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 (28º15'30"E, 25º44'30"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 lead 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 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 $7m^2$ 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 NH_3-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 m^2. 370 Plants were established with an area of 2.75m^2 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 60ºC. 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 100ºC 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 600ºC for 4h. The crucibles plus ash were then weighed after cooling in a desiccator (AOAC, 2000).

%DM = (Mass of oven dry sample / Mass of air dry sample) x 100

%Ash = (Mass of Ash / Mass of air dry sample) x 100

%OM = 100 - %Ash (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: "N_2, freed by pyrolysis and subsequent combustion, is swept by CO_2 carrier into nitrometer. CO_2 is absorbed in KOH and the volume of residual N_2 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 MHCl 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 A*triplex* 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 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 micro-organisms, particularly when there has been time to adapt to high-oxalate diets (Underwood and Suttle, 1999). Vitamin D_3 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 Table2.4. 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 (Grovum 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, (molebdate, 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 palatatable 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 i*n 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 NH_3-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.