CHAPTER 1

INTRODUCTION

In the arid and semi-arid regions of the world, goats are the cornerstones of livestock production in both commercial and communal sectors. The majority of goats in the world exist on rangelands where seasonal feed shortages and low value of available feed resources are considered the most widespread technical constraints to small-stock production systems (Schlecht *et al*., 2006; Salem & Smith, 2008). These production systems are regarded as essential in many parts of the developing world (Mellado *et al*., 2004; Ouedraogo-Kone *et al*., 2006). The low quality and seasonal nature of forage supply, together with low intake rate by animals and poor digestibility of forage, contribute to the low productivity of goats (Shinde *et al*., 2000; Ngwa *et al*., 2000; Sanon *et al*., 2007). The processes governing digestibility are primarily defined by the forage being fed, whereas those governing intake are functions of the forage and the animal as impacted by its environment (Coleman *et al*., 2003).

The rangelands of Southern Africa support diverse and dynamic ecosystem that sustains wildlife, game and livestock farming (Tefera *et al*., 2008). In South Africa, approximately 80% (68.4 million ha) of land available for agricultural purposes can only be utilised effectively by free ranging herbivores (de Waal, 1990). Although the natural vegetation provides the bulk of the nutrients for domestic livestock and all the nutrients for wild herbivores (Harris *et al*., 1967), its ability to sustain animal production varies substantially according to climate, geography, plant community, bush encroachment and range deterioration (Keskin *et al*., 2005). Knowledge of the feeding behaviour, diet selection and nutritive value of the diets selected by free-ranging goats is of primary importance in estimating the productivity of any rangeland for any particular species of animal (Sanon *et al*., 2007). However, factors that affect the diet selection and food intake rate by goats are poorly understood (Dziba *et al.*, 2003; Torrano & Valderrabáno, 2005).

Grazing goats, therefore, exist in a highly dynamic situation where its productivity is primarily dependent on the net nutrient intake beyond maintenance requirements (Sun *et al*., 2008). Nutrient intake is, in turn, a function of the quantity and quality of the dry matter ingested (Dziba *et al*., 2003) which is regulated by a series of short-term decisions made by the goat such as which plants are selected and how long to search between bites (Gordon, 1995). In previous work (Mogorosi *et al.*, 1996; Raats *et al.*, 1996a; Raats *et al.*, 1996b; Dziba *et al*., 2003), it was found that goats prefer some species to others and that intake rates vary between plant species. Long-term decisions concern the length of time to spend feeding and where to feed (Gordon, 1995). This collection of decision-making factors is defined as the foraging strategy of the animal (Gordon & Illius, 1992). In general, individual grazers tend to focus on the nutrient rich items when resources are abundant, and increase the diversity of plant species in their diet when food availability decreases (Torres & Puig, 2010). Understanding the mechanism by which herbivores interact with forage resources and adjust foraging behaviour, is a driving force behind many research projects (Rogosic *et al*., 2007).

If the most efficient use of the plant and animal resources available in marginal areas is to be made, it is essential to improve our understanding of the foraging strategies of the goats which use these ecosystems (Gordon, 1995; Torrano & Valderrábano, 2005; Sanon *et al*., 2007). For achievement of acceptable levels of goat performance compatible with resource preservation, a deep knowledge of feeding behaviour, diet section, digestive and metabolic processes, nutritive values of feeds and nutrient/energy requirements is needed. Efficient utilization of available resources also requires the provision of data on plant density, forage species and phytomass at any specific site to define its carrying capacity and strategies of feed supplementation according to desired level of production (Lachica & Aguilera, 2003; Sanon *et al*., 2007; Yayota *et al*., 2009).

The reasons for studying the foraging behaviour of goats are to estimate intake and energy budgets; to understand the relationship between resource distribution, sward structure and herbage intake; to explain between-animal variation in intake and performance in relation to animal nutritional status, grazing regime and management practices and to provide answers to questions about the distribution and impact of livestock on the vegetation. Included is the effect of climatic conditions and land use on the relative use of resources by herbivores (Gordon, 1995).

A further reason for measuring the diet composition of range animals (plant species preference, nutrient composition and harvesting rate of different plants) is to rank plant species according to their potential feeding value in different animal production systems. An understanding of diet selection and intake rates by ruminants on rangelands underpins efficient management and profitable animal production (Torrano & Valderrábano, 2005; Sanon *et al*., 2007). This plant value system provides a basis for the assessment of veld condition in relation to both primary and secondary production (Gordon, 1995).

Knowledge of the grazing animal's food habits and forage preference is fundamental to the effective design of grazing systems, the evaluation and prediction of the effects of grazing use on plant communities and formulation of economical supplementation programmes on nutritional deficient ranges (Malecheck & Leinweber, 1971; Lachica & Aguilera, 2003; Sun *et al*., 2008). However, not much is known about the feeding behaviour, plant species selection and digestive efficiency of free ranging Tswana goats or how they compare to Boer goats.

The North West Province is a semi-arid area characterised by low rainfall which results in seasonal shortages and low quality of available feed resources. The majority of farmers in the area obtain their livelihood from goat farming as goats are able to survive under harsh environmental and nutritional conditions. The two most common goat breeds in the North West Province are indigenous Tswana goats and the Boer goats which are kept in communal grazing lands. The feeding behaviour and diet selection of Boer goats is well documented, but not much is available on the Tswana goat, even though many farmers insist that these goats are superior. In order to practice sustainable goat production in the North West Province, farmers must be provided with information about the nutrient requirements of the goats and the available feed resources and their utilization within the animal body. The current study aimed at obtaining such information by conducting research on the feeding behaviour, plant selection and digestion efficiency of these free ranging goats. Tswana and Boer goats being the common breeds in the Province, the study examined both breeds to ascertain if any differences do exist and to improve available knowledge on the feeding behaviour and diet selection. Results of the research will give a clear understanding of factors affecting the feeding behaviour, diet selection, nutrient content and digestibility of forages selected by free ranging goats.

1.1. Objectives

The objectives of the study were to:

1. Compare diurnal changes in feeding behaviour and plant species selection of the Tswana and Boer goats (variation within and between breeds) during the cold-dry season and the hot-wet season;

2. Compare the nutritive values of feeds selected by the Tswana and Boer goat during the cold-dry season and the hot-wet season; and

3. Determine the rate of ruminal degradability of the three most preferred bush species selected by the Tswana and Boer goats during the cold-dry season and the hot-wet season using *in sacco* digestion.

1.2 Hypotheses

1. Indigenous Tswana goats spend more time browsing than the Boer goats, and time spent browsing will be influenced (negatively) by the availability of forage.
2. Indigenous Tswana goats and Boer goats have different diet selection patterns between browse species.
3. Indigenous Tswana goats tend to select more nutritious diets than do the Boer goats.
4. Indigenous Tswana goats are more efficient at digesting fibrous forage than do the Boer goats.

CHAPTER 2

LITERATURE REVIEW

2.1. Origin of goats

Goats were amongst the first animals to be domesticated for the production of meat, milk, skin and fibre (Anbarasu *et al.*, 2004; Webb & Casey, 2010). Originating in Asia before 7500 BC, goats have spread all over the continents and inhibit almost all climatic zones from the arctic circle to the equator. Goats belong to the genus *Capra*, within the tribe *Caprini* of the family *Bovidae*. The world's goat population is today over 750 million (Lu *et al.*, 2010). In 2005, South Africa had a goat population of about 6.4 million (Statistics released by FAO in 2006). In South Africa goats are found predominantly in the Eastern Cape (EC 2 483 811), Limpopo (LP 1 062 814), KwaZulu Natal (KZN 855 426) and North West (NW 782 860) provinces as shown in Figure 2.1.

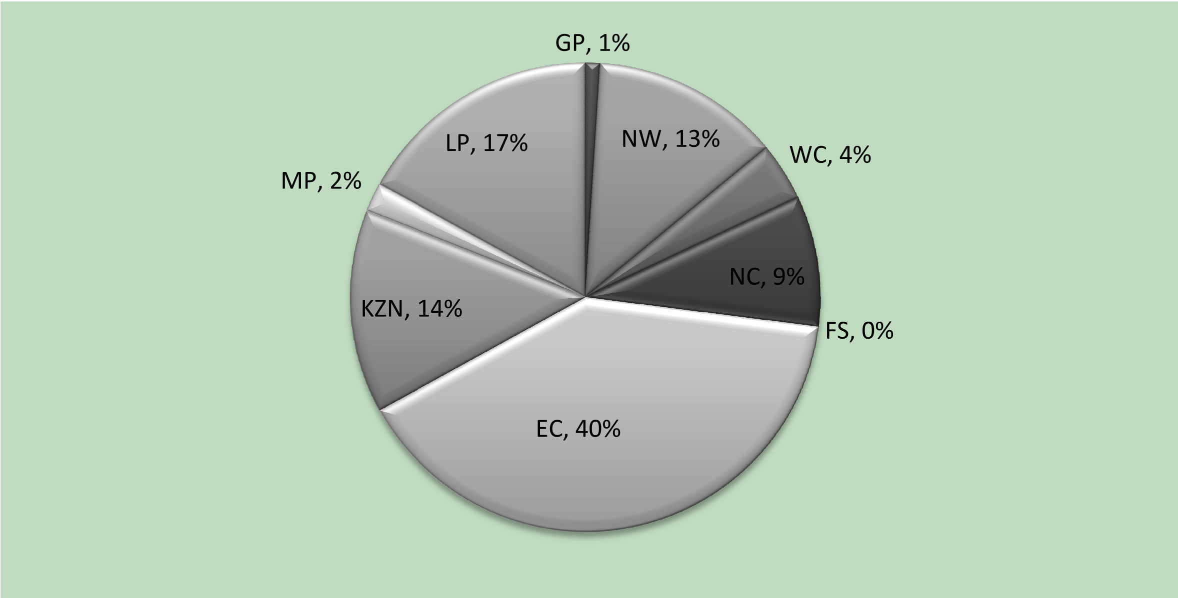

Figure 2.1. Distribution of goats in the different Provinces of South Africa (Gauteng = GP, North West = NW, Western Cape = WC, Northern Cape = NC, Free State = FS, Eastern Cape = EC, KwaZulu Natal = KZN, Mpumalanga = MP, Limpopo)

2.1.1. The Indigenous Tswana goat

The majority of goats and sheep in Africa are indigenous types, although both species were originally domesticated in Asia (Bjelland & Grøva, 1997). Their genetic resources have evolved under the stress of the African environment and are well adapted to the local conditions. Indigenous types constitute over 95% of the small ruminant population of Africa (Rege, 1994). However, there are hardly any indigenous goats which have been adequately characterised. The goats are owned by the majority of small-scale rural farmers, for whom this resource is critical for nutrition and income.

In the past, South Africa possessed a wealth of indigenous livestock which were well adapted to the harsh environment of this region. The majority of the indigenous livestock were traditionally kept under substantially lower levels of nutrition, management, disease control and higher temperatures than exotic breeds. The desired characteristics of these breeds were, therefore, masked to such an extent that they were generally regarded as inferior to the exotic breeds (Bjelland & Grøva, 1997).

The Tswana goat is a multicoloured medium size breed with long lopping ears, short coarse hair structure and is predominantly bearded and horned (Katangole *et al*., 1996). The apparent wide variation in coat colours and hair structure among Tswana goats is indicative of the fact that the breed has not been purified through selection and therefore great opportunities exist for its improvement. The propensity towards white coat colour and/or white in combination with other colours especially black and brown, appears to be an adaptive trait to withstand pronounced seasonal fluctuations in the intensity and duration of light, heat and cold (German, 2008). Tswana goats are mainly found in Botswana and Bophuthatswana (Mafikeng) (FAO, 1991).

In the arid and semi-arid regions, indigenous goats should be the cornerstones of livestock production in both commercial and communal sectors. Their supposedly inferior production was a misconception due to a very narrow definition of production. If production is simply measured as growth rate or milk production per animal, then the European breeds outperform the indigenous breeds. But if maintenance cost, reproduction and mortality are considered, then indigenous breeds often outperform the so-called improved breeds (De Lange, 1994).

The accelerating demand of a growing human population and the pressure of economic development, are affecting the security and survival of many indigenous African breeds. Indigenous breeds are, therefore, threatened, even though they have been naturally selected for the local environments and are therefore best adapted (Bjelland & Grøva, 1997).

On the basis of body size and height at the withers, the Tswana goat can be classified as a medium size breed, according to one of the goat classification criteria suggested by Devendra and McLeroy (1988). Male goats generally grow faster and are heavier with superior body conformational measurements than female goats. Age significantly affects body traits. Tswana goats breed all year round. The recovery capacity of goats from drought is remarkable and is due to their efficient reproductive behaviour which includes twinning and shorter kidding intervals. Tswana goats have low maintenance requirements which become an advantage in unfavourable environments (Horst, 1984).

2.1.2. The Improved Boer goat

The origin of the Boer goats is vague and probably rooted in ancestors kept by Namaqua Hottentots and migrating tribes of "Southern Bantu" people. The Boer goat is an improved indigenous breed, which consist of a mixture of blood from various goats, principally those from Eastern countries and India (Erasmus, 2000). The occurrence of polledness indicates some possible influences of the European, Dutch dairy goat (Steele, 1996). Considering migratory and trade practices of early inhabitants of Southern Africa, it seems evident that the Boer goats contain genes from these pools. The Boer goat was observed as early as 1661. The noun "Boer'' means farmer in Dutch, and was used to distinguish the Boer goats from the Angoras imported in the nineteenth century (Casey & Van Niekerk, 1988).

Three types of un-improved Boer goats are recognised (Devendra & McLeroy, 1982): common Boer goat, medium in size, with short glossy coat which is white in colour with brown spots on reddish brown heads and necks; long-haired Boer goat, larger, heavier and late maturing; and polled multi-coloured Boer goat with distinct dairy conformation, suggestive of the influence of introduced milk breeds.

The fact that makes the breeding history of the improved Boer goat unique is that the breed was not created from two or more pure breeds, as is the case with other varieties of animals bred in South Africa. Rather, the prototype for the breed was selected from all existing breeds of goats in South Africa to achieve the functional characteristics and type as they are today, hence the name improved (or ennobled) Boer goat (Malan, 2000). This pioneer work was chiefly carried out by a handful of farmers in the Eastern Cape, particularly in the district of Somerset East. The highlight in the history of the Boer goat was when the Boer Goat Breeders Association of South Africa was founded on 4 July 1959 at Somerset East (Casey & Van Niekerk, 1988; Malan, 2000).

The South African Boer Goat Breeders Association adopted a purposeful breeding policy and applied strict selection guidelines. Breed standards stipulate the ideal colour of the improved Boer goat to be white with a red head and blaze. A limited number of red patches are allowed. A pigmented skin is preferred, particularly in areas with no hair cover. Furthermore, they must be robust, with good conformation and have a Roman nose. Legs must be short, well fleshed with good thighs and hind quarters, which is important for good carcass characteristics (Casey & Van Niekerk, 1988). The improved Boer goat is a remarkable small-stock ruminant that posses distinctive qualities enabling it to excel as an efficient red meat producer (Erasmus, 2000).

Boer goats are very fertile and not seasonal breeders. The goats have multiple births with an average kidding percentage of 180 which exceeds the average attained by other livestock. They are early maturing and at the age of one to one and a half years, a significant number of ewes produce multiple kids. The mean body weight of the adult ram varies between 100 and 120 kg while that of does varies between 70 and 80 kg (Erasmus, 2000; Malan, 2000). The Boer goat yields lean meat of high quality which is succulent, tender, extremely attractive and tasty (Malan, 2000). Goats should be marketed between the ages of 6 to 15 months and the carcass should weigh no more than 23 kg. Growth rate of kids is associated with sufficient milk production by the doe and good mothering instincts (Casey & van Niekerk, 1998; Erasmus, 2000). The Boer goat is able to maintain economic production up to the age of approximately 10 years (Malan 2000).

2.2. Importance of goats

The special attributes of goats that make them particularly important in rural resource poor communities compared to other domestic ruminants include: ability to graze and utilize a wide range of poor quality forages and browse (Misra & Singh, 2002; Keskin *et al*., 2005); ability to walk long distances in search of feed (Morand-Fehr *et al*., 2004); short generation intervals and high reproductive rates; high turnover rates on investment and hence low risk on investment (Lebbie, 2004); low maintenance costs (Misra & Singh, 2002); high energetic efficiency of milk production; efficient utilization of marginal lands; smaller carcasses which are conveniently marketed or consumed over a short time period which is an important factor in rural areas without cold storage; and a good flocking instinct which makes herding by younger and older members of the family possible (Malan, 2000; Lebbie, 2004).

Within the African society, goats comprise a great proportion of the total wealth of poor households (Peacock, 1996). In general, goats do not contribute much to direct income earnings in rural households. As tangible financial assets, however, goat product consumption and sales enhance economic stability of households in times of crop failures and currency fluctuations (Lebbie, 2004; Morand-Fehr *et al*., 2004). Goats provide immediate cash to meet day to day family needs and off-farm inputs for crop production and thus contribute to the sustainability of agricultural production (Misra & Singh, 2002; Morand-Fehr *et al*., 2004). Goat keepers assist in meeting local demands for animal products but also indirectly enhance national economic stability through the reduction of foreign currency expenditure on importation of these products to meet domestic demands. Goat keeping provides employment for the rural poor women and their children, whose responsibility is to take care of the goats (Lebbie, 2004).

Goats contribute meat, milk, fibre, leather and other functions that are significant to the productivity, stability and sustenance of many farming systems (Sheridan *et al*., 2003; Anbarasu, *et al*., 2004; Lebbie, 2004; Sahlu, *et al*., 2004; Salem & Smith, 2008: Lu *et al*., 2010). Goats in developing countries are generally an integral, but not dominant component of complex agricultural systems. It is in countries with low per capita income (less than US $150) that goats are heavily concentrated, especially in South East Asian region and in the sub-Saharan Africa, where estimates show that approximately 70% of the human population is undernourished (Devendra, 1981). It is believed that goats could make a much greater contribution towards meeting the protein needs in developing countries (Bjelland & Grøva, 1997). The potential for goats to contribute to the attainment of food security, economic development and environmental sustainability is tremendous (Lebbie, 2004; Sahlu *et al*., 2004).

Goats have a number of biological and behavioural characteristics that make them preferable to cattle and other large ruminants. Goats produce more meat and milk per unit of feed than other ruminants (Okello & Obwolo, 1985). Most goat populations inhabit harsh environments with extreme climatic fluctuations (Iniguez, 2004; Morand-Fehr, 2004). The ability of goats to adapt to a wide range of climatic and nutritional conditions could possibly be accounted for by their unspecialised grazing habits and their ability to assume a bi-pedal stance that greatly maximises the available grass and tree stratum within a given area (Lu, 1988; Mellado *et al.,* 2004). In arid and semi-arid regions, the harsh environments cannot support crop production in a reliable manner. The communities in these environments depend largely on indigenous livestock breeds raised under traditional nomadic and transhumant pastoral systems based upon communal grazing. Goats, because of their unique adaptive capacity to harsh environments, feature very well among the households (Lebbie, 2004).

The most common concept of goats influencing the vegetation is their use as a biological means of controlling bush encroachment (Morand-Fehr *et al*., 2004; Yayneshet *et al*., 2008) in mixed livestock systems, thereby optimising the use of diverse rangeland resources (Dziba *et al*., 2003; Torrano & Valderrábano, 2005). It has been well documented (Merril & Taylor, 1981; Morand-Fehr *et al*., 2004) that goats can be used to positively modify the vegetation cover, particularly to clear areas rich in bushes, shrubs, thorny vegetation or under the canopy in woods, so that afterwards other species such as cattle and sheep can graze a more nutritive vegetation and have more open areas, while at the same time the spread of veld fires can be reduced or avoided.

Goats have been successfully utilized for the biological control of weeds and the improvement of grazing capacity of ranges (Radcliffe, 1985; Lebbie, 2004). In mixed species situations, goats complement cattle and sheep rather than compete with them for feed, because of their inherent ability to utilise a wide variety of plant species (Lebbie, 2004).

Manure and urine from goats is an invaluable source of organic fertilizer for maintaining or improving agricultural production (Lebbie, 2004; Azeez *et al*., 2010). While its contribution is limited, it is important where most rural goat keepers cannot afford the expensive inorganic fertilizers for use in their traditional low-input crops and horticultural production systems (Lebbie, 2004).

Most studies have shown that roughages with a higher fibre and low nitrogen contents are digested to a greater extent in goats than in sheep (Sheridan *et al*., 2003; Morand-Fehr *et al*., 2004; Gazmi-Boubaker *et al*., 2006). Thus it has been suggested that goats would be superior to sheep in digesting forage cell wall (Domingue *et al*., 1991; Morand-Fehr *et al*., 2004). Goats have been shown to be also more efficient at digesting tannin-rich feedstuffs (Odenyo *et al*., 1999) and the ability to detoxify higher amounts of tannins compared to other ruminants (Silanikove *et al*., 1996).

Special feeding habits of goats typical for the species differ from those of other ruminants and are the basis for much of the criticism directed at goats. It is often suggested that goats are destructive grazers (Bellingham *et al*., 2010), grazing more closely on bushes and grass, thereby reducing chances of plant regeneration from seedlings (Gihad *et al*., 1980; Lebbie, 2004; Morand-Fehr *et al*., 2004; Animut & Goetsch, 2008). However, Gihad (1976) and Morand-Fehr *et al*., (2004) reported that those criticisms of the goat are really a result of overstocking and the lack of good, scientific husbandry and management.

2.3. The natural vegetation

At least one third of the world's land surface may be considered natural grazing grounds (Le Houèrou, 1980). Natural grazing is our most valuable natural resource as it is the basis for animal production (De Lange, 1991; Sanon *et al*., 2007) contributing to the protein supply of mankind. The rangelands of Southern Africa support diverse and dynamic ecosystems that sustain wildlife, game and livestock farming (Tefera *et al*., 2008). The most important use of vegetation is as a nutrient source for many grazing animals (Kawas *et al*., 2010), and is thus changed with regard to the diversity and structure by the herbivores (Hodgson & Illius, 1996). Grazing ruminants thus form the backbone of most of the world's ruminant livestock enterprises (Gordon, 1995).

In Africa, over 250 million head of domestic animals live in natural grazing areas, classified as arid, semi-arid and montane, where browse plays an essential role in animal production (Le Houérone, 1980). Approximately 80% of the total area of South Africa consist of meadows and pastures (Britannica World Data, 1988) much of this being semi-arid. In semi-arid Savannah, two clearly defined forage resources are available: grass and bush. Forages provide an important source of minerals for ruminants in preventing diseases and stimulating ruminal microbial activity (Spears, 1994). Viewed holistically, the most economic farming system here would be one where browse and grass are used together in order to achieve maximum sustained production per unit area (Aucamp *et al*., 1985). Sustainable use of this valuable resource, which ruminants convert to food and other products for human consumption, is essential for the well being of the rural population (Bjelland & Grøva, 1997).

In South Africa, pastoralism or extensive animal farming is the most widely practised form of land use, as almost 75% of the agricultural area in South Africa is suitable for extensive livestock production only (Raats, 1996). The amount of forage available to grazing animals depends on season, but is also influenced by land-use patterns (Schlecht *et al*, 2006). Thus, for the purpose of maintaining sufficient growth and reproductive performance, animal producers and wildlife managers need to comprehend the heterogeneity, variability and nutritional changes of ranges (Ramirez *et al*., 2004; Agreil & Meuret, 2004). This indicates the extent of implications and potential of knowledge on the science of free range ruminants. Understanding the foraging strategy in combination with the anatomical and physiological adaptation of goats is important for the management of both vegetation and goats in traditional pastoral systems (Mellado, 2005).

2.4. Feeding behaviour of goats

Free ranging animals respond to the quantity and distribution of vegetation on offer by altering their foraging behaviour (Gordon, 1995). The primary foraging variables which researchers are interested in are time spent on, feeding activities (browsing/grazing and plant species selection), non-feeding activities (walking, standing, lying, drinking) and rumination.

2.4.1. Grazing and browsing

Goats are opportunistic foragers (Lu, 1988; Sharma *et al*., 1998; Ngwa *et al*., 2000; Kawas *et al*., 2010) that can adapt to a wide range of climatic and nutritional conditions as well as rough country (Gihad *et al*., 1980; Animut & Goetsch; 2008). The ability of goats to adapt to these conditions could possibly be accounted for by their higher tolerance for bitter substances and their relatively unspecialised feeding habits. The use of browse by goats is probably an important factor where herbaceous forage quality is poor and does not provide minimal nutrition to support cattle and sheep (Sidahmed *et al*., 1981; Papachristou, 1996; Animut & Goetsch; 2008). The high degree of browsing by goats could be due to several morphological features related to the foraging behaviour which apparently contribute to the goat's success as a browser. These include the mobile upper lip and tongue that give goats a greater ability to harvest forages from the shortest grasses and forbs to the thorniest shrubs (Lu, 1988; Mellado *et al*., 2004) and the ability to assume a bi-pedal stance when feeding (Taylor & Kothman, 1990; Ngwa *et al*., 2000; Mellado *et al*., 2004). Among domestic animals, goats alone seem to possess this bi-pedal stance trait (Ngwa, *et al*., 2000). The bi-pedal stance greatly maximises the available grass and tree stratum within a given area and gives goats the advantage of foraging overhead, thus increasing the quantity of forage available in wood and shrub lands (Lu, 1988; Ngwa, *et al*., 2000).

Browsing horizons up to 2m in height by goats commonly occur in areas where trees and hanging vines are abundant (Lu, 1988). This is particularly important during the dry season when the ground layer forage is either dry or depleted from grazing and decomposition (Ngwa *et al*., 2000). Goats in arid environments survive on diets composed mostly of browse (Ramirez *et* *al*., 1993; Provenza, 1995; Ammar *et al*., 2008; Ramírez-Orduña *et al*., 2008; Kumara Mahipala *et al*, 2009), which is least affected by drought (Silanikove, 2002). Kadzere (1995) suggested that in southern Africa, the importance of browse increases with increasing aridity.

Goats will walk long distances in search for food (Bjelland & Grøva, 1997) and are thus exposed to a greater variety of forage species (Gihad *et al*., 1980). The extent of travelling is dependent on forage availability, water resources, comfortable resting areas, season of the year, size of the goat and other animal factors. Goats are alert and inquisitive in their environment (Sharma *et al*., 1998). Eye level feeding is a common foraging posture and has been considered a valuable mechanism for protection from predators. A secondary benefit from this behaviour is the reduction of the risk of infection by parasite eggs found on surface vegetation (Lu, 1988). Although goats generally orient towards the wind, they have been observed to evaluate an area upon arrival and subsequently direct the foraging path towards brushy areas (McMahan, 1964).

Based on their ability to browse shrub, grass and tree foliage, ruminant species have been classified as grazers or browsers (Gordon, 2003). Goats are neither exclusively grazers nor exclusively browsers (Lu, 1988). Goats are able to graze short grass and to browse on foliage not normally eaten by other domestic livestock. The exceptional economic value of goats lies precisely in their ability to utilise certain plants which are less appetising to other stock breeds (Malan, 2000). Goats, being the most rugged grazers of domestic livestock, prefer browse plants which form approximately 60% of their diet, the other 30% is made up of grasses and 10% of selected forbs when available (Gihad *et. al*., 1980, Malecheck & Provenza, 1981). This shows a heavier dependency of goats on browse, irrespective of the presence of the opportunity to choose between browsing and grazing (Lu, 1988).

The shift between browsing and grazing by goats is largely dependent on the availability of browse and grass (Lu, 1988; Mogorosi *et al*., 1996; Dziba & Raats, 1998). The ratio between grazing and browsing, is however, subject to drastic change, depending on prevailing conditions (Lu, 1988; Raats & Tainton, 1992). Seasonal and geographic variations and intensity of stocking appear to influence the nature of the intake (Pontes *et al*., 2010).

Goats have thus developed a unique feeding behaviour (Raats & Tainton, 1992) which set them apart from other species of livestock (Lu, 1987). The unique feeding behaviour together with the inquisitive feeding habits, enables goats to thrive in dry areas receiving less than 750 mm of rainfall (Bjelland & Grøva, 1997) and with little high quality forage (Ouedraogo-Kone *et al*., 2006). The foraging behaviour is central to understanding plant-herbivore interactions, efficient management of gazing systems and eventual profitability of the livestock enterprise (Ungar, 1996; Torrano & Valderrábano, 2005; Sanon *et al*., 2007).

2.4.2. Plant species selection and plant preference

Under rangeland conditions, the herbivore is surrounded by an apparent super-abundance of potential food items (Mogorosi, 2000). Grazing herbivores select from structurally and chemically diverse spectrum (Fraser *et al*., 2009). Selection of individual sward components by grazing herbivores can influence animal performance through variation in both the quality and quantity of ingested forage material (Wilmhurst *et al*., 1999). Diet selection is a functional category of the general feeding behaviour of animals and is defined in terms of the outcomes of behaviour (Hughes, 1993). The fact that grazing herbivores exhibit dietary selection has long been established (Emlen, 1966; Bell, 1971; Raats, 1993; Sun *et al*., 2008), but the basis upon which animals select their diets has been a point of contention among scientists (Dziba, 2000).

Several hypotheses have been suggested to explain diet selection. Some experiments have advocated diet selection based on intake rate (Spalinger *et al*., 1986), or nutritional balance (Alonzo-Diaz *et al*., 2008; Berteaux *et al*., 1998; Rafferty & Lamont, 2007; Sanon *et al*., 2007; Baraza *et al*., 2009; Stolter *et al*., 2009), while others suggested that the density of the vegetation (plant species and the relative abundance of each) is the basis of selection (Black & Kenney, 1984; Merril & Taylor, 1981; Murden & Risenhoover, 1993; Barroso *et al*., 1995; Schlecht *et al*., 2006; Sanon *et al*., 2007). Others suggest that plant height and species mixture is the basis of the discrimination (Newman *et al*., 1995). The ability of the animal to select sufficient quantities of nutritious plant material is affected by animal related factors (genetic makeup, prior experience or conditioning, prevailing nutritional and the physiological state of the animal) as well as environmental factors (environmental temperature due to seasonality, topography, heterogeneity of the vegetation, availability or abundance of various plant species (Raats & Tainton 1992; Keskin *et al*., 2005; Celaya *et al*., 2007; Ellis *et al*., 2005). What a goat actually chooses to eat is determined by the selection criteria which will alter as the relative quantities and qualities of items change (Pellew, 1984). Most importantly, the understanding of the relationship between resource availability and intake rate underlies the prediction of foraging choices in heterogeneous systems (Spalinger *et al*., 1988, Ungar, 1996)

Goats are more selective feeders than cattle and sheep (Van Soest, 1982). Diet selection is a major determinant of animal and plant production through its effect on sward structure and plant parts remaining for selection as time passes. Plant species selection or preference and physical activities (feeding/non-feeding) constitute an important part of behaviour of range animals (Bjelland & Grøva, 1997). Preference or acceptability indices can be used as evidence of feed selectivity and to rank different species, in a given environment, in terms of their relative acceptability by a category of animals (Owen-Smith & Cooper, 1987). Preference indices are useful tools for different management decisions, such as determining carrying capacity studying plant-animal interactions and modelling range utilisation (Nelson, 1978; Duncan, 1983).

It appears that the physical structure of plants, and its interaction with nutritional value (Westoby, 1978; Fraser *et al*., 2009), plays an important role in feed selectivity of goats (Genin & Pijoan, 1993). Goats tend to select a diet containing a higher proportion of green leaves and a lower proportion of stems and dead material than is in the pasture (Flachowsky & Tiroke, 1993). The fractions which goats most often select, the buds, leaves, fruits and flowers, contain less fibre and more protein and are thus more digestible than stems and petioles (Lu, 1988; Ouedraogo-Kone *et al*., 2006; El Aich *et al*., 2007; Baraza *et al*., 2009). Alonso-Diaz *et al*., (2008) state that goats may be able to discriminate among feeds in order to select those with higher digestibility.

Animals expand their diet to include other food types as food availability from favoured species decline over the seasonal cycle (Owen-Smith, 1997; Alonso-Díaz *et al*., 2008; Yayneshet *et al*., 2008). Animals may also increase their feeding duration in patches of food plants and adjust foraging paths (Ungar, 1996). Diet selection may also be affected by period of occupation and stocking rate (Mbuti *et al*., 1996; Raats *et al*., 1996a).

The most direct influence animals have on the plant community is through their diet selection (Hughes, 1993). Diet selection is important for understanding fundamental ecological interactions between animals and their habitat (Pyke, 1984). It also determines which plants are consumed and where, when and to what degree they are consumed (Gordon, 1995). Diet selection, therefore, is a central process in the herbivore plant interactions, with consequences to the structure, species composition and ecological relations of plant communities and their ecosystems (Nantis, 1997; Illius *et al*., 1999).

2.4.3. Diurnal variation in feeding

It is known that ruminants can have 8 and 10 grazing periods per day (Arnold, 1962). Diurnal variation in the feeding behaviour of goats has been observed by Dumont *et al*., (1995) and Bjelland & Grøva (1997). Similar variations were also found in the diet composition of fistulated animals, in nitrogen content (Langlands, 1965; Hodgson, 1969; Obioha *et al*., 1970), lignin (Obioha *et al*., 1970), digestibility (Hodgson, 1969) and botanical composition (Coates e*t al*., 1987). Two major feeding periods are normally recognised in both extensive and intensive systems (Lu, 1988). Askins & Turner (1972) reported that the morning feeding period commenced at daylight and continued until mid morning. The second major meal began about 3 hours prior to sunset and lasted until darkness. Minor meals were reported to last about 1 hour and occurred at mid-day. However, this diurnal pattern is modified by factors such as frequency of feeding, amount of feeding, forage availability and environmental stress such as heat and rain (Lu, 1988). In their study, feeding behaviour of goats changed extensively throughout the day. On average, morning feeding period was dominated by browsing (43%) while grazing was the dominant activity in the afternoon (41%).

2.4.4. Rumination and non-feeding activities

Goats can spend more than one-third of their time ruminating (Lu, 1988). Bell & Lawn (1957) reported that the time spent ruminating ranged from 3 hours 22 minutes to 13 hours 12 minutes per day in apparently healthy goats. Lu (1987) on the other hand reported that the average time spent in ruminating ranged from 5 hours 48 minutes to 7 hours per day in goats depending upon the particle length of forage. Bell & Lawn (1957) reported that during the night hours (20h00 to 08h00) a large portion of the time was spent on rumination. Forage particle length, amount of forage fed and thermal stress are some of the factors affecting rumination time in goats. Forage particle length and amount of forage fed are positively correlated with rumination time (Lu, 1987) while environmental temperature is negatively correlated (Appleman & Delouche, 1958). Goats have been observed to spend (31%) of their time on non- feeding activities both in the morning and afternoon feeding periods (Bjelland & Grøva, 1997).

2.5. Techniques to measure the foraging strategy of free-ranging goats

The present review on techniques to measure the foraging strategy of goats is extensively based on the review by Gordon (1995) and will be limited to animal-based techniques only.

2.5.1. Feeding behaviour

The oldest and most frequently used method for measuring feeding behaviour is by direct observation, usually recording events with a manually operated data logger or video recorder. As with most observational techniques, this method is time consuming, it is difficult to collect data over a 24 hour period without night vision equipment, and the presence of a human observer can alter the behaviour of even tame animals (Gordon, 1995). To avoid these problems, a number of mechanical and electronic devices have been developed to measure one or more of these variables automatically. These systems monitor leg or jaw movements (Penning, 1983; Alkon *et al*., 1989; Janeau *et al*., 1987; Matsui & Okubo, 1989) for estimating the rate and interval between bites and grazing time which allows the differentiation between grazing and ruminating. Most of these devices were developed for use on cultivated pastures and are generally found less effective under natural grazing conditions due to the transducer being punctured by thorns.

2.5.2. Intake rate

Reviews on the methodology to determine the intake of grazing ruminants are available by Van Dyne (1969), Cordova *et al.* (1978) and Allison (1985). Generally, intake is divided into short- and long-term intake rates. Short-term intake rate is normally measured over a period of not more than one hour and is defined as a combination of bite size and rate of biting, with units given in mg s^{-1} or g min^{-1}. A number of techniques are available to estimate the short-term intake rate. Firstly, it can be estimated by the visual monitoring of the size and rate of bites from tamed, free ranging animals, followed by clipping or hand-plucking simulated bites from the vegetation (Bjugstad *et al.*, 1970). Secondly, changes in body mass during grazing, using very accurate balances or pressure transducers attached under each hoof, are used to determine short-term intake rates (Penning & Hooper, 1985). The third option is to determine the number of boluses swallowed by measuring the changes in the geometry of the oesophagus (Stuth *et al.*, 1981) or the change in the conductance or pressure on an oesophageal cannula (Forwood *et al.*, 1985) with the passing of food boluses down the oesophagus. Finally, short-term intake rate and bite size can be estimated from the amount of extrusa obtained from oesophageal fistulates over a known time period and the simultaneous recording of bite rates (Stobbs, 1973). The development of the remote controlled oesophageal fistula valve (Raats & Clarke, 1992) makes it possible to even measure harvesting rates per bite or unit time of specific plant species under free range conditions (Mogorosi *et al.*, 1996). According to Gordon (1995), the oesophageal fistula method appears to provide the most accurate estimate of intake rate per bite. An alternative approach to estimate short-term intake rate is to present plant material to animals confined in pens, arenas or using a 'grazing cage' (Burlison *et al.*, 1991; Gordon, 1995).

Techniques for measuring long-term (daily) intake rates are based on either the rate of depletion of offered forage or the amount of herbage ingested using internal or external markers. Gordon (1995) states that the majority of pasture-based methods are of limited value except on simple swards. The reasons for the limited value are (a) errors associated with measurement of pasture growth and senescence, (b) the difficulty in estimating intake from vegetation community mosaics, (c) the inability to provide estimates of between-animal variation in intake and (d) problems in estimating intake by individual animal species in multispecies grazing systems. Markers, on the other hand, provide a more direct measure, though the estimation of faecal output and digestibility on which this method relies, has its own set of problems and errors. More recently, however, the use of long-chain *n*-alkanes as both internal and external markers (Mayes *et al.*, 1986; Dove & Mayes, 2005) has been proven very effective in determining diet digestibility and intake in a number of animal species (Oliván *et al.*, 2007). The use of slow release capsules (Mayes *et al.*, 1991) which deliver a constant dose over a period of up to 30 days (20 days sampling), further improved the accuracy of this method and avoid the need for frequent dosing of animals.

2.5.3. Diet composition

Reviews on the methodology to determine diet composition of grazing ruminants are available by Harris *et al.* (1967), Van Dyne (1969), Theurer *et al.* (1976), Van Dyne *et al.* (1980), Holechek & Vavra (1981), Holechek (1982) and McInnis *et al.* (1983). A number of techniques are available for determining species selection or preference of grazers and browsers. These include: visual observations (animal and plant based), tiller/branch marking (plant based), faecal microscope and *n*-alkane techniques. To obtain results on species selection or preference of browse/graze in this study, animal and plant based techniques were used. A popular method to obtain qualitative estimates (plant species preference) is to follow an animal and record the species that are grazed/browsed. Obtaining, simultaneously, clipped or hand-plucked samples which mimic each bite taken and recording of time and bite size (Decandia *et al*., 2000) could supply additional quantitative data on the nutrient composition of the diet (Bryant *et al*., 1981). Major disadvantages of this technique are the difficulty of identifying grass species in a mixed vegetation (Holechek *et al*., 1982) and the error involved in clipped or hand-plucked samples (Langlands, 1974). Alternatively, the micro-histological examination of plant fragments (usually cuticle) in the oesophageal extrusa, alimentary tract or faeces can be used to obtain qualitative information on diet composition (Crocker, 1959; Ward, 1970; Dove & Mayes, 2005). Oesophageal fistulated animals have been used widely to determine the diets of domesticated livestock (Vavra *et al.*, 1978) and is accepted as the most accurate method available for this purpose (McInnis *et al.*, 1983) provided proper protocols and management are implemented.

2.5.4. Location of animals in the field

The decision-making processes invoked by the foraging animal may differ in relation to the landform scale (Senft *et al.*, 1987; Stuth, 1991) and spatial dispersion of resources (Gordon, 1989). Traditionally, information on the location of animals was gathered by direct observation (Arnold, 1984). In order to overcome some of the problems associated with this method, highly advanced technology, such as rodiotelemetry (Warren & Mysterud, 1991) and Global Positioning Systems (GPS) (Roberts *et al.*, 1993) to track animals and record their positions are being used to monitor the position of free range animals.

Grazing ecologists, today, have a wide variety of techniques available to measure components of foraging strategy. Of these techniques, Gordon (1995) states that: “There is no ‘best’ technique for measuring foraging strategy. The most appropriate technique will depend upon the goals of the research and the circumstances under which the measurements are made including such circumstances as the time scale of the study, grain of heterogeneity, the availability of tame animals, logistics and funding”.

In view of the fact that oesophageal fistulated animals were used to collect the samples that were used to determine plant species composition and nutrient content of the diet selected by free ranging goats, it is appropriate to discuss these specific techniques as well as the development and validity of the valve technique at this point.

2.5.5. The oesophageal fistula valve technique

The prototype fistula valve technique developed by Raats and Clarke (1992), consists of an oesophageal fistula valve which allows the fistula to be opened and closed, a rechargeable battery pack and motor to operate the valve, a remote controller and receiver to activate the valve motor, and a harness to attach the equipment to the body of the animal. This sampling system is generally referred to as the oesophageal fistula valve technique. In most respects, this technique is identical to the standard oesophageal fistula (bag) technique (Torell, 1954), with the added advantage that the number and size of extrusa samples can be varied and collected throughout the day.

The development of the fistula valve technique (Raats & Clarke, 1992) substantially improved the versatility of this technique. Raats (1993) listed four improvements to the standard fistula technique, namely: (a) The collection of different numbers and sizes of samples throughout the day is possible without disturbing the animals' normal feeding behaviour. (b) The collection of forage samples as selected by goats in extensive areas having heterogeneous plant populations is possible. (c) Sampling from specific plants or plant communities is facilitated. (d) The need to starve animals overnight in order to reduce the possibility of extrusa samples being contaminated with rumen contents is obviated. Since the development and testing of the first prototype sampling system, further improvements were made to the fistula valve, radio and receiver. Specific adaptations for use in goats have recently been made (Booyse *et al*., 2009) and the new fistula valve was used in the present study.

2.6. Estimating digestibility of forages selected by free ranging goats

The potential value of a feed for supplying a particular nutrient can be determined by chemical analysis, but the actual value of the food to the animal can be arrived at only after making allowances for the inevitable losses that occur during digestion, absorption and metabolism (McDonald *et al*., 2002). The performance of the herbivores when grazing, depend directly on forage digestibility and intake (Ramírez *et al*., 2000; Decruyenaere *et al*., 2009). Evaluation of feeds should provide nutritionists with the necessary information to formulate a diet from both a physiological and an economical point of view, in order to optimize the animal performance. One of the most useful measures of the nutritional value of feedstuff is its apparent dry matter digestibility (Omed *et al*., 1989). Digestibility provides the best practical evaluation of the quality of the grazing animal's diet because it indicates the portion that can actually be used by the animal's body.

2.6.1. Laboratory methods of estimating digestibility

Digestibility can be measured *in vivo* (in the animal), *in situ* (in a bag) and *in vitro* (in glass).

2.6.1.1. *In vivo* digestion

Digestion trials are an excellent way to evaluate feedstuffs. Forage is fed to several animals and the amount of forage fed and faeces produced in a 10-14 day period measured, recorded and sampled for analyses. Feeds offered and refused feeds are used to determine dry matter intake (DMI). The faecal output is determined by total collection of faeces by a tray or a faecal bag. From this, apparent dry matter digestibility (ADMD) can be determined by assuming that DMD of the forage is the difference between DMI and faecal output (Mc Donald *et al*., 2002). The method is effective for confined animals. *In vivo* determination is a standard method for digestibility testing, but it is laborious and expensive as it requires a substantial number of animals and large amounts of feed (Omed *et al.,* 1989; Decruyenaere *et al*., 2009; Karlsson *et al*., 2009). Dohme *et al*. (2007) states that *in vivo* trials are not feasible for routine evaluation of a high number of different specific forages. Several laboratory methods have been proposed for its estimation and include *in vitro* and *in sacco* techniques.

2.6.1.2. *In vitro* digestion

The *in vitro* or artificial rumen technique has become the commonly used procedure for estimating forage or diet sample digestibility (Holechek *et al*., 1982) and nutritive value. This technique attempts to simulate natural ruminant digestion under laboratory conditions. Although a number of artificial rumen procedures have been used, the Tilley and Terry (1963) two-stage technique has become the standard. It involves an initial fermentation of the sample with rumen micro-organisms followed by inoculation with an acid pepsin solution for digestion of protein residues.

Pearson (1970) and Kartcher & Campbell (1979) provide reviews on the sources of variation associated with the Tilley and Terry (1963). Uresk *et al*., (1975) found rumen inoculum followed by hydrochloric acid accounted for most of the digestibility when the Tilley and Terry (1963) technique was used. However, additional digestion by pepsin was not significant. Research reported by Smith *et al*., (1971) showed that silica reduced *in vitro* digestibility by about 2 percentage units for each percentage unit increase in the silica content of the forage. Their study indicates that the *in vitro* digestibility data should be presented on an organic matter basis (Holechek *et al*., 1982).

Considerable research shows that the species of animal used as an inoculum source for *in vitro* digestion is not important if the donor animal is fed a diet similar to the diet under evaluation (Cowan *et al*., 1970 & Scales *et al*., 1974). The number of animals needed as inoculum donors has not been well established. Van Dyne & Weir (1964) reported that replication was needed but Scales *et al*., (1974) did not find any increase in predicative ability when inoculum composited from several animals was compared to that from one animal.

Pearson (1970) and Kartcher & Campbell (1979) reviewed the period of time required for incubation. A 48 hour period for both fermentation and acid-pepsin digestion has become standard on the basis of research by Tilley & Terry, (1960), Van Dyne (1962) and Pearson (1970). Several studies have shown that *in vitro* digestibility can give an accurate evaluation of actual digestibility (Tilley & Terry, 1963; Palmer & Cowan, 1980). The two-stage technique (Tilley & Terry, 1963) was developed as an end-point digestibility method and thus, unless lengthy and labour intensive time-course studies are completed, the technique does not provide information on the kinetics of forage digestion (Theodorou *et al*., 1994).

2.6.1.3. *In sacco* or *in situ* digestion

Rumen degradability has been measured in several laboratories by the nylon bag technique. The nylon bag technique also called the *in sacco* or *in situ* technique is based on depositing feedstuffs into separate bags which are incubated in the rumen of several rumen cannulated animals fed standardised diets for appropriate time intervals (Spanghero *et al*., 2003). The main objective is to measure the rate of disappearance of dry matter and other nutrients. It thus provides a useful means of evaluating the rate of disappearance of feed constituents from specific plants or diets placed in the bags and incubated in the rumen for varying periods (Kandylis & Nikokyris, 1991). After a prescribed period of incubation the samples are removed, washed, dried and weighed. Degradability (or disappearance) of the substrate is determined by the weight loss during the incubation periods.

The nylon bag technique has been used by many workers in order to estimate the ruminal dry matter and protein degradation during the evaluation of the nutritive value of feedstuffs for animal production (Dohme *et al*., 2007). Nylon bags have also been used to predict energy values of concentrates, and in this context they have been more accurate than the analytical data, enzymatic degradation and *in vitro* digestibility (Sauvant *et al*., 1985). The nylon bag technique thus provides a means of ranking feeds according to the rate and extent of degradation of dry matter, organic matter, nitrogen and other nutrients. This method is most appropriate for providing information on nutritive value of feeds for ruminants and is a powerful tool for improving our understanding of the processes of degradation which occur in the rumen (Ørskov *et al*., 1980; Dohme *et al*., 2007).

As nylon bags are usually used to contain the forage, free movement in the rumen does not occur and true *in vivo* conditions are thus not obtained with this method, leading to the technique now becoming known as the *in situ* technique (Osuji *et al*., 1993). Various materials have been used in the construction of the bags (Ørskov *et al*., 1980). In early experiments (Quin *et al*., 1938) silk bags were used to incubate samples. These were later replaced by other types of clothes like dacron (Schoeman *et al*., 1972; Mehrez & Ørskov, 1977) nylon, and polyester.

2.7. Factors affecting ruminal dry matter and protein degradability

The main factors influencing the degradability estimates of the supplements and feedstuffs are:

2.7.1. Replication of measurements

Mehrez & Ørskov (1977) observed that the greatest source of variation of the *in sacco* technique was the host animal. It has been suggested that to measure degradabilities of dry matter and protein, a sample has to be incubated for at least two periods in three animals to give an accurate estimation for one given incubation. There is little to be gained by repeating treatments within the rumen of the same animal. The number of animals needed, will depend on the expected magnitude of the differences between treatments. There are small or no differences in the *in sacco* degradation rate from samples incubated in either sheep, goat or cattle (Ammar *et al.,* 2008; Mehrez & Ørskov, 1977). The use of cattle, in contrast to sheep and goats, has the advantage of allowing a large number of bags or larger size of bags per period.

2.7.2. The basal diet of the cannulated animal

The diet of the "host" animal can have a profound effect on the rate of degradation of the material being incubated, for example, animals given diets with a high proportion of concentrates will have reduced cellulolytic activity in the rumen. The diet chosen for the animal used will obviously depend on the purpose of the experiment.

2.7.3. Preparation of the test sample and mastication

Preparation of samples for incubation is critical as the sample should represent, as far as possible, the materials, as they would appear in the rumen had they been consumed by the animal (Ørskov, *et al.,* 1980). Therefore, the ideal sample preparation would be a masticated digesta from animals fitted with oesophageal cannula (Ørskov, 1992). As this is not feasible in most cases, it is suggested that a dry and milled sample is used instead. The dry sample should be milled through a 2.0-3.0 mm diameter sieve.

2.7.4. The rate of outflow from the rumen of unfermented feed particles

The extent to which ruminal dry matter and protein degradability varies with outflow rate depends on the rate at which the degradation of the protein proceeds. In addition several other factors can influence the accuracy of the nylon bag technique, such as:

2.7.4.1. Bag size

The optimum size of the bag has been investigated by a number of workers (Rodriguez, 1968). The optimum size is essentially a compromise between two opposing factors. On the one hand the necessity to have the bag large enough relative to the sample size used, so as to ensure that rumen fluid can easily enter the bag and mix with the sample. On the other hand there is the necessity to have a bag small enough to be easily withdrawn through the rumen cannula. The ratio of width to length of the bags should be between 1:1 (i.e. square) and 1:1.25. Standard recommend bag sizes used today are 5 cm x 5 cm and 5 cm x 10 cm. The bottom corners should be rounded so as to prevent any of the sample being trapped, and the bag can be closed either by tying or with a simple draw string (Ørskov *et al*., 1980).

2.7.4.2. Pore size of the bag material

The ideal pore size shall allow the entrance of rumen liquor and micro-organisms i.e. protozoa, bacteria and fungi and the efflux of degraded fraction and accumulated gases. When the gas does not escape, the bags may float on top of the solid phase of the rumen and give very variable results. Bag pores should also be sufficiently small to minimize losses of undegraded feed particles, while maintaining an active microbial population and also preventing blockages of the pores by feed components. The choice of bag porosity must thus be a compromise between loss of undegraded feed particles and the movement of micro-organisms through the bag. A pore size between 40-60µm is adopted as a standard (Ørskov, 1992).

The efflux of feed particles from the bags without breakdown by rumen micro-organisms is corrected for by using zero-hour bags. These bags are filled with the substrate but are not incubated in the rumen. They are washed and dried in the same way as the incubated bags. Furthermore, the zero-hour bags are used to correct for passage of material from pressure applied to the nylon bags during washing.

2.7.4.3. Sample size to bag surface ratio

The ideal ratio has been quoted as about 15mg DM/cm^2 (Ørskov, 1992; Michalet-Doreau & Ould-Bah, 1992). With the size of the bags suggested, samples of between 3 and 5g of DM are appropriate. For smaller bags, the quantity should be less, but with a minimum of 2g DM. The incubated sample should be able to move freely within the bags to avoid formation of microenvironments that affect replication of the analysis. A reduction in degradability was observed by many workers as sample size, for a given bag size, was increased (Tomlin *et al.*, 1967; Mehrez & Ørskov, 1977). The smallest amount of sample necessary may be defined as that which will provide adequate amount of residue required for further analysis after incubation.

2.7.4.4. Number of bags incubated

The number of bags at one given time should depend on the species of the host animal (Ørskov *et al.*, 1980). In cattle which generally can have much larger rumen cannulae than sheep, the number of bags incubated at one time can be greater than with sheep and have been quoted at 12 and 20 by Balch & Johnson, (1950) and Miles, (1951) respectively. With sheep, Mehrez & Ørskov, 1977) found it preferable to incubate no more than five bags in the rumen. Since most of the cannulae are now 40 mm internal diameter, nine bags can now be used in sheep. The major constraint is the removal of the bags from the rumen, and not interaction between bags within the rumen. The tendency of the bags to clump together can be minimised by introducing the bags individually and slightly varying the length of string allowed free, or by tying the bags in a line (Ørskov *et al.*, 1980).

2.7.4.5. Time of incubation in the rumen

Much of the published data relate to experiments in which the researchers tended to incubate bags for only a few different times, and attempted to relate dry matter losses from the bags to the apparent digestibility of the feedstuff. The emphasis is now on measuring the rate of degradation, which requires a number of measurements of the degradation after different times. The total time for complete degradation will vary with the characteristics of the material being incubated, and hence the intermediate times chosen will also vary from 6 to 120 hours. As a rough guide: concentrates require 12-36 hours, good quality forages 24-60 hours and poor quality forages 48-72 hours. Ørskov *et al.*, (1980) states that these are times required to reach, or nearly reach, the asymptote (potential degradation).

2.7.4.6. Positioning of the bags in the rumen

Balch & Johnson, (1950) reported that a more rapid digestion was obtained when the bags were incubated in the ventral rumen sac of cattle, though later work by Erwin & Elliston (1959) and Rodriguez (1968) showed that the position of bags in the rumen had little or no effect on the degradation of the various feeds. No reduction in the variability in the DM disappearance between bags has been shown by attaching weights so as to anchor the bags in the ventral sac of the rumen, but Rodriguez (1968) found that variation between bags was reduced when the bags were attached to 50 cm of string rather than to 30 cm. He suggested that the longer string allowed greater movement of the bags within the rumen of the steer, and thus minimised the effects of variations in the rumen environment.

2.7.4.7. Replication of measurements

The important source of variation is between the animals (Mehrez & Ørskov, 1977). To measure degradabilities of dry matter and protein, at least 3 animals are needed per treatment.

2.7.4.8. Washing of the bags

In order to eliminate other feed particles and micro-organisms from the bag after incubation, it can be washed by hand or machine (Michalet-Doreau & Ould-Bah, 1992). The residue is dried to determine the losses during incubation time. Feed samples should be placed in more than two different bags, and then washed in the same way in order to determine the washing losses. Such analysis should provide information on the presence of very fine particles and/or rapidly degradable fraction in the sample.

2.8. Interpretation of *in sacco* results

It is assumed that sample disappearance is synonymous with degradation (Karlsson *et al*., 2009). Although this is generally true, there are several cases where the assumption is not valid, for example, substrates with a fast disappearance rate or water soluble material (Ørskov, 1992). The degradation curve should plot the sample degradation against time. The curve may be expressed mathematically using the equation proposed by Ørskov & McDonald (1979):

$$\mathrm{P} = a + b(1 - e^{-ct})$$

Where p is the percentage degradation with time *t*; *a* is the soluble fraction; *b* is the insoluble but potentially degradable fraction. The $a + b$ value is the potential degradability of the material, all expressed in percentage, and *c* is the degradation rate, expressed in percent/hour. The extent of dry matter and protein breakdown will depend upon the time for with the feed sample remains in the rumen. Ørskov & McDonald (1979) pointed that the effective degradability P may be defined as follows:

$$\mathrm{P} = a + \left[\frac{bc}{\mathrm{c} + r}\right][1 - e^{-(c+r)t})$$

Where, r is the rate of passage from the rumen to the abomasum. As the time of incubation increases, the fraction of the protein remaining in the rumen falls to zero, as does the rate of breakdown, and P may be defined as follows:

$$\mathrm{P} = a + bc/(c + r)$$

In this equation *a* is the immediately degraded protein, and $bc/(c + r)$ the slowly degradable fraction. The value of r may be determined by the treatment of protein with dicromite. The *a*, *b* and *c* values are used to determine the feed potential of forages as well as to recommend feeding strategies. Feed potential indicates the consumption of digestible energy relative to maintenance.

2.9. Summary

The objectives of the study were to compare diurnal changes in feeding behaviour and plant species selection of the Tswana and Boer goats (variation within and between breeds) during the cold-dry season and the hot-wet season, to compare the nutritive values of feeds selected by the Tswana and Boer goat during the cold-dry season and the hot-wet season and to determine the rate of ruminal degradability of the three most preferred bush species selected by the Tswana and Boer goats during the cold-dry season and the hot-wet season using *in sacco* digestion. Experiments were designed to test the hypotheses by comparing free ranging Tswana and Boer goats in the hot-wet season and the cold-dry season using many of the techniques described above. The area chosen to study the goats was the Eastern Cape Province where a complete study of the vegetation was first completed. Feed selection, species composition and the behaviour of the goats was intensively studied over a period of a year. An analysis of all the factors affecting plant selection was also completed. The nutritive value of certain plants and their potential degradability was studied in order to gain further insight into seasonal variations in plant selection and possible management implications.