Chapter 1
Introduction and Literature review

1.1. Introduction

Nutrition of domestic animals in semi-arid regions is mainly based on the utilization of rangeland resources, which are subject to many quantitative and qualitative variations throughout the year. Fodder trees and shrubs are an integral part of the diet of animals in such areas and often constitute the main source of protein, minerals and vitamins during the dry season. A number of fodder shrubs have been identified as potentially valuable species and introduced into forage production systems of the arid and semi-arid regions in the form of shrub plantations. These plantations play a key role in providing animals with forage, especially during critical periods (Bouzid & Papanastasis, 1996).

Rangelands occupy more than 70% of South Africa's land surface. Sixty percent of this is moderately to seriously degraded. These semi-arid rangelands are under enormous pressure due to the injudicious use of natural resources and the occurrence of periodic droughts. The visible symptoms of disturbed rangelands are obvious and include degraded vegetation, bush and shrub encroachment and soil erosion (Snyman, 2003). In certain rangeland areas, natural vegetation is degraded to such an extent that the application of management practices, or even withdrawal of grazing animals, will not have an effect on the recovery. In such cases more drastic reclamation measures need to be applied to re-establish the vegetation and ensure sustainable animal production (Snyman, 2003). Rangeland deterioration begins very subtly and farmers often only realize that the land is deteriorating when drastic changes such as bare patches occur. The approaches to reclamation depend on the soil type, climate and the causes and degree of degradation. Reclamation is an expensive and time-consuming process and needs careful planning (Snyman, 2003).

The use of drought tolerant fodder shrubs and trees in semi-arid or arid areas is becoming a widely discussed topic. Not only do these plants provide a source of food for animals during the critical dry periods but they may also contribute to the reclamation of degraded rangelands. The establishment of drought tolerant crops also makes more efficient use of the available moisture, an important consideration in areas where rainfall and irrigation is limited. The establishment and maintenance of such crops is economical as they have a high recovery ability after utilization (Sparks, 2003). These browse plants may also serve as a cheap alternative feed source which can sustain and increase ruminant production on land not suitable for crop production. Forage from such rangelands is deficient in nitrogen, energy and some minerals and cannot support production (Ngwa *et al.*, 2002). As supplements these plants can benefit low-resource farmers who cannot afford the purchase of conventional protein sources. The nutritive value of these plants has also not been extensively researched, but more interest is now being shown in them, especially indigenous species. Published information shows that these fodder species, particularly the leguminous ones are able to provide forage that could maintain a productive state in livestock. If a proper management strategy is developed and followed, a lot of progress can be made and these plants can be properly utilized.

1.1.1 Desertification in South Africa

Semi-arid districts are defined as those in which the average annual rainfall was 300-600mm and where rain-fed crops succeed in four out of five years without irrigation. Arid districts are those in which the average annual rainfall was less than 300mm and conditions are generally too dry to grow the most drought-resistant crops without irrigation (Dean & MacDonald, 1994).

In Southern Africa, a region which is to a very large extent covered by arid land, the topic of desertification inspires a great deal of discussion and debate. According to the 1978 United Nations conference on the subject, desertification can be defined as the '...diminution or destruction of the biological potential of the land', in other words a conversion from a more productive state to a less productive one. Desertification according to Dean and MacDonald (1994) may be defined as a functionally irreversible decline in useable secondary production from untransformed semi-arid and arid rangelands due to local human influence and is indicated by long-term changes in total system diversity. The prediction that the area covered by desert in South Africa is increasing in size involves changes in the ratios between grass cover and shrub cover (Dean & MacDonald, 1994). The Karoo used to be perennial, palatable grassland (sweetveld) prior to habitation by European farmers. Today the occurrence of overgrazing and trampling has been so heavy that the grasses and shrubs have thinned out and have been replaced by unpalatable shrubs characteristic of the Karoo today (Dean & MacDonald, 1994). Selective and persistent grazing has played an important role in occurrence of unpalatable shrubs. The percentage of grass cover increases from the west to east following the rainfall gradient. The summer rainfall in the eastern regions provides a hot, wet season favouring the growth of C4 grasses (these grasses produce a 4-carbon molecule during photosynthesis which make them more adapted to warm and hot seasonal conditions, therefore growth periods occur during the warm season). The fact that the grass cover is decreasing in this region and the shrubs taking over provides an impression that the Karoo is spreading eastwards (Dean & MacDonald, 1994).

The consequence of desertification is that it is accompanied by severe soil erosion. Therefore, the topsoil is no longer protected by grass cover and is lost by erosion and grasses can no longer re-establish themselves. Invasion by unpalatable Karoo bushes does not prevent erosion because their growth habit does not protect the topsoil (Van Breda & Barnard, 1991). There are large areas of the Karoo where the grazing quality has deteriorated and continuing to do so, especially since most of the topsoil has been eroded. Where palatable shrubs have been replaced by unpalatable ones, recovery may be hampered by the fact that many succulents and shrubs do not have soil-stored seeds. Palatable shrubs that have been heavily browsed are unlikely to be replaced if they die, even if browsing pressures are temporarily lifted (Van Breda & Barnard, 1991). There is also no natural restoration process whereby unpalatable shrubs are replaced by palatable ones. Field trials that have attempted to reintroduce certain palatable species have been met with limited success. Many farmers and arid-zone ecologists are aware of degraded farms and patches in these areas (Van Breda & Barnard, 1991). Hoffmann & Cowling (1990) suggest that karroid dwarf shrub lands are resilient to sustained grazing pressure, but nevertheless note that grazing in the Karoo subtly alters species composition and population structure. A large proportion of the highly palatable perennial shrub species of the winter rainfall region are currently rated as both scarce and fast disappearing or vulnerable (Van Breda & Barnard, 1991).

The Karoo is a complex ecosystem, which we do not yet fully understand. The soil, rainfall, temperature and seasonality gradients are pronounced. The rainfall varies from 50 – 500mm per year, with a marked increase in unpredictability in the drier regions to the west. The vegetation is also varied and includes succulents, shrubs and grasses. In the past it was believed that in order to minimise veld deterioration and maximise yields farmers should adopt a specific grazing management system. Today the systems are more farm specific (Lovegrove, 1993).

Over the years the demand for wool and other animal products provided the economic incentive for overstocking and overgrazing. Today, although the Karoo represents about one third of South Africa's farmland, the gross annual income from their agricultural products is only 6.2 percent (%) of the countries gross annual income. It has been estimated that for a farming unit in the Karoo to be economically viable, it must support at least 1200 small stock such as sheep (Lovegrove, 1993). There is a possibility that large tracts of unproductive and denuded Karoo land could be granted to subsistence farmers but the result will be uncontrolled overgrazing and an accelerated rate of desertification and erosion (Lovegrove, 1993). There are alternatives to overstocking so that the area can be made economically viable. Veld conservation, through understanding of plant establishment and the conditions needed for this, is the most important requirement. Lower stocking rates, which result in the preservation of vegetation, generate far greater long-term gross income for the farmer than high stocking rates (Lovegrove, 1993).

Grazing by domestic livestock is thought to be a major force leading to dry land degradation in the semi-arid and arid rangelands of Southern Africa (Dean & MacDonald, 1994). It has been shown that decreases in stocking rates reflect decreases in the carrying capacity/secondary productivity of rangelands and this may be one of the symptoms of desertification. The present stocking rates in the semi-arid and arid regions reflect the maximum number of livestock units that rangelands can carry. Since stocking rates have been reduced, it is logical to suspect that the productivity of forage plants of these rangelands has declined over the past few decades. Changes in the absolute and relative abundance of fodder plants, together with irreversible losses of topsoil and changes in infiltration rates in semi-arid and arid rangelands has reduced the biomass of domestic livestock that can be carried on these rangelands (Dean & MacDonald, 1994).

1.2. Leguminous trees and shrubs

Legumes are known for their ability to grow in a symbiotic relationship with nitrogen-fixing bacteria. Many legumes are also very drought resistant. Legumes are superior to grasses in protein and mineral concentration and their nutritive value declines less with age. There are, however, certain nutritional disorders associated with certain legumes (McDonald *et al.,* 2002). Legumes can improve the quality of the diet of ruminants in three ways: by increasing the protein concentration of the diet; by increasing the intake of energy and protein by animals and by increasing the length of time that green forages is available to animals (Minson, 1994).

Animals grazing mature grass pastures often supplement their diet by consuming the foliage of trees and shrubs, many of which are legumes. The collective term applied to food obtained this way is 'browse'. In addition to the plants being harvested by animals, browse can be cut and fed to animals. The foliage of leguminous trees is high in protein 200-300g/kg dry matter (DM)) and minerals, but is also high in fibre (500-600 neutral detergent fibre (NDF)/kg

DM) (McDonald *et al.,* 2002). Foliage of some species also has a high concentration of condensed tannins, which can be problematical. Low to moderate concentrations of tannin precipitate soluble plant proteins and thus protect them against digestion in the rumen, but if the proteins are too firmly bound to the tannins they are not digested in the small intestine (McDonald *et al.,* 2002). Tannins can thus act as toxins and/or digestion inhibitors, with resultant suppression of feed intake and passage rate (McSweeney *et al.,* 2001). Tannins and other constituents may reduce the palatability of browse, so that its nutritional value may be rather as a food reserve, to be utilized when grass herbage is no longer available (McDonald *et al.,* 2002). Some of the commonly known browse species include leucaena (*Leucaena leucocephala),* sesbania (*Sesbania sesban)* and acacia (*Acacia angustissima)* (McDonald *et al.,* 2002).

Animal production from tropical legumes will be limited if they contain insufficient minerals or protein and if these nutrients cannot be obtained from other sources. The potential of legumes to provide these nutrients varies with the element and between legume species, stage of growth, and other variables (Minson, 1994). Tropical legumes contain, on average, 0.29% phosphorus, which is slightly higher than tropical grasses (0.22%). The calcium level (1.21% vs. 0.40%) is also higher and is usually well above that required by grazing ruminants, the magnesium trend being similar. The sodium concentration of most tropical legumes is, however, low (0.05%), which is the minimum dietary level recommended for ruminant production. However, certain non-leguminous fodder shrubs, such as *Atriplex,* may contain higher levels of sodium. Tropical legumes generally have a high crude protein concentration which declines slowly over time and even when mature they generally contain more than nine percent as such can be used as protein supplements to mature tropical grasses, leading to an increase in intake of grass (Minson, 1994). The chemical composition of legume forage hays may differ due to a variation in the leaf content of the hay and stage of growth. Some losses of leaf material can occur during harvesting and drying. The leaves contain more protein while the stems more fibre (neutral and acid detergent fibre) (Mupangwa *et al.*, 2000). The protein concentration in leaves and stems is 23% and 17% respectively with the solubility of the crude protein (CP) in leaves being lower, which may be due to a high tannin content. The apparent digestibility of the CP varies considerably. Most of this variation is positively associated with the level of CP. The capacity of legumes to produce an ammonia-rich rumen environment and by-pass protein that provides amino acids to the lower gastro-intestinal tract (GIT) gives an additional advantage of this type of feed (Ngwa *et al.*, 2002). The gross energy concentration in tropical legumes appears to be similar to those in grasses and temperate legumes. Not many values for metabolisable and nett energy have been published. The quantity of dry matter eaten by ruminants is the single most important factor controlling production. Unless large quantities of legume are eaten, production will be low due to a low intake of digestible energy (Minson, 1994).

A disorder that is frequently encountered in cattle and sheep grazing on legume-dominated pastures is bloat. Lucerne is one of those posing a serious problem (McDonald *et al.,* 2002). The primary cause of bloat is the retention of the fermentation gasses in a stable foam, preventing their elimination by eructation. Soluble leaf proteins are thought to play a major role in the formation of the foam. Legumes that contain significant concentrations of condensed tannins (>20g/kg) are unlikely to cause bloat, probably because of the ability of tannins to precipitate soluble proteins. Another disorder associated with grazing sheep on pure lucerne is a sudden death syndrome termed 'redgut' (McDonald *et al.,* 2002). This is thought to be caused by the rapid passage of highly digestible forage through the rumen that causes increased fermentation in the large intestine. A large number of species are known to contain compounds, which have oestrogenic activity, the activity of these compounds can be increased as a result of metabolism in the rumen (McDonald *et al.,* 2002). The consumption of oestrogenic pasture plants by sheep leads to severe infertility and post-natal death in lambs. The infertility can persist for long periods after the ewes have been removed from the pastures. Cattle grazing these pastures do not appear to suffer infertility problems (McDonald *et al.,* 2002).

Leucaena contains a toxic amino acid, mimosine. In the rumen it is converted to dihydroxypyridine (DHP), a compound with goitrogenic properties. In countries with a natural population of leucaena, grazing animals' posses a rumen microorganism capable of destroying DHP (McDonald *et al.,* 2002).

All legumes appear to have the C3 photosynthetic pathway, but they can still be separated into cool and warm season types based on their adaption to temperature. The photosynthesis response of Lucerne (*Medicago sativa)* to light is intermediate between cool and warm season grasses even though the leaf anatomy and enzymes involved with CO_2 fixation are clearly C3 (Nelson & Moser, 1994).

Leguminous multipurpose trees that are rich in nitrogen and widely used in the tropics offer an opportunity for use as nitrogen supplements to livestock fed on crop residues. Supplementation of *L. leucocephala* and *S. sesban* to sheep provided higher concentrations of rumen metabolites, which naturally improved rumen function and feed digestibility (Bonsi *et al.*, 1995).

1.3. Plant species

1.3.1 *Cassia sturtii*

Forage shrubs are useful forages for arid areas because of their adaptation and productivity in dry climates and poor soils (Ventura *et al.*, 2004). These plants can increase the carrying capacity of the land for grazing animals. They also have the potential to restore degraded rangelands. One of the most promising, in the Israeli experience, is *Cassia sturtii*, an exotic shrub from southern Australia (Faucon, 2001). It is a legume belonging to the family *Fabaceae*. The plant is an evergreen shrub, up to 1.8m tall and 1.8m wide with grey-green leaves and yellow flowers. It flowers during April. Once established it can survive with little water and is, therefore, able to tolerate drought and full sun (Faucon, 2001). It remains palatable year round, has good grazing resistance and the leaves have a reasonably high protein concentration (12%). Annual dry matter yields of about 1 ton per ha in a 200 mm rainfall area have been recorded (Pasternak *et al.*, 1986). Figure 1.1 gives an idea of the physical appearance of *C. sturtii*.

Figure 1.1 The flowers and leaves of *C. sturtii* (University of Pretoria Experimental Farm)

Relative to *Atriplex* species, *C. sturtii* recovered better after browsing; it recovered it's biomass in the two highest planting densities and in the three lower densities; it had approximately 70% of its initial biomass at the beginning of a fifth browsing season. *C. sturtii* out-yielded *A. canescens* in edible biomass production but not *A. nummularia* (Benjamin *et al.*, 1995).

Wilcock *et al* (2004) reported a DM yield for *C. sturtii* (University of Pretoria Experimental Farm) over a 6 month period of approximately 500 g DM per plot (plot size; 60m in length and 17.5m wide). The growth of these plants may have been affected by frost during the winter; however the plants did recover quickly. As the plants increased in size, there was a decrease in percentage leaf material (Wilcock *et al*, 2004). This leaf and stem material were analysed for *in vitro* digestible organic matter (IVDOM), ash and CP. The results are shown in table 1.1.

Table 1.1 The *in vitro* digestible organic matter, ash and crude protein concentrations of the leaves and stems of *C. sturtii* (Wilcock *et al.,* 2004)

Nutrient	Stems (<3mm)	Leaves
IVDOM %	41.8	55.4
Ash g/kg DM	53	73
CP g/kg DM	76	147

The concentration of nutrients and IVDOM observed in leaf material was higher than in the stems. Similarly Van Niekerk *et al.* (2004,a) reported CP values for leaf material of *C. sturtii* from 114 to 147 g/kg DM and IVDOM varied from 529 to 574 g/kg DM. Both authors stated than *C. sturtii* proved to have fair potential and met requirements as a fodder crop.

In a trial conducted by Ventura *et al.* (2004), the nutritive value of three forage shrubs endemic from Canary Islands (*Bituminaria bituminosa, Rumex lunaria, Adenocorpus foliosus*) and two introduced shrubs (*Acacia salicina, Cassia sturtii)* were studied throughout a year. Although the above species have been widely used in ruminant feed, little research has been carried out to determine their nutritive value. Ruminal degradability and *in vitro* digestibility trials were conducted on the above legume shrubs.

The chemical composition of *Cassia sturtii* used in the trial conducted by Ventura *et al.,* (2004) is shown in Table 1.2, 1.3 and 1.4.

Table 1.2 Chemical composition (g/kg DM) of the edible portion of *C. sturtii* (Ventura *et al.,* 2004)

	DM	OM	CP	NDF	ADF	ADL
Mean	446	937	102	390	254	88

Table 1.3 Mineral (g/kg DM) concentration of the edible portion of *C. sturtii* (Ventura *et al.*, 2004)

	Ca	P	Mg	Na
Mean	13.4	1.7	1.2	3.6

Table 1.4 Organic matter and protein ruminal degradability (OMD, CPD, %), *in vitro* dry matter and organic matter digestibility (IVDMD, IVOMD, %) and digestible organic matter (DOM, g/kg DM) of the edible portion of *C. sturtii* (Ventura *et al.*, 2004)

	OMD	CPD	IVDMD	IVOMD	DOM
Mean	53.5	56.4	42.7	38.8	364

C. sturtii had the lowest CP concentration (mean 10%), compared to the endemic forage shrubs (Canary Islands) which varied between 15 and 18.5%. The fibre concentration was moderate (390g NDF/kg DM), but with a relatively high lignification (25% of NDF was ADL) and similar to the endemic species. The *C. sturtii* in this trial was shown to contain a significant amount of tannins. Organic matter (OM) and protein degradability was moderate (53.5 and 56.4% respectively). IVOMD and DOM values were low, probably because of the negative effects of tannins on digestibility. The mean NE concentration was low (3.2-3.3Mj/kg DM). The results of this research suggest that more than 1.5kg DM of *C. sturtii* is needed to provide the energy and protein requirements for the maintenance of a 50kg goat (INRA, 1988; as referred to by Ventura *et al.,* 2004). However the tannin content could affect the intake of these shrubs (Ventura *et al.,* 2004).

Some of the *Cassia* spp. have been shown to contain toxic compounds which make ruminants and monogastrics susceptible to poisoning by *Cassia* spp. A few articles have been published on the toxicological effects of *Cassia obtusifolia* and *Cassia occidentalis* which is also part of the *Fabaceae* (legume) family. Several compounds that bind strongly to cell membranes occur in *Cassia* spp., but the specific toxin responsible for muscle degeneration has not been identified (Herbert *et al.*, 1983). The toxin induces acute muscle and liver degeneration that can be rapidly fatal in most animals. The greatest concentration of the toxin appears to be in the seeds with *C. obtusifolia* and *C. occidentalis* considered to be more toxic than other species, but all *Cassia* spp. should be considered toxic unless proven otherwise (Mercer *et al.*, 1967). Pods from *C. occidentalis* fed to cattle at a rate of 0.5 percent of their body weight induced severe muscle degeneration and poisoning occurred when the green plant was eaten at 0.4 to 12 percent of body weight (O'Hara *et al*., 1969). Suliman and Shommein (1986) showed that at lower doses, *Cassia* spp. can cause diarrhea and decreased weight gain. The plant is not very palatable and tends to reduce feed intake. Some of the clinical signs are abdominal pain, straining and diarrhea are thought to be due to the irritant effects of anthraquinones in *Cassia* spp. Depending on the amount of plant or seed pods consumed, muscle degeneration begins several days after, causing weakness and recumbancy. The urine may be coffee coloured due to myoglobinuria. The levels of serum enzymes creatine kinase and aspartame transaminase are usually elevated. Renal failure may develop and in severe cases hepatic failure may be the predominant organ failure leading to death of the animal. Gross lesions at postmortem examination consist primarily of pale skeletal muscles similar to those seen in white muscle disease (O'Hara *et al*., 1969).

Although these species are known to be troublesome weeds of the South eastern United Stated, Hawaii, Mexico and most of the tropical world, the studies conducted, have shown them to be deleterious. Whether the species *C. sturtii* also contains some of these toxic compounds is questionable but one worth investigating.

1.3.2 *Sutherlandia microphylla*

Sutherlandia microphylla (family-Leguminosae) is widely distributed in the Karoo, but prefers disturbed and gravely soils. It is a soft shrub about 0.3-1.5 m tall and has a typical pea flower, scarlet to orange on colour. The fruit is an inflated pod, red when young and pale brown and papery when ripe. Although it is very palatable with a high nutritional value and good production, it is not, however, long lived. It is often grazed down to bare stems (Le Roux *et al.,* 1994). *Sutherlandia frutescens* is another species of the same family which grows in the same areas and only grows to 0.2-0.5m tall. The flowers and fruit are very similar. It has the same uses as *S. microphylla* but this species is often used in medicine (Le Roux *et al.,* 1994). The physical appearance of the flower of *S. microphylla* can be seen in Figure 1.2.

Figure 1.2 The flower of *S. microphylla* (University of Pretoria Experimental Farm)

Wilcock *et al.* (2004) reported that *S. microphylla* had the highest DM yield over a 6 month period, of approximately 1600 g DM per plot (plot size; 60m in length and 17.5m wide) when compared to *C. sturtii* of 500 g DM per plot and *Tripteris sinuatum* of 500g DM per plot (plot size; 60m in length and 17.5m wide). However, *S. microphylla* had the largest percentage decrease in leaf material with increase in plant size. The harvested material was analyzed for IVDOM, ash and CP concentrations. The results are shown in Table 1.5.

Table 1.5 The *in vitro* digestible organic matter, ash and crude protein concentrations of the leaves and stems of *S. microphylla* (Wilcock *et al.*, 2004)

Nutrient	Stems (<3mm)	Leaves
IVDOM %	38.9	66.0
Ash g/kg DM	25	64
CP g/kg DM	88	225

Sutherlandia is regarded as an indigenous multi-purpose medicinal plant in Southern Africa. Its efficacy as a safe tonic for diverse health conditions comes from a long history of use in numerous cultures. *Sutherlandia* assists the body to mobilize its own resources to cope with diverse physical and mental stresses and is, therefore, more correctly known as an adaptogenic tonic. Some of its uses include immune support, stress, depression, cancer, diabetes, gastritis and rheumatoid arthritis. Prof. Ben-Erik van Wyk (University of Johannesburg) and Dr. Carl Albrecht (Cancer association of South Africa) studied the chemistry of *Sutherlandia*. Four known key compounds contribute to the efficacy of this medicinal plant and are described below in more detail. The potent non-protein amino acid L-canavanine is an L-arginine antagonist with antiviral, antibacterial, antifungal and anticancer activities and is found in significant levels in the leaves of *Sutherlandia*. Canavanine is distinctively immunosuppressive of critical cellular immune response against cancer cells and infectious organisms. *Sutherlandia* is, therefore, potentially an extremely dangerous plant and ought not to be sold as a safe and efficacious plant (Thomson, 2002).

Several legumes, often the whole plant, but in particular the seeds, contain this known toxic chemical canavanine, that, after being eaten, is imported into protein in place of arginine. Some herbivores, which are mixed feeders, have developed several survival defenses of their own. A number of canavanine-degrading bacteria may break down sufficient amounts of the dietary canavanine so that the toxic effects of this compound are reduced when ruminants eat these foods (Thomson, 2002). The earliest toxicity reports were of observed effects in rats fed canavanine-containing meal. Later experiments quantified the mammalian toxicity of canavanine, with 20mg/kg body weight having no effect, 200mg/kg showing clear damage and 2g/kg leading to death, all within 24 hours. When 1g/kg of arginine was fed with 200mg/kg canavanine, no toxicity was observed (Thomson, 2002). An explanation of the toxic effects was a disturbance of protein metabolism related to the disturbance of arginine functions. Relatively moderate canavanine feeding was observed to lead a reduction in normal weight gain. Milk production reduction was markedly reduced after feeding canavanine to dairy cows. When feed was given with protein-rich fodder, few ill effects were noted. Canavanine is rapidly metabolised in the liver, yet damage in this and other organs is reported. Post mortems of animals allowed to graze freely on canavanine rich plants have revealed lesions and haemorrhages of the lymph glands. Canavanine has, furthermore, been determined to be a vitamin B_6 antagonist (Thomson, 2002).

The compound Pinitol, which is an antidiabetic agent and Gamma-aminobutyric acid (GABA) an inhibitory neurotransmitter, have both been isolated from the leaves of *S. microphylla* as well. Asparagines have also been found (Thomson, 2002).

The published biological activities of these compounds appear to validate some of the traditional uses of *S. microphylla*, and further support the use of *S. microphylla* as a quality of life tonic in cancer and HIV-AIDS patients (Van Wyk, 2004 personal communication).

Very little research has been done on the nutritive value of this indigenous shrub for domestic animals. The fact that it is indigenous may lead to great interest in its use as a fodder shrub in the semi-arid rangelands of South Africa, but careful research needs to be conducted because the shrub may be potentially toxic.

1.3.3 *Medicago sativa* (Lucerne)

Lucerne (*Medicago sativa)* is an important forage legume widely planted in temperate areas and in many tropical and sub-tropical countries. It is commonly grown on its own and used as a hay crop (McDonald *et al.,* 2002). In Table 1.5 an example of the dry matter composition of lucerne is presented.

Table 1.6 Composition of the dry matter of lucerne (McDonald *et al.,* 2002)

	Pre-bud	In-bud	Early flower
Crude fibre (g/kg)	220	282	300
Ash (g/kg)	120	82	100
Crude protein (g/kg)	253	205	171
Digestible organic matter (g/kg)	670	620	540
Metabolisable energy (MJ/kg)	10.2	9.4	8.2

The value of lucerne hay lies in its relatively high crude protein concentration, which may be as high as 200g/kg if it is made from a crop cut in the early bloom stage (McDonald *et al.,* 2002). The traditional method of conserving green crops is that of haymaking. The aim of haymaking is to reduce the moisture content of the green crop to a low level as rapidly as possible to inhibit the action of plant and microbial enzymes. The custom of cutting the crop in a mature state, when moisture content is at its lowest, is clearly a sensible procedure for rapid drying and maximum yield, but unfortunately the more mature the herbage, the poorer the nutritive value (McDonald *et al.,* 2002). If optimal drying conditions are present hays made from early cut crops will be of higher nutritive value than those made from mature crops. Chemical changes such as oxidation, leaching and mechanical damage arise during the drying process and result in a loss of valuable nutrients (McDonald *et al.,* 2002).

Protein in lucerne forage is degraded both rapidly and extensively in the rumen. Forage protein is often wasted due to excessive ammonia formation in the rumen. The excess soluble protein, and/or protein in relation to available energy, often leads to an inefficient use of lucerne forage protein by ruminants (Bekker, 1995). The synchronous supply of nitrogen (N) and energy to rumen micro-organisms will maximise the capture of rumen degradable nitrogen (RDN) and optimise microbial growth rate and efficiency resulting in an increased duodenal amino-N flow (Bekker, 1995).

The nutritive value and rumen kinetics are of particular interest and an experiment conducted by Bekker (1995) supplies some useful information on these particular parameters. The mean chemical composition over the three periods is shown in Table 1.7.

Table 1.7 Fibre parameters (% of DM) of lucerne in autumn, spring and summer. (Bekker, 1995)

Parameter	Period		
	Autumn	Spring	Summer
NDF	35.7	38.9	39.6
ADF	27.7	31.0	31.2
ADL	6.81	7.36	7.11
Cellulose	20.9	23.7	24.1
Hemicellulose	7.95	7.87	8.34

Significant seasonal effects were observed for NDF, ADF, ADL and cellulose (Bekker, 1995).

The effect of season was significant for organic matter intake (OMI) and digestible OMI (DOMI) where intakes in the third period were lower. No cultivar effects were identified. The influence of season on the digestibility and organic matter intake is presented in Table 1.8.

Table 1.8 The influence of season on organic matter intake and digestibility by sheep. (Bekker, 1995)

Parameter	Period		
	Autumn	Spring	Summer
OMI (g/d)	964	877	634
OMI (g/kg W0.75/d)	45.4	40.9	29.9
DOMI (g/d)	601	575	417
DOMI(g/kg W0.75/d)	28.4	26.8	19.7
Total tract apparent OM digestibility (%)	61.7	65.2	65.8

Table 1.9 shows the results of total volatile fatty acid (VFA) concentration and molar proportions of VFA in the rumen. No significant seasonal effects were observed between autumn and spring (Bekker, 1995).

Table 1.9 The influence of season on VFA production and molar proportions of VFA's in the rumen of sheep. (Bekker, 1995)

Parameter	Period		
	Autumn	Spring	Summer
Total VFA (mmol/100ml)	33.5	32.3	29.0
Molar proportions			
Acetic acid	0.638	0.642	0.662
Propionic acid	0.223	0.219	0.195
Butyric acid	0.102	0.100	0.106
Valeric acid	0.036	0.039	0.037
Acetic/Propionic	2.87	2.95	3.43

The results for nitrogen intake and rumen ammonia are presented in Table 1.10.

Table 1.10 The influence of season on nitrogen intake and rumen ammonia. (Live weight basis) (Bekker, 1995)

Parameter	Period		
	Autumn	Spring	Summer
N intake (g/d)	35.2	34.1	29.2
Rumen NH_3-N (mmol/l)	33.7	44.4	51.9

Significant seasonal effects were observed for mean N intake and rumen ammonia concentrations. Differences between autumn and spring are attributed to seasonal effects since both were conducted at a mature growth stage. Differences between spring and summer are attributed to growth stage effects since both were conducted in the same growing season but at different maturity stages. It follows that the effects for growth stage were more pronounced than seasonal effects. The results on a live weight basis show the trends (Bekker, 1995).

A lower total VFA production at the younger growth stage explains the lower OMI and DOMI. At the younger growth stage a greater proportion of the forage protein is of leaf origin and is highly degradable (Bekker, 1995). At a younger growth stage, total VFA production in the rumen was significantly lower than the mature stage. This is attributed to the lower intake of digestible OM. Even though N intake was lower, rumen ammonia concentration was significantly higher in the younger stage.

1.4. Nutritive value

Poor nutrition is one of the major constraints to livestock productivity in sub-Saharan Africa. This is because animals thrive predominantly on high fibre feeds which are deficient in certain nutrients essential for microbial fermentation (Dicko & Sangare, 1984). Consequently, the digestibility and intake of digestible nutrients are unavoidably low. By supplementing the diet with feeds containing the deficient nutrients the deficiencies can be mitigated. Roughage diets and supplements differ vastly in quality and, therefore, quantity eaten by the animal (Dicko & Sangare, 1984). Previously, digestibility and chemical composition were used to describe the nutritive value of fibrous feeds; however an understanding of the factors which affect rumen degradability of low-quality basal feeds and microbial protein production, as well as determining the response (performance) from feeds, will provide more efficient designing of diets that can be utilised more efficiently (Osuji *et al.,* 1993b).

Forage quality can be defined as a function of both forage intake and digestibility. Ruminant productivity is the ultimate measure of forage quality (Paterson, 1994). Compared to grasses, fodder trees and shrubs have relatively higher concentrations of CP, minerals and NDF plus ADL, while their average concentration of ADF, as well as their average dry matter digestibility (DMD) are both lower. Chemical constituents such as N, NDF, ADF and lignin are essential to predict the nutritive value of shrubs (Kaitho *et al.,* 1998). These nutrient concentrations are subject to less variation than with grasses and this particularly enhances it's value as dry season feeds for livestock (Dicko & Sangare, 1984).

Supplementation of tropical grasses with legumes has been reported to result in increased dry matter intake and to improve digestibility (Ndlovu & Buchanan-Smith, 1985).

A study was conducted by Mupangwa *et al.* (2000) on the herbaceous tropical forage legumes *Cassia rotundifolia* (Cassia), *Lablab purpureus* (Lablab), *Macroptilium atropurpureum*

(Siratro) and *Stylosanthes guianenis* (Stylo) to investigate the effect of feeding four legume hays as sole diets to mature sheep on DM intake, apparent digestibility, rumen ammonia levels, urinary excretion of purine derivatives and rumen microbial protein production. Although these forage legumes have great potential as protein supplements to supplement low quality roughages, studies on them as sole diets are scarce. Very little is known about these legumes regarding it's intake by ruminants and the rumen microbial protein production and levels of animal response they can elicit when given to ruminants as sole diets (Mupangwa *et al.,* 2000). The nutritional parameters of these legume hays are presented in Table 1.11.

Table 1.11 Some nutritional parameters of legume hays given to sheep as sole diets (Mupangwa *et al.,* 2000)

	Cassia	Lablab	Siratro	Stylo	SED
DM intake (g/kgW$^{0.75}$)	12.1	48.2	52.6	50.9	2.94
Apparent digestibility-DM	0.550	0.638	0.581	0.577	0.034
N intake (g/day)	5.75	16.5	25.1	27.7	0.83
Faecal N (g/day)	1.08	4.77	4.81	4.20	0.55
Urinary N(g/day)	10.2	23.1	29.1	23.9	3.54
N retention (g/day)	-5.53	-11.4	-8.68	-0.53	4.04
Rumen NH_3-N (mg N/l)	150	225	159	161	15.9
Allantoin (mmol/day)	2.89	3.29	3.58	4.73	1.16
Microbial N supply (g/day)	2.70	3.15	3.43	4.53	0.98
Microbial N supply (g/kg DOMR)	50.1	12.9	16.0	18.1	8.69

DOMR (Digestible organic matter in the rumen) = 0.65 x DOMI (g/day)

The DM intake of the other hays was higher than that of *Cassia*. This difference could be due to higher apparent DM digestibility which may result in lower rumen retention time and greater turnover rate from the rumen of sheep. *Cassia* has been reported to have a relatively low acceptability which could be due to anti-nutritive factors such as condensed tannins. The tannins are reported to reduce voluntary intake through an unpleasant sensation in the mouth and an inhibition of microbial enzyme activity (Kaitho *et al.,* 1998).

The metabolisable energy intake of sheep in the four hays in Table 1.11 was 1.30, 5.92, 5.17 and 6.03 MJ/day respectively. The maintenance requirements for ME are 6.19 MJ/day (NRC, 2007). Animals consuming any of the hays are in a negative energy and nitrogen balance and needed to mobilise body reserves to meet requirements. The type of protein and its degradability and an incorrect protein to energy ratio are the concern. This results in a reduced efficiency of rumen ammonia utilisation leading to excess ammonia in the bloodstream and loss in the urine as urea (Mupangwa *et al.,* 2000).

This study has demonstrated that an extensive loss of legume protein as ammonia in the rumen occurs in the absence of a readily fermentable energy source, which can result in a reduction of undegraded dietary protein flowing to post-ruminal sites. The efficiency of microbial production from rations based on forage legumes can be limited by a lack of a readily available energy source and the addition of such a source may assist in giving increased ammonia utilisation and microbial protein production. The legumes can be fed as protein supplements to ruminants consuming low quality tropical grasses and crop residues (Mupangwa *et al.,* 2000).

1.5. Digestibility and voluntary feed intake

Supplementation of tropical grasses with legumes has been reported to result in increased DM intake and improve DM digestibility. They also have great potential as protein supplements to these low quality roughages (Mupangwa *et al.*, 2000).
Prediction of voluntary intake of roughages by ruminants has long been a research priority in animal feeding. The level of feed intake is dependant on feed characteristics, animal and environmental factors and their interactions (Fonesca *et al.*, 1998). Feed characteristics are recognised as the most important factor when low quality roughages are offered. In the past simple and multiple regression equations were used to predict intake and digestibility, however a simpler method of feed evaluation was proposed.

The nylon bag technique, in which samples of feed are directly incubated in the rumen, has become widely used. This technique allows rumen digestion to be studied at different periods of time, and thereby the kinetics of digestion (Fonesca *et al.*, 1998).

1.5.1 *In situ* digestibility

The history of the development of methods for the assessment of the value of feedstuffs for animal production is a long one. In the early attempts in Europe feeding trials were used, and the workers also tried to predict the nutritive value of feedstuffs by the extraction of the "solubles" with water, alkali, ether and alcohol. As knowledge increased, the early methods were modified and developed, in order to improve the reliability with which laboratory techniques could be used to predict nutritive value to the animal. Although highly developed laboratory procedures are now available, such as acid detergent fibre, the modifications which have been introduced have often simply attempted to mimic the *in vivo* process. For the evaluation of feedstuffs, *in vivo* techniques are nearly always preferred. The use of the nylon bag has the advantage of giving a very rapid estimate of the degradation of feedstuffs in the functioning rumen (Orskov *et al.*, 1980).

The nylon bag technique provides a means of ranking feeds according to the rate and extent of degradation of dry matter, organic matter, nitrogen or other nutritional parameters. It involves incubating samples of feeds in the rumen of fistulated animals for periods of from six to 120 hours and subsequent determination of the disappearance of the different feed components (Orskov *et al.*, 1980).

1.5.2 Intake

Domestic ruminants utilize trees and shrubs as both browse and "cut and carry" branches in the stall. On rangelands, animals have the advantage of selecting from a wide choice of browse and obtaining high quality feed. Consumption of various types of forage reduces chances of poisoning. The "cut and carry" system obviates the limitation of inaccessibility of certain browse. The system also facilitates rational usage of fodder. Its disadvantages include damage to the trees due to injudicious lopping and the imposition of a limited variety of feed which may increase the risk of poisoning (Dicko & Sangare, 1984).

Regulation of intake in ruminants is primarily a function of physical fill for diets that are energetically bulky and less digestible, such as high forage diets; but intake becomes primarily a function of metabolic control for dense and highly digestible high concentrate diets. Cell wall concentration of forage diets is the best single chemical predictor of intake. Depression of dry matter digestibility associated with increased intake is less for legumes than for grasses (Milford & Minson, 1965a).

Voluntary intake is determined by offering animals a known quantity of feed and determining the amount at the end of the feeding period. Digestion and retention coefficients are determined by collecting all the excreta (urine and faeces) and analysing feed and excreta samples. The amount of some of the nutrients absorbed and retained in the body or stored can also be determined by analysing excretions such as urine (Osuji *et al.,* 1993a).

Mgheni (2000) conducted a trial to describe tropical forages in terms of its rumen degradability characteristics, digestion and passage rates of fibre and the resultant rumen pool sizes in order to estimate the physical fill and potential intake of tropical forages. The results demonstrated that intake of these forages can adequately be described from physical fill based on degradability characteristics, rumen pool size and passage rate of NDF measured by the rumen evacuation technique. The use of NDF parameters as predictors of voluntary feed intake is recommended as a realistic estimate of forage dry mater intake because NDF was found to be distinct from microbial and endogenous materials (Mgheni, 2000).

1.5.3 Rumen evacuation

Rumen digestibility of the dietary component is a function of the rate at which it is digested (k_d) and the rate at which it passes (k_p) from the rumen. Each rate expresses the fraction of the rumen component pool which is digested (k_d) or passes (k_p) from the rumen, per unit time. The use of markers has indicated that a decreased intake is associated with a decreased passage rate, increased rumen pH and an increased rate of digestion of NDF or its components (Robinson *et al.*, 1987). The components of rumen fibre kinetics are graphically explained in Figure 1.1 below.

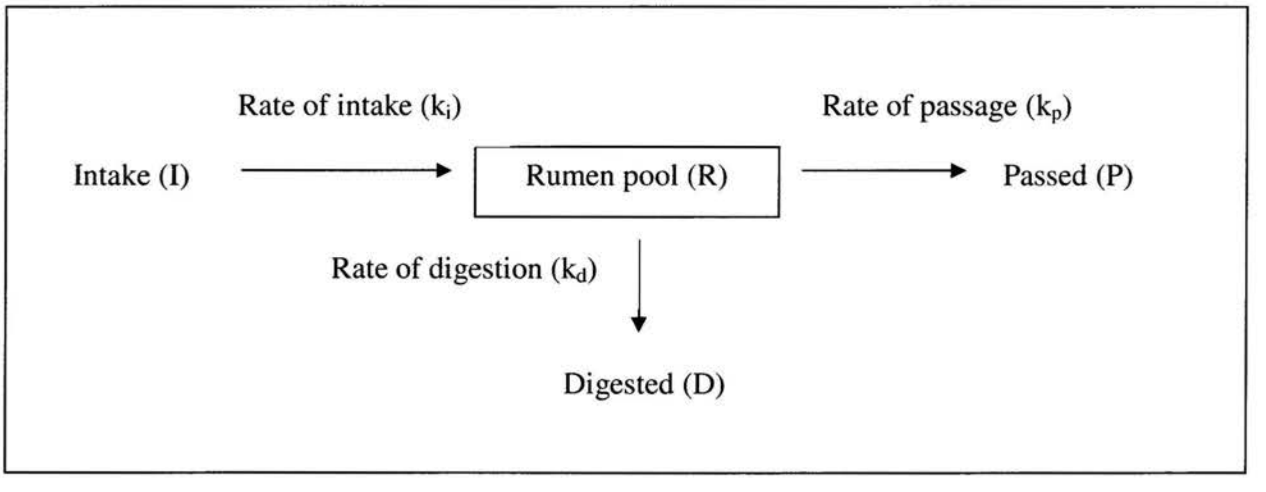

Fig. 1.3 Rumen fibre kinetics (Robinson *et al.*, 1987)

The complete removal and mixing of reticulorumen contents appears to be a valid technique in digestion studies. Rumen evacuation derived rates of digestion of fibre (k_d) are highly correlated with *in vivo* digestibility of fibre; therefore it is a useful technique in estimation of the rate of fibre digestion (Khalili, 1993).

Estimating the rate of fibre digestion in the rumen using the nylon bag technique gave results lower than the results based on the rumen evacuation data (Tamminga *et al.*, 1989). The porosity and closed surface area of the bags and the lack of rumination may provide some explanation for the different results. According to Tamminga *et al.* (1989), including rumen evacuation data in a rumen digestion model resulted in a level of rumen digestion which was much close to data observed *in vivo* than those based only on nylon bag incubations.

1.5.4 Flow rates

The extent of digestion of a feed depends on its rate of digestion and on the time the feed spends in the digestion pool. The animal's requirements are met from the digested component of intake. Flow rate is the rate (mass/time) at which digesta (feed or a marker) leaves a compartment per unit time. Flow rate or fractional outflow rate are estimated to determine the mean duration feed remains in the GIT, usually called the mean retention time (MRT). The time available for digestion in each pool ($t_{1/2}$) is also estimated since it is reported to have a strong positive correlation with OM digestibility (Grovum & Williams, 1977). Markers or rumen evacuation can be used to estimate both rumen volume and passage rates (Osuji *et al.,* 1993a). The determination of passage rate of NDF using the rumen evacuation technique, was much lower (Huhtanen & Khalili, 1991) than that based on chromium (Cr) mordanted straw particles (Huhtanen, 1988) in cattle fed similar diets. Aitchison *et al.* (1986), Robinson *et al.* (1987) and Tamminga *et al.* (1989) observed higher rates of passage (k_p) for the Cr-mordant than the value based on rumen evacuation. The reason for these different results is that mordant particles are not digested. Recent data (Tamminga *et al.,* 1989) showed that Cr-mordanted particles gave fairly accurate estimates of the passage of indigestible cell wall materials.

There are certain impediments to particle passage from the rumen, such as the fibre mat and reticulo-omasal orifice which affect the mechanism of particle passage. There are also factors which control the passage, these include; specific gravity of a feed particle which must increase so that it can drop from the mat into the liquid layer to pass through the rumen; size of particle must be reduced by rumination and microbial digestion, which allows for passage through the fibre mat and reticulo-omasal orifice; particle shape will also affect passage rate as well as rumen volume and motility (Firkins *et al*, 1998). Passage rates of animals with a higher rumen pool size will have a lower rate of passage than those with smaller rumens. Typical values for rate of passage of roughages are 1-6% per hour (Firkins *et al.*, 1998).

As the level of intake increases, the passage of liquid and solid digesta increase and where there is an increase in fibre concentration, the passage rate of liquid and smaller particles will increase. This effect of fibre varies with the type of roughage. When lucerne is fed as the forage the digesta separates into a liquid and fibre mat and the grain particles will fall into the liquid fraction. By increasing the amount of forage in the diet, there is an increase in rumination and therefore secretion of salivary buffers. These buffers increase the osmotic pressure of the rumen contents and therefore increase the passage of liquid digesta and grain which reduces grain digestibility in the rumen. An opposite example is one where cotton seed hulls are fed as the forage. These do not ferment as quickly as lucerne does and it also does not form a mat, but rather a homogenous mixture with liquid digesta and grain. Higher amounts of cotton seed hulls therefore reduce the passage rate of grain and increased rumination of the grain, increases digestibility in the rumen (Firkins *et al.*, 1998).

The time of day feeding can also affect the rate of passage but only really applies to protein supplements (Firkins *et al.*, 1998).

The rate of passage affects both rate and site of digestion. At a constant rate of digestion, increasing the passage rate will decrease the digestibility of a feed in the total tract and increase the proportion of digestion that occurs in the lower tract. The depression in digestibility associated with increased rate of passage is greater for starch than cellulose and may also be acceptable, if the increase in intake increases the total amount of digestible dry matter consumed. For example, in typical dairy rations a 0.9% increase in rate of passage will lead to a 1% increase in digestible dry matter intake. Grinding the feed will also be more effective in increasing digestible dry matter intake of low quality forages than high quality ones (Firkins *et al.*, 1998).

The rate of passage may also have an effect on the VFA production, where an increased rate of passage will decrease the total VFA production. This effect is associated with a reduced dry matter digestion. A higher turnover rate of the liquid fraction will increase the production and concentration of acetic acid, butyric acid and methane and decrease propionate (Firkins *et al.*, 1998).

1.5.5 Rumen fermentation

Rumen fermentation can normally provide about 70 – 100% of the amino acids supplied to ruminants while volatile fatty acids (VFA), the main end products of microbial fermentation, supply about 70-85% of the energy absorbed. Poor quality roughages are often unable to support rumen conditions that are conducive to optimal microbial activity because of their deficiency in total N, true protein, readily fermentable carbohydrates and minerals. Leguminous forages have a potential as high quality, low cost and readily available supplements and can contribute to better utilization of poor quality roughages (Tolera & Sundstol, 2000).

The ammonia-N in the rumen fluid is the key intermediate in the microbial degradation and synthesis of protein. However, rumen ammonia-N concentration only reflects the balance between production, absorption and incorporation into microbial cells (Tolera & Sundstol, 2000). An imbalance in energy and protein fermentation has been reported to cause an accumulation of rumen ammonia nitrogen and the rate of *in situ* DM and NDF degradation are slower, which could be a result of limited available energy for incorporation of rumen ammonia N into microbial protein (Melaku *et al.,* 2004). There is a lot of disagreement in literature concerning the optimum rumen ammonia-N level for microbial activity in the process of digestion. McDonald *et al.* (1996) put the estimates in a range of 85 -300mg/l NH_3-N rumen fluid, while Abdulrazak *et al.* (1997) indicated that rumen ammonia concentration of 50-80 mg/l NH_3-N rumen fluid could be sufficient for fibre digestion. In general, the minimum value of ammonia concentration for optimal rumen function could be variable depending on the type of feed (Tolera & Sundstol, 2000).

The quantities and relative proportions of the VFA present in the rumen depend on the type of fermentation, which in turn is determined by the microbial population which depends on the type of feed and feeding regime. The proportion of acetic acid usually increases with increasing levels of cellulose in roughage diets (Orskov, 1994).

In the study done by Melaku *et al.* (2004) the rumen fermentation pattern in sheep supplemented with the various leguminous trees was a typical fermentation pattern for roughage feeds, which is characterised with a high rumen pH. High rumen pH encourages growth of cellulolytic microorganisms and the synthesis of acetate as a major product of fermentation with low proportions of propionate and butyrate. This could be attributed to the high fibre concentration in the supplement feeds. Differences in molar proportions of rumen fermentation end products can influence energy metabolism pathways, thereby efficiency of feed energy utilization. Higher molar proportions of propionate in the trees and their mixtures may have decreased energy losses in inter-species hydrogen transfer and thereby, methane production in the rumen. Therefore, supplementation with the trees and their mixtures appears to be efficient due to the higher propionate production which has a positive relationship with efficiency of energy utilization (Van Houtert, 1993).

In an experiment done by De Visser *et al.* (1992) it was discovered that rumen fluid contents increased sharply after feeding, resulting in dilution of the VFA and buffering the pH to decline. In addition, rate of absorption from the rumen increases with higher VFA concentrations. The ruminant animal has a number of mechanisms which will prevent the average VFA concentration from rising above the maximum of 150 mmol/l (Tamminga & Van Vuuren, 1988), thereby preventing a drop in pH values that inhibit the rate of degradation. It is also been shown that the production of total VFA decreases linearly as intake declined (Robinson *et al.*, 1987).

1.6. Protein

A significant variation in CP concentration (6 to 23% DM) occurs between (tree and shrub) species and even between edible parts of the same plant. In general, leaves are higher in CP than stems, almost twice as much in the case of southern African browse according to Walker (1980). Leaves also contain more CP on average than the pods although the latter were characterized by a higher organic matter and digestibility. Leguminous species were found to contain 25-30% more CP than non-leguminous plants (Dicko & Sangare, 1984). Nitrogen retention is considered as the most common index of the protein nutrition status of ruminants (Melaku *et al.,* 2004).

1.6.1 Microbial protein production

Studies on the urinary excretion of purine derivatives by ruminants have been stimulated by the possible use of their excretion as an estimator of the rumen microbial protein supplied to the animal. This is because in ruminants nucleic acids flowing to the small intestines are essentially of rumen microbial origin. Absorbed purines are degraded to hypoxanthine, xanthine, uric acid and allantoin, which are excreted in the urine and should relate quantitatively to the amount of purines and hence microbial protein absorbed. However, some of these purine derivatives originate from the animals tissues, and the endogenous contribution has, therefore, to be quantified (Chen *et al.*, 1990).

Measurement of microbial protein supply to ruminants has been an important area of study in ruminant protein nutrition. An estimate of microbial protein contribution in the intestinal protein flow is incorporated into the new protein evaluation systems already being used in different countries. The supply of microbial protein to the animal per unit feed ingested, usually expressed as g microbial N/kg digestible organic matter fermented in the rumen (DOMR), varies by almost 4 folds (14-60gN/kg DOMR) (Agricultural Research Council, 1984). This variation is due to the influence of various factors relating to the diet or rumen environment. The effects of many of these factors have not yet been conclusively demonstrated or quantitatively defined (Chen & Gomes, 1992).

Microbial protein contributes a significant part (0.42-0.93) of the total protein flux into the small intestine in ruminants. Its proportion is usually determined with microbial markers, including nucleic acids, diaminopimelic acid (DAPA), 32P and 15N. These methods are tedious and require cannulated animals, infusion of isotopes and separation of rumen microbes. Cannulation can also cause some changes in digestion, may reduce intake and limits the amount of experimental animals. Many attempts have been made to find an indirect measurement of microbial protein synthesis in intact animals (Djouvinov & Todorov, 1994).

The microbial protein entering the duodenum can be estimated by quantification of urinary allantoin. The nucleic acids synthesized by the rumen micro-organisms are enzymatically degraded to purine and pyrimidine bases which are absorbed; their final products are excreted in the urine with allantoin being in the greatest proportion (Tebot *et al.*, 2002). Several authors have revealed a close relationship between microbial nucleic acids reaching the small intestine and the urinary excretion of purine derivatives, especially allantoin (McAllan & Smith, 1973 and Antoniewicz *et al.,* 1980). The relative contribution of allantoin to the total excretion within each animal is relatively constant, irrespective of purine output, therefore the measurement of allantoin alone could be used an estimator of the supply of purines. In ruminants, allantoin appears to originate predominantly from nucleic acids synthesised by rumen microbes (Antoniewicz *et al.,* 1980).

1.7. Fibre

The fibre components of feeds inhibits the intake of forages due to slow digestion compared to cell solubles (Van Soest, 1982), and a limitation on feed intake is apparent when fibre concentration of feeds contains more than 500g per kg of forage DM (Van Soest, 1965). However, Milford & Minson (1965) reported that forage intake dropped sharply when sheep were fed forages with CP levels below 70g/kg DM. The digestibility of feed is closely related to its chemical composition, and feed which varies in composition is more likely to vary in digestibility. The fibre fraction of feed has the greatest influence on digestibility, with both the amount and chemical composition of the fibre being important. When forages are heated with a neutral detergent solution, the cell contents are dissolved and the residue remaining is the NDF which contains the cell walls. The cell wall fraction is further divided into hemicelluloses and cellulose plus lignin (ADF) (McDonald *et al.*, 2002). The digestibility of the cell wall (cellulose) depends on the degree of lignification (lignin concentration of the ADF). Tropical forages generally have a lower digestibility because their leaves contain more vascular bundles, therefore more lignin, and their dense mass of cells resist digestion by micro-organisms (McDonald *et al.*, 2002).

1.8. Minerals

Mineral elements have various functions in the animal body and the concentration must be maintained to ensure functional and structural integrity of the tissues and to ensure that the growth, health and productivity of the animal are unimpaired (Underwood & Suttle, 1999). Large numbers of livestock in many parts of the world consume diets that do not meet the requirements which may lead to nutritional disorders, ranging from acute mineral deficiency or toxicity diseases to mild conditions where unsatisfactory growth, production and fertility are a result (Underwood & Suttle, 1999). There are many mineral interactions with other nutrients or minerals as well as animal and environmental factors which can affect their availability to the animal.

The concentration of minerals in forages depends on the species of plant, the type of soil on which the plant grows, the climatic conditions and the stage of maturity (Underwood & Suttle, 1999).

In foraging situations, the diet sample collected may not be a representation of the material actually eaten by the animal, because of selective grazing and soil contamination in the field. Animals show preferences for different plant parts, which can vary in mineral concentration. Estimates of mineral intake and plant composition do not take into account the absorption and utilization by the animal for example; zinc and manganese concentrations can be adequate when there are normal levels of calcium or phosphorus but deficient when high in those elements (Underwood & Suttle, 1999).

Leguminous species are generally richer in macro elements. The trace elements, notably iron, copper and zinc are also higher in legumes. Phosphorus concentrations decline with advancing maturity, as does the concentration of magnesium, zinc, copper, manganese and iron but not to the extent that phosphorus does. A decrease in mineral concentration with maturity is usually a reflection of increases in the proportion of stem to leaf, stems and older leaves have lower mineral concentrations than young plant parts (Minson, 1990).

The concentration of calcium and potassium is usually higher than that of other minerals; the average being around 1 to 1.5% for southern African browse (Walker, 1980). Some abnormally high concentrations of some minerals such as sodium chloride and selenium may be found in browse (Dicko & Sangare, 1984).

Trace minerals are essential components in the animal body for growth and the prevention of a wide range of clinical and pathological disorders. Some naturally occurring diseases were associated with a deficiency in trace minerals and were found to respond to trace mineral supplementation. There are also many documentations of interactions between trace minerals and other minerals, for example that of copper and molybdenum (Underwood and Suttle, 1999).

Very little is known about *C. sturtii* and *S. microphylla* regarding their intakes by ruminants and other nutritional effects they may have when given to ruminants as sole diets.

The value of these forages to provide animals with sufficient nutrients for maintenance during dry periods is a neglected topic.

The research in this thesis will investigate the effect of feeding these legume hays (*C. sturtii* and *S. microphylla*) compared to *M. sativa*, as sole diets to sheep on intake, digestibility, rumen parameters and microbial protein production.

Their role in alternative sources of feed for semi-arid regions and the reclamation of degraded rangelands warrants more research.