

The rumen fluid samples were defrosted, mixed thoroughly and 10ml centrifuged at 2500 rpm for 15 minutes. The clear fluid was then diluted one hundred times with distilled water and the ammonia nitrogen concentration determined using a Technicon Auto-Analyser (Technicon Auto-Analyser II. Industrial method No 334-74 A, Jan 1976). These values, in parts per million, were corrected for the two dilutions made by multiplying it with 100 and again with 1.1667. This is for correcting for the 5ml of 0.5 M sulphuric acid added to 30ml of rumen fluid in the preservation of the rumen fluid.

Rumen VFA

The samples (rumen fluid/NaOH mixture) were defrosted and 1.1ml of 50% v/v ortho-phosphoric acid was carefully added to 10ml of the sample. This mixture was then centrifuged at 4500 rpm for twenty minutes. Exactly 1ml of internal standard was added to the 9 mm of clear supernatant. The samples were then placed in a refrigerator until required for analysis.

The standard solution was prepared as followed:

Forty ml of cooled (15 °C) distilled water and 2 ml of ortho-phosphoric acid were added to a 100 ml volumetric flask. The volatile fatty acids were then added to this solution in quantities that are normally present in the rumen. The fatty acids were added in the following quantities: 450 mg acetic acid, 200 mg propionic

acid, 70 mg n-butyric acid, 25 mg iso-butyric acid and 25 mg iso-valeric acid. To this 10 ml of the internal solution was added, the solution was then made up to a volume of 100 ml with distilled water. The internal standard solution consisted of 2000 mg/1000 ml Pivalic acid.

The Varian 3300 gas chromatograph with flame ionisation detector fitted with a 1.8 m glass column (2 mm internal diameter) packed with 60/80 Carbopack C/0.3 % Carbowax 20M/0.1 % H₃PO₄ was used. The column was conditioned overnight at 150 °C and a flow of 15ml helium per minute.

The analysis was done under the following test conditions:

Carrier gas (Helium) flow:	35 ml/minute
Flame gasses:	Hydrogen and air
Column temperature:	130 °C
Injection port temperature:	160 °C
Detector temperature:	180 °C

One μ l of the standard solution was injected repeatedly until consecutive results were comparable. The samples were then injected in 1 μ l volumes and integrated.

4.2.12. Statistical analysis

An analysis of variance with the Proc GLM model (Statistical Analysis System, 1994) was used to determine the significance between different treatments, period and animal effects for the balanced data. Means and standard deviation (s.d.) were determined. Significance of difference (5%) between means was determined by Bonferroni's test (Samuels, 1989).

4.3 Results and discussion

4.3.1 Qualitative intake

In this section the quality of the oesophageal collected *A. nummularia* (Hatfield Select) material is discussed. Special attention is given to the CP, NDF and IVDOM content of this material.

4.3.1.1 Crude protein

The CP concentration of *A. nummularia* (Hatfield Select) edible plant material selected by sheep and goats during five days is illustrated in Table 4.1.

Table 4.1 The %CP of oesophageal samples, selected by goats and sheep browsing *Atriplex nummularia* (Hatfield Select) (DM-basis)

	Goat	Sheep
Day 1	18.0 ^a ₁ (± 4.30)	19.9 ^a ₁ (± 2.56)
Day 3	16.0 ^a ₁ (± 5.98)	19.6 ^a ₁ (± 2.28)
Day 5	3.9 ^b ₁ (± 3.51)	6.6 ^b ₁ (± 4.77)

*Different superscript letters within a column indicates significant difference between days (P =0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P =0.05)

*Values in brackets represent the standard deviation

In general there was no significant difference in CP selected by goats and sheep during any of the three days. In contrast to our hypothesis, however, that goats would select a higher quality diet, sheep selected a diet higher in CP than goats. This tendency was noted on all three days.

Masson *et al.* (1989) (as cited by EAAP, 1991) did a comparative chemical composition of forage offered and the oesophageal contents between goats and sheep. These authors reported a higher CP concentrations in the oesophageal collected plant material in sheep than in goats. The two species were fed on alfalfa hay with an average CP concentration of 16.2 %. The sheep selected a CP concentration of 16.8 % and the goats of 15.8 %. The same was observed when wheat straw with an average CP concentration of 13.4 % was fed, with

goats selecting a CP concentration of 9.5 % and sheep a CP of 13.3 %. This confirms the tendency from the current study where oesophageal samples of *A. nummularia* (Hatfield Select) selected by sheep had a higher CP concentration than that selected by goats. This is illustrated in Table 4.1. This finding is also contrary to the hypothesis stated in the beginning of this chapter.

Within animal species, there was a significant difference in CP selected over time of *A. nummularia* plant material. For goats there was no significant difference in CP selected during day 1 and day 3, but the CP in material selected on day 5 was significant lower than day 1 and 3. The exact same trend was found for sheep selecting a significantly lower CP on day 5 than on days 1 and 3. The CP value of selected material during day 5 was much lower than the material selected during day 1 and 3. This much lower CP value for selected material during day 5 is because of a shortage in edible material available and not necessarily because of selection. It was the only material available to the animals.

Sparks *et al.* (2003) also noted a decrease in the CP concentration, of oesophageal material collected from *A. nummularia*, towards the end of the grazing period. In that study, CP concentration decreased from 10.2 % CP to 6.3 % CP and 21.1 % CP to 15.9 % CP from the start to the end of the grazing period. In the current study the CP concentration of selected material decreased from 19.9% to 6.6 % CP for sheep and from 18.0 % to 3.9 % CP for goats from the start (day 1) to the end (day 5) of the grazing period. Animals in the current study exhibited a much larger decline in CP % selected than the animals in the study of Sparks *et al.* (2003), but this could be related to the degree of utilization in the respective studies.

When the CP level of grazing drops below 6-8 %, appetite is suppressed and pasture intake by the animal is reduced (Minson, 1982 as quoted by Sparks *et al.*, 2003). From Table 4.1, the CP concentrations on day 1 and 3 were well

above this 6-8 % CP range. By day 5 the CP concentration of diets selected by both goats and sheep were beneath this CP range. This could explain part of the low intakes observed at day 5 and will be discussed later.

4.3.1.2 Neutral detergent fibre

The NDF concentration of *A. nummularia* (Hatfield Select) plant material selected by goats and sheep on three days is presented in Table 4.2.

Table 4.2 The % NDF of oesophageally collected samples between goats and sheep browsing *Atriplex nummularia* (Hatfield Select) (DM-basis)

	Goat	Sheep
Day 1	55.4 ^a ₁ (± 11.31)	47.4 ^a ₁ (± 4.33)
Day 3	60.1 ^a ₁ (± 16.99)	48.5 ^a ₁ (± 3.98)
Day 5	66.2 ^a ₁ (± 10.70)	53.1 ^a ₁ (± 19.06)

*Different superscript letters within a column indicates significant difference between days (P =0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P =0.05)

*Values in brackets represents the standard deviation

It is noted from Table 4.2 that there were no significant differences in the NDF concentration of the selected plant material between goats and sheep. Against expectations, sheep selected plant material with a lower NDF value than goats, though not significant. This tendency for sheep to select plant material with lower NDF values was noted on all three days. This means that goats were less selective and most probably consumed more stem material than sheep.

Alcaide *et al.* (1997) reported that goats had a lower daily intake of NDF but a higher intake of $\text{NDF}/W^{0.75}$ than sheep on a low quality pasture from a semi-arid land. By converting the data of this author to concentrations, goats selected plant material with 51.6 % NDF (OM-basis) while sheep selected material with 55.84 % NDF (OM-basis). In the current study, the opposite were found, with goats selecting material of a higher NDF concentration.

When the samples collected are compared to each other in terms of NDF value selected by the two species, no significant differences were noted between the three days of collection. Both animal species initially selected plant material of lower NDF during Day 1. As time progressed, NDF value of material collected increased on Days 3 and 5. This increase in NDF value of sampled material over time, is because of a decrease in availability of low NDF edible material and an increase in the stem:leaf ratio. This forces the animals to consume plant material of a lower quality.

Sparks *et al.* (2003) noted a decrease in the NDF concentration of oesophageal material collected from *A. nummularia* plant material from the start to the end of a 50% defoliation grazing trial. This decrease in NDF concentration could not, however, be explained. During a 100% defoliation trial, an increase in the NDF was noted from the start to the end. This increase in NDF concentration was, however, not significant. Increases of between 44.3% to 57.2% and 41.8% to 48.4% were noted from the start to the end of this grazing treatment. The increase in NDF concentration in diets selected by sheep in the current study compares to the increases noted by Sparks *et al.* (2003), but diets selected by goats were higher.

Van Niekerk (1997) also illustrated this increase in NDF concentrations in selected materials from the start to the end of a grazing period. This author reported significant increases of NDF concentrations of oesophageal selected samples of *Digitaria eriantha* (Smuts finger grass) and *Medicago sativa* (alfalfa). NDF concentration increased from 59.0% to 61.1% for *D. eriantha* and from 36.9% to 42.6% for *M. sativa*. The values of *D. eriantha* compare well to the values of Table 4.2. although, these are two totally different species that are being compared.

4.3.1.3 *In vitro* digestible organic matter

In Table 4.3 the chemical analyses for the IVDOM of edible material of *A. nummularia* (Hatfield Select), selected by goats and sheep over five days, is presented.

Table 4.3 The %IVDOM of oesophageally selected samples between goats and sheep browsing *Atriplex nummularia* (Hatfield Select) (DM-basis)

	Goat	Sheep
Day 1	59.6 ^a ₁ (± 8.43)	66.4 ^a ₁ (± 10.94)
Day 3	48.4 ^a ₁ (± 16.31)	59.3 ^a ₁ (± 5.18)
Day 5	44.9 ^a ₁ (± 13.14)	52.4 ^a ₁ (± 11.71)

*Different superscript letters within a column indicates significant difference between days (P =0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P =0.05)

*Values in brackets represent the standard deviation

From Table 4.3 no significant differences in the IVDOM of plant material can be reported between goats and sheep for any of the three days on which oesophageal samples were taken. On all three days, sheep selected, on average, a much higher quality plant material, with a higher IVDOM. This tendency has already been evident in Tables 4.1 and 4.2. In Table 4.2 the sheep selected plant material of a lower NDF concentration than goats. NDF concentration is negatively correlated to digestibility (Reid *et al.*, 1988), thus a selection of higher IVDOM could have been foreseen.

In a study by Louca *et al.* (1982), sheep selected a diet with a higher apparent digestibility than that selected by goats, when fed the same diet. For alfalfa hay consisting of 23.1% CP and 24.1% CF, sheep had a 68.6% apparent digestibility and goats 67.4%. This tendency was also noticed for both barley hay and barley straw. One can assume that the animals were still able to select from these diets fed to them. This difference is the apparent digestibility of DM and can't be compared to Table 4.3, but it gives an illustration that goats selected less

digestible material than sheep. This tendency was also noticed in the current study where sheep selected *A. nummularia* (Hatfield Select) plant material with a non-significant higher IVDOM concentration than that selected by goats.

Within both animal species, there was a tendency to initially select a higher quality diet, with the quality and thus the IVDOM content decreasing towards Day five. For both goats and sheep, the material selected on Day 1 was much higher in IVDOM concentration than Day 3 and 5. There were, however, no significant differences, in IVDOM concentration, between Days 1, 3 and 5. The reason for this is most likely due to animal factors affecting selection of plant material causing large variation between samples. The much lower IVDOM content of plant material at the end of the grazing period, was due to a restriction in the availability of high quality grazeable material. By Day 5 most of the edible leaf material had already been removed. This caused the selection of a diet high in fibre, high NDF (Table 4.2) and low IVDOM (Table 4.3). The higher NDF and lower IVDOM concentration coincides with the finding by Reid *et al.* (1988) that the NDF concentration is negatively correlated with digestibility.

Sparks *et al.* (2003) reported that as with the NDF concentrations, IVDOM of oesophageal *A. nummularia* samples increased from the start to the end of the 50% defoliation grazing period. A decrease in IVDOM concentration was, however, noted in the 100% defoliation grazing period. This decrease in IVDOM concentration was not significant except for one period. During this period the IVDOM concentration decreased from 52.4% at the start of grazing to 43.5% at the end of the period. Starting IVDOM concentrations, in the current study, were higher than those reported by Sparks *et al.* (2003), even though NDF concentrations in the current study were higher than those observed by Sparks *et al.* (2003). The end (Day 5) IVDOM concentrations in the current study compared well with the end IVDOM concentrations of Sparks *et al.* (2003).

Chriyaa *et al.* (1997) reported an IVDMD of 62.2% for *A. nummularia* harvested by hand. This could not be compared to Table 4.3, because it represents the DM digestibility, but it is of interest. Abou El Nasr *et al.* (1996) reported an apparent DM digestibility of 62.6%, while Weston *et al.* (1970) reported IVDMD for *A. nummularia* of 60.8%, which compares to the IVDOM values reported in Table 4.3.

Van Niekerk (1997) reported significantly lower IVDOM concentrations for *D. eriantha* and *M. sativa* at the end of the grazing period than at the start. Van Niekerk (1997) reported a decrease in IVDOM between 69.6% and 61.5% for *D. eriantha* and 66.3% to 63.7% for *M. sativa*. The initial IVDOM concentration of *M. sativa* compared to the IVDOM concentration of *A. nummularia* for sheep in Table 4.3. The IVDOM concentration at the end (day 5) of the grazing period in Table 4.3. was much lower than the IVDOM of either of the two species mentioned above. This could be because of a much lower availability of edible material at the end of the current study. This is a comparison between three totally different species, which should not be compared to each other. This comparison does, however, illustrate the tendency of IVDOM to decrease from the start to the end of a grazing period.

4.3.2 Quantitative intake

In this section the quantity of *A. nummularia* (Hatfield Select) consumed by goats and sheep over a five day grazing period is compared. Special attention is given to OMI, DOMI and DOMI/kgW^{0.75}.

Meissner *et al.* (1989) stated that the relationship between NDF and intake is more pronounced than the relationship between IVDOM and intake. This author stated that NDF is related to bulk density of forages which is negatively associated with intake and that NDF includes those components which have the slowest rate of clearance from the rumen.

4.3.2.1 Organic matter intake

The OMI of goats and sheep grazing *A. nummularia* (Hatfield Select) is compared between animal species and day of grazing, in Table 4.4.

Table 4.4 The OMI (g/day) of goats and sheep browsing *Atriplex nummularia* (Hatfield Select) (DM-basis)

	Goat	Sheep
Day 1	525.6 ^a ₁ (±201.59)	482.4 ^a ₁ (± 277.04)
Day 3	435.8 ^a ₁ (± 99.14)	442.6 ^a ₁ (± 186.33)
Day 5	431.7 ^a ₁ (± 113.40)	275.6 ^a ₁ (± 112.88)

*Different superscript letters within a column indicates significant difference between days (P=0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P=0.05)

*Values in brackets represent the standard deviation

From Table 4.4 it tends that a higher OMI for day 1 and 5 can be reported for goats than for sheep, while a slightly higher OMI can be reported for sheep during day 3. There were, however, no significant differences in OMI between goats and sheep for any of the three days. Taking into consideration Table 4.2, sheep should have had a higher OMI than goats. This is because NDF concentration is negatively correlated to intake (Abou El Nasr *et al.*, 1996). A higher NDF concentration in the diet, as noted for goats, normally correlates to a lower passage rate of feed particles in the rumen and thus a lower intake (Meissner *et al.*, 1989).

There were no significant differences in OMI for either of the two animal species between Days 1, 3 and 5. There was, however, a tendency in both animal species for OMI to decline from Day 1 to Day 3 and Day 5. The OMI decreased by almost 100 g/day for goats between Day 1 and 3. The OMI between Day 3 and 5 was more or less the same. For sheep, OMI decreased with approximately 40 g/day from Day 1 to Day 3. From Day 3 to 5 OMI in sheep decreased 167 g/day. This decrease in OMI, as mentioned above, is because of a decrease in

the amount of available grazing material and an increase in the fibre content of the available edible material. It is interesting to note that OMI in goats decreased after the first day to Day 3 of grazing, while the OMI of sheep decreased at Day 5. It is also interesting to note that the OMI of sheep eventually decreased to a level of 165 g/d lower than goats on Day 5. This could be due to the ability of goats to browse the last leaves between the branches where the sheep could not reach, but this is purely speculative. Another possible reason for the higher intake by goats, on Day 5, could be a higher cellulolytic activity in the rumens of the goats than sheep (Van Soest, 1982). This could cause higher fibre digestion of goats and thus a higher passage rate. Huston (1978) also noticed a higher passage rate of stained feed particles in goats than in sheep, fed on low-quality roughage. This higher passage rate could have caused a higher intake on this high fibre diet on Day 5 by goats.

Sparks *et al.* (2003) reported a decrease in OMI (g/day) of *A. nummularia* between the start and the end of a grazing period. This difference was not significant, but did illustrate the tendency. During some periods of the 50% defoliation treatment, Sparks *et al.* (2003) reported an increase in OMI. Decreases in OMI of between 1101 g/day to 996g/day and 1802 g/day to 1304 g/day were noted between the start and the end of the grazing period. These OMI's reported by Sparks *et al.* (2003) were much higher than the OMI of the current study. Except for the slightly higher NDF (bulky) concentration, animal factors and possible environmental conditions, this difference cannot be explained.

Wilson (1977) on the other hand reported an intake of 432 g/day for sheep which were fed *A. nummularia* leaf material. This low intake compared to the low intakes of Table 4.4. Nutritionally these intakes can't be compared because Wilson (1977) fed leaf material to the animals and the animals were not allowed to graze this material. Weston *et al.* (1970) reported an OMI of 510 g/day for sheep which compares to OMI in Table 4.4 during day 1. This OMI was obtained

by feeding sheep in metabolism cages and should not be compared to the OMI of free grazing animals.

Van Niekerk (1997) reported a significant decrease in OMI (g/day) for sheep grazing *D. eriantha* and *M. sativa* between the start and end of the grazing period. This author reported decreases in OMI of 860 g/day to 674 g/day for *D. eriantha* and 918 g/day to 784 g/day for *M. sativa*. These OMI's were also higher than those reported in the current study. This is not a comparison between species, but it illustrates the decrease in OMI over time within a grazing period.

4.3.2.2 Digestible organic matter intake

Table 4.5 illustrates the DOMI of *A. nummularia* (Hatfield Select) between goats and sheep over a five day period (DM-basis)

Table 4.5 DOMI (g/day) of goats and sheep browsing *Atriplex nummularia* (Hatfield Select)

	Goat	Sheep
Day 1	321.5 ^a ₁ (± 159.32)	339.8 ^a ₁ (± 217.77)
Day 3	220.5 ^a ₁ (± 123.53)	266.4 ^a ₁ (± 120.71)
Day 5	184.5 ^a ₁ (± 10.54)	150.5 ^a ₁ (± 89.44)

*Different superscript letters within a column indicates significant difference between days (P=0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P=0.05)

*Values in brackets represent the standard deviation

There were no significant differences in the DOMI of *A. nummularia* (Hatfield Select), between goats and sheep, for any of the three days on which DOMI was determined. During Day 1 and 3, sheep showed a slightly higher DOMI where-as on Day 5 goats showed a slightly higher DOMI than sheep. This difference in DOMI was not of any significance due to large variation in DOMI between animals of the same species. From Table 4.4 it is noted that goats have a larger OMI, but in Table 4.5 a smaller DOMI is observed for goats than for sheep. This is because of the higher IVDOM selected by sheep than by goats.

This higher DOMI by sheep is in contrast to the results of Domingue *et al.* (1991), who reported that goats had higher rumen ammonia concentrations than sheep, when fed on low quality roughages. Alam *et al.* (1983) concluded that this was why goats had a higher DOMI when offered diets with OM digestibilities lower than 60%. Tan *et al.* (1987) showed that this higher DOMI and rumen NH₃-N of goats was not associated to a higher rate of digestion in the rumen, when fed on a low quality forage.

From Table 4.5 there were no significant differences in DOMI of *A. nummularia* (Hatfield Select) between the three days of evaluation within each animal species. Within goats, there was a decrease of approximately 100 g DOMI from Day 1 to Day 3. From Day 3 to 5 DOMI decreased further with approximately 36 g. Within sheep, a 73 g decrease in DOMI was noticed between Day 1 and 3. From Day 3 to 5 an 116 g decrease was noticed. This same tendency was noticed for OMI where goats had a sudden drop in intake shortly after initiation of grazing, while sheep decreased intake at the end of the grazing period.

Van Niekerk (1997) noted a significant difference in the DOMI between the start and the end of the grazing period of both *D. eriantha* and *M. sativa*. This author reported DOMI decreases of 612 g/day to 421 g/day for *D. eriantha* and 620 g/day to 512 g/day for *M. sativa*. This confirms the tendency, noted in Table 4.5, for the DOMI to decrease over grazing period as the availability and quality of grazing material declines.

4.3.2.3 Digestible organic matter intake per metabolic live weight

The DOMI/kg W^{0.75} of goats and sheep grazing on *A. nummularia* (Hatfield Select) is compared in Table 4.6. This was measured on three days over a five-day grazing period.

Table 4.6 The DOMI/kg $W^{0.75}$ (g/day) of goats and sheep browsing *Atriplex nummularia* (Hatfield Select)

	Goat	Sheep
Day 1	21.8 ^a ₁ (± 11.89)	15.5 ^a ₁ (± 9.72)
Day 3	14.2 ^a ₁ (± 5.58)	12.3 ^a ₁ (± 5.31)
Day 5	12.4 ^a ₁ (± 1.06)	7.1 ^a ₁ (± 4.19)

*Different superscript letters within a column indicates significant difference between days (P=0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P=0.05)

*Values in brackets represent the standard deviation

Between goats and sheep there were no significant differences in the DOMI/kg $W^{0.75}$. Goats did, however, have a higher DOMI/kg $W^{0.75}$ during all three days of evaluation, even though goats had a lower DOMI in Table 4.5. Because the body weight have such a large influence on DOMI/kg $W^{0.75}$, the higher DOMI/kg $W^{0.75}$ for goats than sheep could be due to a much lower body weight of goats than sheep, but more or less the same DOMI. During Day 1 sheep had a non-significant lower DOMI/kg $W^{0.75}$ than goats. The goats sustained their body weight at 37 kg from the start to the end of the grazing period. The sheep, however, recorded an average loss of 1.5 kg over the same period, going from 60 kg to 58.5 kg from the start to the end of the grazing trial. This decrease in body weight of sheep could have had an influence on DOMI/kg $W^{0.75}$.

In a study by Louca *et al.* (1982), the quantities ingested (g DM/kg $W^{0.75}$) by goats were higher than those ingested by sheep. In a diet of alfalfa hay containing 23.1% CP and 24.1% CF, these authors reported DM intakes of 67.8 g/kg $W^{0.75}$ for goats and 67.0 g/kg $W^{0.75}$ for sheep. This tendency was also noted for barley hay, containing 9.8% CP and 31.4% CF, where intakes of 48.4 g/kg $W^{0.75}$ and 45.1 g/kg $W^{0.75}$ were recorded for goats and sheep respectively. These data by Louca *et al.* (1982) also demonstrates higher intakes per metabolic weight for goats than for sheep. Higher DOMI/kg $W^{0.75}$ were also noted for goats utilizing *A. nummularia* (Hatfield Select) in the current study (Table 4.6). The

higher DOMI/kg $W^{0.75}$ could be because of the larger rumen volume of goats than sheep (EAAP, 1991).

Within each animal species, DOMI/kg $W^{0.75}$ decreased from Day 1 to Day 5. There were no significant differences in DOMI/kg $W^{0.75}$ between the different days, due to variation within the animal species, but the tendency was noticeable. The low DOMI/kg $W^{0.75}$ on Day 5 was because of the low availability of edible plant material at the end of the grazing period.

Sparks *et al.* (2003) reported a non-significant decline in the DOMI/kg $W^{0.75}$ /day between the start and the end of a 100% defoliation grazing period. These authors reported declines in DOMI/kg $W^{0.75}$ from 24 g/day to 19 g/day and 37 g/day to 16 g/day for sheep grazing *A. nummularia* to 50 or 100% defoliation respectively. These intakes are slightly higher than the intakes illustrated in Table 4.6. The reason for this difference in intake between these two studies could be because of different grazing pressures and the amount of selection taking place.

Van Niekerk (1997) reported a significant decrease in DOMI/kg $W^{0.75}$ between the start and end of several grazing trials. This author reported DOMI/kg $W^{0.75}$ declines of 46.4 g/day to 29.7 g/day for *D. eriantha* and 44.2 g/day to 32.6 g/day for *M. sativa*. These intakes are much higher than the intakes noted for sheep and goats in Table 4.6. This proves the tendency for DOMI/kg $W^{0.75}$ to decrease over the grazing period due to a decrease in availability in high quality grazing material. This tendency was also noticeable in the current study.

4.3.3 Rumen parameters of qualitative intake

In this section some rumen parameters will be compared between goats and sheep grazing *A. nummularia* (Hatfield Select). Rumen parameters at three different stages of the grazing period will also be compared. Attention will be given to rumen NH_3 -N and the three most important VFA (acetic-, propionic- and butyric acid).

4.3.3.1 Rumen ammonia nitrogen

“Food proteins are hydrolysed to peptides and amino acids by rumen micro organisms, but some amino acids are degraded further to organic acids, ammonia and carbon dioxide. The ammonia produced, together with some small peptides and free amino acids, is utilised by the rumen organisms to synthesize microbial proteins” (McDonald *et al.*, 1995).

“The ammonia in rumen liquor is the key intermediate in the microbial degradation and synthesis of protein. If the diet is deficient in protein, or if the proteins resist degradation, the concentration of rumen ammonia will be low (5 mg/100ml) and the growth of rumen organisms will be slow. In consequence, the breakdown of carbohydrates will be retarded. On the other hand, if protein degradation proceeds more rapidly than synthesis, ammonia will accumulate in rumen liquor and the optimum concentration will be exceeded. When this happens, ammonia is absorbed into the blood, carried to the liver and converted to urea of which the greater part is excreted via the urine. Estimates on the optimum concentration of ammonia in the rumen liquor vary widely, from 8.5 to over 30 mg/100ml rumen fluid” (McDonald *et al.*, 1995).

The rumen NH₃-N concentrations of goats and sheep, grazing on *A. nummularia* (Hatfield Select), are compared in Table 4.7. Table 4.7 also compares the rumen NH₃-N concentrations at three time intervals of a five day grazing period.

Table 4.7 Rumen ammonia concentration (mg NH₃-N / 100ml rumen fluid) of goats and sheep browsing *A. nummularia* (Hatfield Select)

	Goat	Sheep
Day 1	9.17 ^a ₁ (±1.87)	11.89 ^a ₁ (±4.27)
Day 3	12.02 ^a ₁ (±3.79)	13.41 ^a ₁ (±1.71)
Day 5	8.26 ^a ₁ (±1.38)	10.64 ^a ₁ (±3.52)

*Different superscript letters within a column indicates significant difference between days (P=0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P=0.05)

*Values in brackets represent the standard deviation

In a comparison of goats and sheep, the rumen NH₃-N concentrations of goats were lower than those of sheep during the experimental period. This difference was not significant, but it does indicate a tendency for sheep to have a higher rumen NH₃-N concentration on *A. nummularia*. This lower rumen NH₃-N concentration of goats confirms the lower CP concentration in *A. nummularia* (Hatfield Select) selected by goats in Section 4.3.1.1. A CP concentration of diet-selected material is not, however, a direct indication of rumen NH₃-N, because the rumen NH₃-N concentration also depends on the rate of degradation of that CP in the rumen. This is described above. If the extent and rate of degradation and the microbial activity in the rumen were the same for goats and sheep, dietary CP would have been a good indication of rumen NH₃-N.

Dominique *et al.* (1991) noted that the rumen ammonia concentration of goats was higher than that of sheep on low quality roughage. This was not seen in the current study where sheep had a non-significant higher rumen NH₃-N concentration than goats.

From the results in Table 4.7, we could assume a higher rate of N degradation for sheep than goats because of the higher rumen NH₃-N concentrations in sheep. This was, however, not true in this study. Table 2.8 illustrates the rate of N (CP) degradation, for hand harvested edible *A. nummularia* (Hatfield Select)

material, between goats and sheep. Sheep had a non-significant lower rate of N degradation. This could leave us with only one explanation for the higher rumen $\text{NH}_3\text{-N}$ concentration of sheep. Sheep most likely had a rate of rumen microbe synthesis, which was lower than in goats, causing a less efficient utilization of rumen $\text{NH}_3\text{-N}$ by sheep. Therefore, sheep had a slightly higher accumulation of rumen $\text{NH}_3\text{-N}$ in the rumen and thus higher rumen $\text{NH}_3\text{-N}$ concentrations.

Comparing the rumen $\text{NH}_3\text{-N}$ concentrations of sheep and goats at three different time intervals, Table 4.7 indicates that there were no significant differences between either of the three days within each animal species. A strange phenomenon can be seen in Table 4.7. The rumen $\text{NH}_3\text{-N}$ concentrations of Day 3 is higher than Day 1. This goes against expectations, for the rumen $\text{NH}_3\text{-N}$ concentration to decline as the grazing period progresses. The rumen $\text{NH}_3\text{-N}$ concentration is, however, the lowest at Day 5, which supports the hypothesis. This low rumen $\text{NH}_3\text{-N}$ concentration on Day 5 is because of a low availability of available dietary CP as well as the low intakes. A possible explanation for this phenomenon could be that there was a difference in the type of "CP" selected during Days 1 and 3. As can be seen in Table 4.1, the CP concentrations of the plant material selected during Days 1 and 3 was more or less the same, with Day 3 being only slightly lower than Day 1. During Day 1 the animals possibly selected plant material with a higher proportion of undegradable protein leading to lower rumen $\text{NH}_3\text{-N}$ concentrations. By Day 3, the material left to select from, which had a CP concentration not much lower than Day 1, had a higher degradability of CP and thus the higher rumen $\text{NH}_3\text{-N}$ concentrations. Another explanation could be that the rumen environment was not favourable for the rumen micro-organisms on Day 3. This could then have caused low utilization of $\text{NH}_3\text{-N}$ for microbial synthesis and thus accumulation of $\text{NH}_3\text{-N}$ in the rumen.

Weston *et al.* (1970) reported a 20.1 g N per day intake in Merino wethers fed *A. nummularia*. Of this 20.1 g N, 18.1 g N left the rumen daily. The quantity of N leaving the rumen in the form of ammonia was 3.6 g N daily, thus the quantity of

N leaving the rumen in the form of NAN was 14.5 g daily. The equivalent of 72% of dietary N left the rumen in the form of NAN. The loss of dietary N during the passage of digesta through the rumen, presumably due to the microbial deamination of dietary nitrogenous substances, was reflected by the presence of significant quantities of ammonia in the rumen. The rumen ammonia concentration was 27 mg N/100ml of rumen fluid. An overall digestibility of dietary N of 75.8% was reported. The rumen NH₃-N concentration of this study was significantly higher than that reported in the current study.

Van Niekerk (1997) reported rumen NH₃-N concentrations of 10.9 and 18.7 gN/100 ml of rumen fluid for *D. eriantha* and *M. sativa* respectively. Although an N concentration of only 1.9% (11.88% CP) for *D. eriantha* was reported, the rumen NH₃-N concentration compares well to that of *A. nummularia* (Hatfield Select) with a CP concentration of 18-20% as selected by goats and sheep. This is probably due to a high N loss in the form of NAN as described by Weston *et al.* (1970).

Satter and Roffler (1977) (as cited by Van Niekerk, 1997) stated that the micro organism's activity can be suppressed by rumen NH₃-N concentrations lower than 5 mg/100 ml. None of the rumen NH₃-N concentrations in the current study reached this minimum level and it can be assumed that rumen microbe activity was not detrimentally affected by rumen NH₃-N concentrations. The rumen NH₃-N concentrations were also not high enough to have a negative influence on animal performance. High levels of rumen NH₃-N concentration, need much more energy to be absorbed and transformed to urea, which depletes the body's energy reserve and thus have a negative influence on animal performance (Satter and Roffler, 1977, as cited by Van Niekerk, 1997).

McDonald *et al.* (1995) stated that if the diet is deficient in protein, or if the protein resists degradation, the concentration of rumen ammonia will be low (5 mg/100ml). In the current study, the rumen NH₃-N concentration never dropped

this low with either goats or sheep. This means that dietary protein and rumen protein degradation was sufficient to obtain microbial activity and carbohydrate breakdown in the rumen. These authors also stated that the optimum concentration of ammonia in the rumen liquor vary widely, from 8.5 to over 30 mg/100 ml. In the current study, rumen $\text{NH}_3\text{-N}$ concentrations were within these boundaries for both goats and sheep, for the whole duration of the grazing period except for goats on Day 5. On Day 5, goats had a rumen $\text{NH}_3\text{-N}$ concentration of 8.26 mg/100 ml. This is not much under the lower boundary of 8.5 mg/100 ml, but it could mean that dietary protein degradation was slightly slower than rumen microbial protein synthesis for goats on Day 5.

4.3.3.2 Rumen volatile fatty acids

Acetic-, propionic- and butyric acids are the end products of aerobic fermentation of forage in the rumen. These VFA's are the form in which most of the energy from forages is absorbed. There will be a decline in the effectivity in which metabolisable energy is used for production if the proportion of propionic acid declines. Acetic- and butyric acid can only be used for growth if there is enough propionic acid or glucose (Hovell and Greenhalgh, 1978; as cited by Van Niekerk, 1997).

“The relative concentrations of the VFA's are often assumed to represent their relative rates of production, but this may be misleading if the individual VFA's are absorbed at different rates. Their total concentration varies widely according to the animal's diet and the time that has elapsed since the previous meal, but is normally in the range of 7-15 mmol/100 ml. The relative proportion of the different acids also varies. Mature fibrous forages give rise to VFA mixtures containing a high proportion (70%) of acetic acid. Less mature forages tend to give a rather lower proportion of acetic acid and a higher proportion of propionic acid. Grinding and pelleting of forages has little effect on the VFA proportions, when the diet consists of forage alone, but causes a switch from acetic to propionic acid when

the diet also contains concentrates. The concentration of butyric acid is less affected by diet than are acetic and propionic acid” (McDonald *et al.*, 1995).

McDonald *et al.* (1995) stated that the absorption of VFA from the rumen could serve as a chemostatic mechanism of food intake. Intra-ruminal infusions of acetate and propionate have been shown to depress intake of concentrate diets by ruminants. Butyrate seems to have less of an effect on intake than acetate and propionate. It is stated that with diets consisting mainly of roughage, VFA's have a less definite effect on food intake. Thus, we can assume that in the current study, VFA did not have a significant influence on intake.

Table 4.8 illustrates the rumen acetic acid concentrations between goats and sheep grazing *A. nummularia* (Hatfield Select). This Table also compares the three days on which the rumen samples were collected.

Table 4.8 Rumen fluid acetic acid concentration (mmol/100 ml) of goats and sheep browsing *Atriplex nummularia* (Hatfield Select)

	Goat	Sheep
Day 1	3.85 ^a ₁ (±1.56)	3.73 ^a ₁ (±1.97)
Day 3	4.51 ^a ₁ (±0.49)	4.68 ^a ₁ (±0.71)
Day 5	4.19 ^a ₁ (±0.46)	2.82 ^a ₁ (±0.52)

*Different superscript letters within a column indicates significant difference between days (P=0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P=0.05)

*Values in brackets represent the standard deviation

In a comparison of goats and sheep, there were no significant differences in rumen acetic acid concentration. During Days 1 and 3 the rumen acetic acid concentration in the two species were similar. On Day 5, however, the rumen acetic acid concentration of sheep was almost two thirds that of goats. This lower rumen acetic acid concentration in sheep on Day 5 is an indication that under the

trial conditions, sheep selected a diet lower in fibre. This can be seen in Table 4.2 where sheep exhibited an insignificantly lower NDF and a lower DOMI than goats. Goats may also have a higher cellulolytic activity in the rumen (Van Soest, 1982), which may contribute to the higher acetic acid concentrations in goats than in sheep. This could also be an indication of the lower DOMI /kg $W^{0.75}$ of sheep on day 5. The lower acetic acid in the rumen fluid could thus be because of the lower total amount of fibre in the diet, which leads to less fibre being digested and thus less acetic acid in the rumen of sheep.

By comparing the different days of sample collection within each species, there was no significant difference in the rumen acetic acid concentration. Within both goats and sheep, the rumen acetic acid concentrations increased from Day 1 to 3. This is because of a combination of an increase in the fibre content of the diet leading to higher acetic acid concentrations and a higher rumen microbe activity as can be seen by the higher NH_3 -N concentration (Table 4.7). From Day 3 to 5, there was, however, a decline in rumen acetic acid concentration. The reason for this is unknown, since the fibre content of the diet increased towards Day 5, as can be seen in Table 4.2 This lower rumen acetic acid concentration on Day five is in contrast to all literature that the rumen acetic acid concentration will increase with an increase in fibre in the diet (McDonald *et al.*, 1995). It could be because of the low intakes on Day 5 allowing too low total fibre to be digested and thus less total rumen acetic acid produced. This lower amount of acetic acid is then partly diluted to a greater extent than usual by the rumen fluid. This dilution results then in a lower rumen acetic acid concentration. This could only be true if the amount of rumen fluid is not directly proportional to intake. The decline in the NH_3 -N (Table 4.7) can also contribute to the lower rumen acetic acid concentration. This lower NH_3 -N indicates a lower rumen microbial activity, which will have a negative effect on the digestion of fibre in the rumen. This negative effect on rumen fibre digestion will cause a decline in the amount of acetic acid produced and thus a lower rumen acetic acid concentration.

No data on the VFA composition of *Atriplex* species could be obtained. A comparison will thus be made with other forage species.

Van Niekerk (1997) reported rumen acetic acid concentrations of 8.5 and 13.8 mmole/100 ml of rumen fluid for *D. eriantha* and *M. sativa* respectively. These values are much higher than those reported in the current study. The higher rumen acetic acid concentrations for *D. eriantha* and *M. sativa* are not due to a higher fibre concentration but rather due to higher fibre digestion.

From Table 2.9, a high rumen degradability of the cell wall fraction (NDF) for *A. nummularia* (Hatfield Select) can be observed. This high NDF degradation indicates a high fibre digestion, which should cause high rumen acetic acid concentrations. Table 2.10 illustrates high rates of NDF degradation. With such high degradation rates, acetic acid should be produced at a faster rate than at which it can be absorbed by the rumen. This will cause a slight accumulation of acetic acid in the rumen and thus a higher rumen acetic acid concentration. With the extent and rate of NDF degradation in mind, the rumen acetic acid concentration in the current study should have been much higher. The only explanation for the low acetic acid production in the current study could be a less favorable rumen environment on a *A. nummularia* (Hatfield select) pasture than on the milled *M. sativa* hay in the degradability study.

Table 4.9 illustrates a comparison of the rumen propionic acid concentrations in goats and sheep grazing *A. nummularia* (Hatfield Select). This table also illustrates the effect of time of sampling over a five day grazing period.

Table 4.9 Rumen propionic acid concentrations (mmol/100ml) in goats and sheep browsing *Atriplex nummularia* (Hatfield Select)

	Goat	Sheep
Day 1	0.97 ^a ₁ (0.40±)	0.98 ^a ₁ (±0.70)
Day 3	0.95 ^a ₁ (±0.10)	1.04 ^a ₁ (±0.22)
Day 5	0.85 ^a ₁ (±0.11)	0.51 ^a ₁ (±0.11)

*Different superscript letters within a column indicates significant difference between days (P=0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P=0.05)

*Values in brackets represent the standard deviation

Between goats and sheep there were no significant differences in the rumen propionic acid concentrations. Comparing goats and sheep on Days 1 and 3, there was not much difference in rumen propionic acid concentration between these two animal species. Sheep did, however, had a slightly higher rumen propionic acid concentration. On Day 5, goats had a nonsignificant higher rumen propionic acid concentration than sheep. The reason for this relatively lower rumen propionic acid concentration in sheep on Day 5 is probably due to the dilution effect of intake discussed previously.

In a comparison of the different days, there were no significant differences in rumen propionic acid concentrations between these days. For both animal species, there was a tendency for the rumen propionic acid concentrations to decline as the grazing period progressed. This is because of an increase in the proportion of fibre that has been consumed as the grazing period progressed, as illustrated in Table 4.2. This increase in proportional fibre consumption leads to an increase in acetic acid production as mentioned and a decrease in the amount of propionic acid produced. Days 1 and 3 for both animal species had more or less the same rumen propionic acid concentration. Towards Day 5, rumen propionic acid concentration showed a relative decrease. From Day 3 to 5 for sheep, the rumen propionic acid concentration more than halved. No explanation can be given for this sudden drop in rumen propionic acid concentration for

sheep on Day 5, except for the increase in NDF concentration and the low intake causing lower total propionic acid produced and thus lower rumen propionic acid concentration as discussed for acetic acid. The decrease in propionic acid concentration is in agreement with the literature, that the propionic acid concentration declines, and acetic acid concentration increases, with an increase in the fibre component of the diet (EAAP, 1991; McDonald *et al.*, 1995).

Van Niekerk (1997) reported rumen propionic acid concentrations of 2.3 and 4.7 mmole/100ml of rumen fluid for *D. eriantha* and *M. sativa* respectively. This is much higher than those reported for *A. nummularia* (Hatfield Select) in Table 4.9. These low concentrations of rumen propionic acid concentration can only be explained by the low intakes of the current study causing lower total propionic acid production and thus a lower rumen propionic acid concentration.

Table 4.10 illustrates a comparison of the rumen butyric acid concentrations between goats and sheep grazing *A. nummularia* (Hatfield Select). This Table also illustrates the effect of time on the rumen butyric acid concentration.

Table 4.10 Rumen butyric acid concentrations (mmol/100ml) in goats and sheep browsing *Atriplex nummularia* (Hatfield Select)

	Goat	Sheep
Day 1	0.47 ^a ₁ (±0.184)	0.47 ^{ab} ₁ (±0.14)
Day 3	0.49 ^a ₁ (±0.07)	0.60 ^a ₁ (±0.14)
Day 5	0.51 ^a ₁ (±0.07)	0.33 ^b ₁ (±0.07)

*Different superscript letters within a column indicates significant difference between days (P=0.05)

*Different subscript numbers within a row indicates significant difference between animal spp. (P=0.05)

*Values in brackets represent the standard deviation

In comparing the two animal species, there were no significant differences in rumen butyric acid concentration. Rumen butyric acid concentration was the same for the two species at day 1, but at day 3, sheep had a higher rumen

butyric acid concentration than goats. By Day 5, goats on the other hand had a higher rumen butyric acid concentration. There was thus no tendency for one of the species to be dominant with respect in rumen butyric acid concentrations.

In a comparison of the different days within each species, it was relevant that goats had a relatively constant rumen butyric acid concentration for Days 1, 3 and 5, while in sheep there was non-significant increase in rumen butyric acid concentration from Day 1 to 3, but a significant decrease from Day 3 to 5. This tendency for rumen butyric acid concentration to increase is because of the increase in fibre in the diet. Rumen butyric acid concentration tends to increase with an increase in diet fibre (EAAP, 1991; McDonald *et al.*, 1995). On the other hand, rumen butyric acid concentration showed the same tendency as rumen acetic acid concentration. There was an increase in rumen butyric acid concentration for sheep from Day 1 to 3 with a sudden significant decrease in rumen butyric acid concentration towards Day 5. This sudden drop in rumen butyric acid concentration is against all expectations and can be due to the dilution effect of the lower intake vs. fibre content as discussed previously or because of low microbial activity.

Van Niekerk (1997) reported rumen butyric acid concentrations of 0.8 and 2.1 mmol/100ml of rumen fluid for *D. eriantha* and *M. sativa* respectively. These values are much higher than those reported for *A. nummularia* in Table 4.10.

From the above discussions of rumen acetic-, propionic- and butyric acid concentrations, there was an overall low rumen concentration in all three the VFA's. Sheep had an overall drop in all three VFA on Day 5. All of the results preceding this discussion indicate that these low VFA concentrations, as well as the drop in VFA concentration of sheep on day 5, could only have been due to low intakes. We can conclude from the previous results that low intakes may have a depressing effect on the rumen VFA concentration.

The concentration of VFA resulting from the breakdown of carbohydrates constitutes a good criterion for microbial activity in the rumen. According to El Hag (1976), it was higher in goats than in sheep, regardless of the diet. The difference increased even further as the quality of the forage decreased. Watson and Norton (1982), however, did not report any significant difference between sheep and goats in the concentration of volatile fatty acids in the rumen. VFA concentrations for alfalfa hay, barley hay and barley straw are illustrated in Table 4.11.

Table 4.11 Concentration of VFA's in the reticulo-rumen of goats (G) and sheep (S) (Hadjipanayiotou and Antoniou, 1983)

Diet	Total VFA (moles/l)		Acetic Acid (molar %)		Propionic acid (molar %)		Butyric acid (molar %)	
	G	S	G	S	G	S	G	S
	Barley hay	54	75	73	75	18	17	8
Alfalfa hay	102	106	80	78	15	16	6	6
Barley straw	28	30	74	76	17	18	8	7

From Table 4.11 it is clear that there are no differences in the proportional VFA composition between sheep and goats. This was partly noted in the current study and is illustrated in Tables 4.8, 4.9 and 4.10. The only difference between animal species was noticed on day five of the grazing period. During this period, sheep had lower VFA (acetic-, propionic- and butyric acid) concentrations than goats.

The ratio of the three most important volatile fatty acids (acetic-, propionic- and butyric acid) are presented in Table 4.12.

Table 4.12 Acetic acid : propionic acid : butyric acid ratio (molar proportions) in goats and sheep browsing *Atriplex nummularia* (Hatfield Select)

	Goat	Sheep
Day 1	0.73 : 0.18 : 0.09 (3.99)	0.72 : 0.19 : 0.09 (3.80)
Day 3	0.76 : 0.16 : 0.08 (4.74)	0.74 : 0.16 : 0.10 (4.49)
Day 5	0.76 : 0.15 : 0.09 (4.92)	0.77 : 0.14 : 0.09 (5.55)

* Values in brackets represents the acetic acid : propionic acid ratio

Table 4.12 illustrates that there were no real differences in the VFA's molar proportions between goats and sheep. This is supported by the findings of Hadjipanayiotou and Antoniou (1983), that there is no difference between goats and sheep in their VFA composition. These authors' finding is illustrated in Table 4.11. There was, however, a tendency for goats to have a higher acetic acid : propionic acid ratio on Days 1 and 3 and for sheep on Day 5. This compares with the individual VFA compositions in Tables 4.8, 4.9 and 4.10. The higher acetic acid : propionic acid ratio in goats agrees with the higher fibre intake of goats in Table 4.2. For future research, a longer grazing period should be investigated to compare goats and sheep in terms of VFA and performance.

In comparing the different days within each animal species, there was a tendency for the proportions of VFA to favor acetic acid towards Day 5. As the proportion of acetic acid increased towards Day 5, the proportion of propionic acid declined, while the molar proportion of butyric acid stayed the same throughout. As the molar proportions of acetic acid increased and propionic acid decreased, the acetic acid:propionic acid ratio also increased towards Day 5. The high acetic acid:propionic acid ratios on Day 3 and 5 indicates a probable shortage of energy towards the end of the grazing period. This is because the increase in the acetic acid:propionic acid ratio causes a decline in the efficiency of utilization of metabolic energy for production (Hovell and Greenhalgh, 1978; as cited by Van Niekerk, 1997). The shortage in energy could also be because of the low DMI.

Van Niekerk (1997) reported molar proportions of acetic-: propionic-: butyric acid for *D. eriantha* of 0.77:0.15:0.07. This compares well with molar proportions obtained in the current study for goats, and especially for sheep, on Day 5. This author also reported a molar proportion of 0.76:0.16:0.08 for *Chloris gayana* (Rhodes grass). These molar proportions compared well with that of goats on Day 5 of the current study. The study of Van Niekerk (1997) was conducted in the winter. This means that the forage was in a dormant phase and of low quality. During summer, when these plants were actively growing again the author reported molar proportions of 0.69:0.20:0.09 and 0.68:0.19:0.09 for *D. erianta* and *C. gayana* respectively. During summer the acetic acid:propionic acid proportions increased. It would be of interest to investigate the effect of season on the VFA composition of *A. nummularia* and to find out if this seasonal effect would be as great as in the above mentioned grasses.

The high proportions of acetic acid in the current study are supported by the high extent and rate of degradation of the cell wall fraction (NDF) of *A. nummularia* (Hatfield Select) as indicated in Table 2.9 and 2.10. A high degree of NDF degradation indicates high digestion of fibre in the rumen and thus a high acetic acid proportion. The high rate of NDF degradation should also increase the acetic acid proportion as the acetic acid is produced faster than it can be absorbed by the rumen.

Chapter 5

Summary, Conclusions and Recommendations

The first aim of this study was to compare the qualitative and quantitative properties of the intake of *A. nummularia* (Hatfield Select) over time. This was done over a relatively short grazing period of five days. The second aim was to compare the qualitative and quantitative intake of goats and sheep over time. Qualitative intake properties such as CP, NDF and IVDOM were determined while quantitative intake was determined by OMI, DOMI and DOMI/kg $W^{0.75}$. Rumen parameters such as rumen NH_3-N and VFA were also compared over time as well as between goats and sheep. These will illustrate the decline in the quality and the quantity of forage consumed as the grazing period progresses, as well as the utilization by goats and sheep.

Oesophageal fistulated goats and sheep were used to collect samples of herbage selected by these animals. Qualitative analyses were conducted on these samples to determine the quality and quantity of intake. Rumen cannulated sheep and goats grazing on the pasture were used to collect rumen fluid which was used to determine the utilization of these material consumed by the animals. This was done by analysis for NH_3-N and VFA.

There was a definite decline in the quality and quantity of intake over the grazing period. Some parameters, for example CP, were significant. The CP concentration declined from 18% to 3.9 % for goats and from 19.9% to 6.6% for sheep. The cell wall constituents (NDF) increased with about 10% from the start to the end of the grazing period. The IVDOM decreased with 14% and intakes were almost halved from the start to the end of the grazing period. Other authors have also observed this decrease in quality and quantity of intake. The lower quality and quantity of intake was because of a decline in the availability of high quality edible material. By the end of the grazing period (5 days), there was no edible material left, which caused an extremely low quality and quantity intake.

Rumen $\text{NH}_3\text{-N}$ concentrations also declined as the dietary CP declined, but it was still present in high enough concentrations to sustain the rumen micro flora population. Rumen VFA's decreased over the grazing period. The acetic acid to propionic acid ratio increased towards the end of the grazing period. This caused a possible decline in the efficiency of utilization of ME for maintenance, as acetic acid has an efficiency in utilization of ME of 59% and propionic acid of 86% (McDonald *et al.*, 1995). This means that energy will have to be supplemented to sustain maintenance. By increasing the DMI, better selection in terms of qualitative parameters will take place. This could compensate for the shortage in energy.

This extreme decrease in the quality and quantity of intake emphasizes the importance of grazing management on *A. nummularia*. It is important not to defoliate these plants more than 70%, because it was noticed that after two-thirds of the grazing period the qualitative and quantitative intake declined far below the animals maintenance requirements. This was evident in the loss of (on average) 1.5 kg of live weight by sheep over the five day grazing period.

Sheep selected a diet of higher quality than goats. This was against expectations, that goats would be superior in quality of diet selected. Sheep selected a diet of higher CP and IVDOM and lower NDF than goats throughout the duration of the grazing period. Sheep also showed a higher OMI than goats, but sheep were twice as heavy as goats and had a $\text{DOMI}/\text{kg W}^{0.75}$ lower than goats. From this it is evident that sheep selected a better quality diet, but due to the lower intake per metabolic live weight, goats would be better able to fulfill their maintenance requirements. To illustrate this, goats had a higher concentration of rumen $\text{NH}_3\text{-N}$ than sheep, which illustrates a higher total intake of N, and a better degradation of the CP by rumen microbes. A higher rumen $\text{NH}_3\text{-N}$ will stabilize a bigger rumen microbial population which will increase the digestibility of a feed further. Initially goats had a larger acetic acid to propionic

acid ratio indicating a higher fibre intake and digestion by goats than sheep. Due to the low intake of sheep towards the end of the grazing period, sheep had a higher acetic acid to propionic acid ratio at the end of the grazing period. This contributes to the fact that goats were better able to maintain body weight through the grazing period.

It is concluded that sheep selected a higher quality diet than goats on *A. nummularia* cv. Hatfield Select. Due to lower intakes of sheep per metabolic weight, goats were, however, more capable of supporting their maintenance requirements than sheep.

For both goats and sheep, it would be advisable to supplement the energy requirement of these animals with feed high in energy. This will also improve intakes and would even support a certain level of production.

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