THE POTENTIAL OF *LEUCAENA PALLIDA* AND *ACACIA ANGUSTISSIMA* FODDER IN IMPROVING THE PRODUCTIVITY OF DAIRY CATTLE IN TABORA REGION

BY

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A THESIS SUBMITTED IN FULFILLMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA

2005

ABSTRACT

Four experiments were carried out to evaluate the feeding value of *L. pallida* and *A. angustissima* and determine how these fodder materials could be managed and used for sustained dairy production in the farming system in Tabora Region, Western Tanzania. The first experiment involved assessing the yield and nutritive value of *L. pallida* and *A. angustissima* as related to cutting management. In experiment 2, the effect of post-harvesting treatment methods on the level of secondary compounds were evaluated. Experiment 3 was carried out to investigate the effect of supplementing *L. pallida* and *A. angustissima* leaf meals to lactating dairy cows fed grass hay on milk yield, quality and financial return of the rations. Experiment 4 was undertaken to determine digestibility and nitrogen balance in dairy cows fed grass hay supplemented with dried leaf meals from *L. pallida* and *A. angustissima*. Results showed that the 3-months cutting interval had the highest fodder yield (3.44 and 5.41 tDM/ha for *L. pallida* and *A. angustissima*, respectively) while 1-month cutting regime had the lowest fodder yield (2.8 and 3.4 tDM/ha for *L. pallida* and *A. angustissima*, respectively). Nitrogen and mineral contents varied significantly ($P < 0.05$) between cuttings and edible fractions, which ranged from 27.1 to 47.7 for nitrogen, 2.37 to 8.49 for calcium, 1.40 to 4.90 for phosphorus and 11.6 to 23.1g/kg DM for potassium. Condensed tannins (CT) in the edible fractions ranged from 8 to 16 and 17 to 33mg/g DM for *A. angustissima* (AA) and *L. pallida* (LP), respectively. Mimosine content ranged from 26.8 to 63mg/g DM in edible fractions of *L. pallida*. In both species, *In-sacco* DM and N degradability at 48 hours of incubation were significantly ($P < 0.05$) higher in 1-month cuttings than in the other cuttings and ranged from 442 to 591g/kg for DM and 503 to 618g/kg DM for nitrogen. Soaking in

water, sun drying, wilting and drying under shade of the edible fractions reduced 37 to 50%, 22 to 40%, 12 to 18% and less than 10% of CT content, while mimosine content was reduced by 74 to 91%, 41 to 55%, 20 to 40% and 22 to 26%, respectively. Milk yield was highest for cows supplemented with cotton seed cake (CSC) (9.94 kg/day) and lowest for cows supplemented with LP (7.78 kg/day). Supplementing mixture of the two browse leaf meals gave the highest net return (104.20 Tshs/litre) while CSC recorded the lowest net returns (66.60 Tshs/litre). Apparent DM and N digestibility were higher for cows supplemented with CSC (585g/kg and 931g/kg for DM and N, respectively) and lowest for cow supplemented with LP (466g/kg and 603g/kg DM for DM and N, respectively). The N absorbed was more efficiently retained ($P < 0.05$) with cows supplemented with CSC (21.8 g/day) and poorly retained with cows supplemented with AA (4.24 g/day). These results indicated that optimal yield and quality of edible fodder materials of the two browse species could be obtained at 2-months cutting interval. Soaking in water and/or drying in the sun could reduce tannins and mimosine content in the edible fractions to an acceptable level before feeding. The two browse species had high CP and mineral contents and were more economical than cotton seed cake as protein supplement. Agronomic strategies to maximize fodder production during the dry season should be given attention. Studies to determine the effect of tannins and other related polyphenolic compounds on protein availability and utilization by ruminant animals should be carried out.

DECLARATION

I, RASHID BADI RAMADHANI MSANGI, do hereby declare to the Senate of Sokoine University of Agriculture that this thesis presented here is my own original work and that to the best of my knowledge it has not been submitted for a degree award to any other university.

Signature.....

Date.....29/08/05.....

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ACKNOWLEDGEMENT

This study was carried out at the Agricultural Research Institute, Tumbi, Tabora in Western Tanzania and in three villages of Tabora municipality and at the Department of Animal Science and Production (DASP) of the Sokoine University of Agriculture (SUA), Morogoro. The work was financed by NORAD through Tanzania Agriculture Research Project (TARP II) of the ministry of Agriculture and Food Security and the International Centre for Research in Agroforestry (ICRAF). I owe a debt of gratitude to the two institutions for the financial assistance.

I wish to thank my employer, the Ministry of Agriculture and Food Security for granting me permission to pursue this study and to use some of the facilities at the Agricultural Research Institute, Tumbi, Tabora to accomplish part of this study.

Many thanks go to ICRAF, Tumbi, Tabora for letting me freely use their experimental animals, office facilities and on-farm experimental plots. The fieldwork was done with the assistance of Mr. D. Mbaruku, ICRAF field technician, whose positive attitude and cooperation created a good working relationship, to which I am grateful.

Special thanks are due to Mrs G. Ndunguru of ICRAF Tumbi, Tabora for drying, weighing and processing all the fodder samples during my fieldwork at Tabora. I am also grateful to all the drivers, particularly Mr. Z. Mwahote and G. Ndunguru, for being very positive and supportive.

I gratefully, express my sincere thanks to the scientific community of the Tumbi Agricultural Institute, Tabora for their assistance throughout the duration of the study. To Dr. Emil Mmbaga, the director of Western zone, Tanzania and Mr. M.L. Kusekwa, the head of livestock programme, Western zone, they really understood the problems I was facing of inadequate research funds and transport. I appreciate that they continued their support during my fieldwork.

Laboratory chemical analyses were conducted at the Department of Animal Science and Production (DASP), SUA, Morogoro and at ICRAF-Shinyanga laboratory. The technical assistance rendered by all the laboratory staff is gratefully acknowledged. Special thanks go to Mrs. M. Mbwana, Mr. G. Mfui and Mr. D. Alute of DASP, SUA, Morogoro and to Ms. M. Rose of ICRAF Shinyanga.

To Cyriacus, Faustin and Benedict of Magadu dairy farm of DASP, SUA, I say thank you for routine control of diseases and treatment of the experimental animals during my trial at Magadu. To Ms. Happy Enock, you are thanked for feeding the animals and removing the *in-sacco* bags from the rumen.

The guidance from my supervisory committee Prof. M. N. Shem, Dr. E.J. Mtengeti and Dr. R. Otsyina is sincerely acknowledged. Without their expert guidance, the completion of this study would have been impossible. I am heavily indebted to Prof. M.N. Shem my main supervisor for his constructive criticism, constant encouragement and guidance throughout my study. Indeed you deserve special thanks.

I wish to extend my appreciation to various members of staff of the Department of Animal Science and Production for assisting in one way or the other throughout the time I conducted my study at SUA, Morogoro.

To my fellow PhD students: Njau, Mwakilembe, Lyimo, Komuhangiro, Hija, Gimbi and Kampeni, sincere thanks for great support and your good company.

Since it is not possible to mention everybody in person, I would like to express my sincere appreciation to all staff members at SUA, Morogoro, and Tumbi, Tabora and ICRAF, Shinyanga who in one way or the other assisted me throughout my study.

Lastly but not least, I am forever grateful and indebted to my wife Miriam for support, continuous encouragement and understanding from the beginning to the " never coming end of this study ". Once again I thank her for accepting the responsibility of taking care of our beloved children and all family matters while I was away.

Lastly to my late father Ramadhani Msengeli who passed away in May 1988, I say " your insight and dedication to academic excellence gave me the encouragement and desire to pursue this study ". Your wish has been accomplished and rest in peace.

DEDICATION

This work is dedicated to my wife Miriam and my children for their tolerance during my long absence from the family for the entire study period.

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LIST OF ABBREVIATIONS AND SYMBOLS

ADF	Acid detergent fibre
ADL	Acid detergent lignin
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
AP	Absorbed Protein
ARC	Agricultural Research Council
Ca	Calcium
CCK	Cholecystokinin
CNG	Cynogenic glycosides
CP	Crude protein (N × 6.25)
CT	Condensed tannins
DM	Dry matter
DMA	Dry matter accumulation rate
DMI	Dry matter intake
DMD	Dry matter digestibility
DOMD	Digestible organic matter in dry matter
FA	Fluoroacetic acid
g	Gramme
Ha	Hectare
HCN	Hydrogen cyanide (hydrogenic acid)
ICRAF	International Centre for Research in Agroforestry
K	Potassium
kg	Kilogramme

LSD	Least significant difference
m	Metre
ME	Metabolizable energy
mg	Milligramme
MJ	Megajoule
ml	Millitre
mm	Millimetre
N	Nitrogen
Na	Sodium
NaoH	Sodium hydroxide
NDF	Neutral detergent fibre
NE	Net energy
NEL	Net energy for lactation
NPN	Non-Protein Nitrogen
NRC	National Research Council
OC	Organic carbon
OM	Organic matter
OMD	Organic matter digestibility
P	Phosphorus
pH	Potential hydroxide
PEG	Polythelene glycol
PRP	Proline rich protein
RDP	Ruminant Degraded Protein
RUP	Ruminal Undegraded Protein

SAS	Statistical Analysis Systems
SEM	Standard error of means
SNF	Solids not fat
t	Ton
TP	Total phenolic
Tshs	Tanzanian shillings
VFI	voluntary feed intake

CHAPTER ONE

1.0 INTRODUCTION

Livestock production is an important component in the cereal-tobacco land use system of Western Tanzania. It is the second predominant economic activity in most farms (1994/95 Sample census). Recently, dairying has become an important animal production enterprise in Tabora town and surrounding villages for food and cash generation. Milk sales supplement low incomes from formal and informal employment. However, one of the major constraints to dairy cattle production in the region is the shortage of dry season feed, particularly shortage of cheap source of supplementary nitrogen.

Dairy cattle management in Tabora is intensive in nature, based on zero and semi-zero grazing systems. The main feed resources are natural pasture and crop residues including maize stover, rice straws, groundnut haulms and bean straws. During the dry months, animals are forced to subsist on mature grass and crop residues which are generally very low in crude protein, have relatively low digestible energy and low concentration of minerals, particularly phosphorus and calcium (Kabatange and Shayo, 1991; Mtamakaya, 2002) and are high in fibre and lignin (Kimbi, 1997; Kimoro, 2003). Consequently, they show poor intake and digestibility. This results into low milk yield.

Strategic supplementation with energy and protein rich concentrates could alleviate the deficiency and significantly improve milk yields. However, conventional protein supplements such as cottonseed and sunflower seed cakes from agro-processing

industries are rarely fed because they are expensive and not readily available to most of the smallholder farmers. This necessitated the search for alternative protein supplements based on locally available feed resources including browse tree fodder.

The intake and digestibility of poor quality roughage can also be improved by physical treatment methods including chopping, pelleting and grinding. These methods, however, do not provide the opportunity for selection of the best parts of the plant materials, thus resulting in intake of inadequate amount of digestible nutrients. Treatment of low quality roughage using chemicals such as sodium hydroxide, ammonia hydroxide, urea and ammonia has been used to increase intake and digestibility of low quality roughage. However, physical and chemical treatments are expensive and difficult to apply in the rural areas.

In Tanzania, and particularly in rural areas, supplementation using tree and shrub fodder could be an alternative option to conventional protein supplements for ruminant animals substing on low quality roughage. The tree and shrub fodder offer a sustainable and economic way of increasing levels of animal production. Browse species have many advantages in animal production, amongst which is high feeding quality based on protein and mineral contents (Ca, P and K), tolerance to wide range of management practices, longevity and presumably because of their deep-root systems, they are capable of producing fodder even during the dry season when other species are dormant (Paterson *et al.*, 1998). Browse species also maintain high levels of protein in the dry season (Norton, 1994b).

Despite their potential as feed resources for ruminants, tropical browse species contain anti-nutritive factors and/or harmful substances that occur naturally which lower nutrient utilization, feed conversion efficiency and animal productivity (Aregheore, 1999). Some of the inherent anti-nutritive factors are tannins (condensed and hydrolysable), saponins, cyanogenic glycosides, alkaloids and toxic amino acids (Barry and McNabb, 1999; Reed *et al.*, 2000). The susceptibility of animals to toxicity, however, varies with factors such as animal species, age and physiological stages, the level of feeding, duration of feeding and rumen microbial ecology (D'Mello, 1995).

The presence of these compounds in tree fodder may reduce nutrients availability and utilization below what their concentration implies from laboratory chemical analysis (Reed, 1995). Screening of forage trees for nutritive values by chemical analysis only may therefore lead to some erroneous conclusion if not supported by feeding trial because of the failure to account for secondary compounds. Feeding trials have an added advantage of providing information on animal health and productivity such as live weight gain and milk production upon feeding such diets.

Anti-nutritive factors in browse fodder can be reduced through mineral supplementation, addition of chemicals such as polythene glycol (Getechew *et al.*, 2001), introduction of microbes to the rumen of ruminant animal to detoxify the compounds (Mathew *et al.*, 1991; Jones, 1994), and avoiding feeding the plant when the levels of the anti-nutritive compounds are high (Lowry *et al.*, 1996). With exception of few methods, the widespread application of these methods has often

been hindered by factors such as practical limitations and/or economic viability. Other simpler methods including wilting, sun drying and soaking in water are available. These methods could be used by small-scale farmers in the rural areas to reduce the effect of anti-nutritive factors before feeding tree fodder.

There are abundant niches on small farms where fodder trees can be grown without affecting crop production. They could be introduced as fodder bank established adjacent to rangeland, farmer's homestead or grown as an upper storey on land used for growing crops (Reynolds and Jabar, 1994). These can be cut and carried to the stall-fed animals or grazed in *situ* on routine basis as protein and mineral supplements to the natural pasture. Nevertheless, the tree and shrub species differ in their ability to cope with repeated cutting or defoliation.

Cutting management has a very important influence on the productivity and quality of browse species. Optimal fodder production depends upon several factors including age at fist cutting, cutting height and cutting interval (Stür *et al.*, 1994). Recommended age at first cutting vary with tree species and depend more on physiological rather than chronological age. Cutting or defoliation at 12 months after planting and when the thickness (diameter) of the stem at 50 cm above the ground level is 8 – 10 cm is usually recommended for most forage tree species (Paterson *et al.*, 1998; Andre, 2004). Cutting height of 50 - 100 cm above ground at an interval of 60 – 90 days have been found to be suitable for most browse species in a number of regions (Stür *et al.*, 1994). However, if sufficient regrowth sites (buds) are available cutting interval has a more dominant influence on total yield than cutting height.

Longer interval between cuttings generally increase total yield, however, the proportion of inedible wood may also increase, leading to decline in foliage quality (Shelton and Brewbaker, 1994). Cutting tree fodder at a time when the proportion of edible materials falls to 50% has been found to maximize yields of edible forage in most browse species (Stür *et al.*, 1994).

Browse fodder, particularly that from *Leucaena* and *Gliricidia species* have been used as supplements to a wide range of forage and agricultural by-products to improve animal performance in term of live weight gain and milk production (Gutteridge and Shelton, 1994; Kakengi *et al.*, 2001). *Leucaena leucocephala* was the most productive fodder tree and highly demanded for supplementation of low quality herbage in Tanzania and other tropical areas (Brewbaker, 1987). However, the damaging effect of the Leucaena psyllid (*Heteropsylla cubana*) has haltered its promotion as important fodder species.

In search for alternative tree species to *Leucaena leucocephala,* several leguminous shrubs and tree species such as *Sesbania sesban, Faidharbia albida, Gliricidia sepium, Acacia spp,* and other *Leucaena spp,* and composites believed to be tolerant to psyllid attack were introduced for screening and evaluation under Tabora environment conditions. A large number of fodder tree species are now available for the replacement of the species. *Leucaena pallida* and *Acacia angustissima* are some of the promising fodder species in Tabora Region when considering biomass production, psyllid resistance and survival (Otsyina *et al.*, 1998). Thus, they are likely to replace *L. leucocephala* in psyllid challenged environment and used to

provide supplementary fodder for low quality feedstuffs. However, there is limited information on the feeding value of these important fodder materials for dairy production. Information on deleterious substances (secondary compounds) of these new fodder materials is also lacking. Furthermore, farmers are lacking information on feeding levels, feeding options (fresh vs dry) and appropriate cutting management of these species.

This study was, therefore, carried out with the major objective of evaluating the feeding value of psyllid tolerant Leucaena species (*L. pallida)* and the shrub legume, *A. angustissima* and determine how these fodder materials could be managed and used for sustained dairy production in the farming system in Tabora Region.

The specific objectives of the study were:

(a) To determine the effect of different cutting regimes on fodder production of the two fodder species.

(b) To evaluate the feeding value of *L. pallida* and *A. angustissima* in terms of their chemical composition and degradation in the rumen.

(c) To determine the effect of different post-harvest processing techniques on the anti-nutritive value of *L. pallida* and *A. angustissima* fodder.

(d) To determine the effect of supplementary feeding of *L. pallida* and *A. angustissima* fodder to dairy cattle fed grass hay on milk yield, quality and financial return of the rations.

(e) To determine digestibility and nitrogen balance in dairy cows fed grass hay supplemented with dried leaf meals from *L. pallida* and *A. angustissima.*

The hypotheses behind this study were:

(a) *Leucaena pallida* and *A. angustissima* have high nutritive value to enable their use as supplements to low quality and fibrous feeds.

(b) Different cutting regimes will result into different fodder production and nutritive value of edible forage.

(c) Post harvesting processing techniques including sun drying, wilting and soaking is capable of reducing or eliminating secondary inhibitors, particularly, tannins present in *L. pallida* and *A. angustissima* fodder.

(d) *Leucaena pallida* and *A. angustissima* fodder could replace or complement the commercial concentrates and offer an economic way of increasing levels of milk production.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background information

Tabora Region lies in mid-western part of Tanzania on the central plateau and has an area of 76.151 km^2 out of which 46% is forestry reserve and 22% is game reserves (TRDD, 1989). The annual cultivated area is estimated to be less than 14% of the area and 18% of the land is wood grassland. Based on 2002 census, the human population is estimated at 1,717,908 with an annual growth rate of 3.6% (PHC, 2003). Agriculture employs 90% of the labour force. Subsistence agriculture is the main form of crop production. The main feature of the farming system is maize/tobacco rotation with livestock integration.

2.1.1 Crop production

Maize is the staple food crop and is grown for 2-3 years, followed by tobacco. Other food crops include sorghum, cassava, sweet potatoes and rice. Maize and cassava are grown in mixtures with legume crops mainly groundnut. Crop yields, however are generally low due to the inherent low soil fertility status, low fertilizer inputs, low and unreliable rainfall and poor traditional crop management practices. Tobacco is the major cash crop and is grown in monoculture. Tobacco growing is a widespread and highly economic activity within the small-scale farming systems in the Region.

2.1.2 Livestock production

Livestock keeping is the second predominant economic activity after tobacco crop production in Tabora Region. Cattle are the most dominant livestock type with the

Tanzanian Short Horn Zebu (TSHZ) being the predominant cattle breed, however substantial numbers of long horned Ankole cattle exist. There are a few improved cattle breed, mainly Friesian and Ayrshire crosses. Other livestock include, goats, sheep, pig, donkeys and poultry. The Region has fairly high livestock population estimated at 1,009,571 cattle, 464,327 goats and 151,034 sheep (1994/95 sample census). Most of the livestock are however, concentrated in the North East of the Region (Igunga and Nzega districts), which is almost entirely tsetse free. The widespread incidence of tsetse (*Glossina moristans*) over much of the Region limits the areas available for grazing.

Most of the ruminant livestock in the region are managed under agro-pastoral system, feeding mostly on natural pasture and crop residues. The dominant grasses are *Hyperrhenia spp*, *Eragrostis spp*, *Themeda spp*, *Sporobolus spp, Panicum spp* and *Seteria spp* on well-drained fertile sites. These are early-flowering grasses, they grow very fast to mature before the onset of dry season and once they are mature they are low in crude protein and digestibility (Karachi and Zengo, 1997). The proportion of herbaceous legumes occurring naturally is too low to supply reasonable amount of protein to cover the deficit in the grasses. In the dry season, the grasses become less abundant as they dry out. At this particular time of the year maize stover and rice straws are the most important feed resources, while sorghum stover, groundnut haulms and bean straw are less common.

Crop residues are grazed *in situ* in the field after grain harvest. This inappropriate practice often results into wastage of stover due to animal trampling and soiling,

termite damage, leaching and wind shattering. Very few farmers harvest and store stover for late use or adopt cut and carry system. Crop residues are deficient in nitrogen, high in lignocellulose content and of low digestibility (Leng, 1991; Van Soest, 1994). Therefore, available feed resources during the dry season are usually unable to provide sufficient nutrients for reasonable livestock productivity, and livestock generally loose weight, become susceptible to diseases and have reduced productivity.

2.1.2.1 Dairy farming in Tabora municipality

Dairy cattle production is an emerging enterprise in Tabora town and surrounding villages for food and cash generation. Milk sales supplement low incomes from formal and informal employment. However, one of the major constraints to this production system is the shortage of dry season feed, particularly shortages of cheap sources of supplementary nitrogen. The supply of the main feed resources is inadequate both in quality and quantity, especially during the dry season. During the dry months, animals are forced to subsist on mature grass and crop residues which are generally very low in crude protein (30-50g/kg DM) and phosphorus (0.04-0.09g/kg DM), marginal in calcium (0.24-3.27g/kg DM) and high in fibre and lignin (Kimbi, 1997; Shem *et al.*, 2001; Mtamakaya, 2002). Consequently they are poorly digested and have long retention times in the rumen.

2.1.2.2 Dairy cattle production systems

Dairy production in Tabora municipality is generally intensive in nature, largely based on zero and semi-zero grazing systems. Most small-scale farmers practice the

zero-grazing system whereby animals are totally confined in shed and stall-fed. Various type of feeds, including pasture grasses gathered from cropping areas, fallow lands and lowland areas (mbuga), crop by-products and crop residues, and to a limited existent fodder from established plots are cut and head carried to the stall fed animals.

Another management system of dairy production is that of semi-zero grazing often seen among the large- scale farmers whereby cows are sometimes confined in an enclosure (mainly during the cropping season) and stall fed, and other times they are set free to forage in the range, especially during the dry season. During the rain season, animals are grazed in the uplands, including fallow land in the cultivation cycle. In the dry season, crop residues on cultivated land, browse and the lowlands (mbugas) are the main grazing feed resources.

In both systems of production there is a wide variation in the quantity and quality of forage offered to the animals. The variation is caused by many factors including availability of the forage, labour and seasonality of plant growth, which further limits the availability of forage to about 5-6 months during the dry season. In most cases animals are underfed due to shortage of feeds.

Very few farmers feed concentrates to their animals because majority of supplements may be too expensive for the small-scale dairy producers to afford on a regular basis. When they are available, maize bran and/or cotton seed cake are fed to dairy cows during milking time in small quantities. During the dry season, most cows (local

breeds) dry up and do not produce milk at all, while milk production of crossbreeds falls to below 50% of the wet season yields (8-12 litres/day) (SADC/ICRAF, 1999). Some dairy farmers grow Napier grass on small plots around their homesteads, which is fed to milking cows and calves. In practice, the forage is usually harvested at an advanced stage of maturity and is highly lignified and have low digestibility and its feeding value is thus little better than that of cereal straws. Other dairy farmers use grazing reserves (ngitiris) for dry season grazing. Although some good quality grass species such as *panicum species* can be found in some localities, grazing reserves in most cases are dominated by *Themeda* and *Hyperrhenia species* which flower and mature rapidly, thereby decline in protein contents, digestibility and intake by grazing animals.

2.1.3 Social economic aspects

Farmers who practice small-scale dairying in urban and peri-urban area of Tabora have land holdings on average less than 2 acres mainly located around the homestead, but few own plots further away. Majority of the farmers have no title to their land, thus land tenure is relatively insecure. Most of the farmers have improved dairy cows, mainly Friesian or Ayrshire zebu crosses, kept in zero or semi-zero grazing systems. The average herd size is 2 livestock units per household. Performance of the small-scale dairy farms in the area is however limited by a number of constraints such as small land holdings, insecure land tenure, labour availability and lack of reliable market.

Small land holdings in urban areas limit some of the farmers to grow enough forage for their cattle. This has resulted in dependency on communal grazing and public lands for forage supply. Farmers without security of land tenure cannot capture the future gains that arise from planting fodder trees or growing forage crops. Privatising land possibly could motivate farmers to grow forages for their animals and adopt tree-based innovations such as fodder banks.

Labour for cutting the pasture is frequently limiting resource, especially during cropping seasons and in the dry season when forage is in short supply and as such animals are usually underfed. The predominant source of labour is the family with some zero graziers hiring labour to cut and carry forage to the animals. Lack of a reliable market for milk and milk products (butter, ghee, cheese and yoghurt) limits the sale of milk especially in the rainy season. The influx of imported milk and milk products in many of our urban centres including Tabora town further magnify the problem and discourage peri-urban dairying. Proper marketing of milk and milk products needs to be established.

2.2 Nutrient requirements of the lactating dairy cow

In this particular study, NRC feeding standards were adopted because there are no local feeding standards. Dairy cows require protein, energy, minerals, vitamins and water for normal body function. In the tropics, the most limiting nutrients for animal production are energy, protein and minerals (McDowell *et al.*, 1983; McDonald *et al.*, 1998).

2.2.1 Energy requirements

Energy requirement is a major factor involved in DMI regulation. In dairy cows, energy requirement is high after calving where a cow can acquire 50-100% DMI than before calving so as to maintain positive energy balance (Faverdin *et al.*, 1995). Dairy cows maximize their energy intake when the diet consists of a mixture of roughage and concentrate. The amount of roughage needed to maximize intake however depends on the species, animal age and level of production (McDonald *et al.*, 1998).

The energy value of feeds for lactating cows is described relative to all physiological functions (NRC, 2001), which include requirements for maintenance, pregnancy, milk production and liveweight changes. The maintenance requirement for energy is defined as the amount of feed energy intake that results in no net loss or gain of energy from the tissue of the animal body (NRC, 1996). Maintenance energy is required for essential metabolic processes, body temperature regulation and physical activity (Fox and Tylutki, 1998).

The energy required for the maintenance of cows varies from 2.6 to 4.8 MJ, depending on body weight and the cow activity. Cows of similar size and breed may vary in their maintenance energy requirements by as much as 10 percent depending on their activities (NRC, 1996). For example, cows managed under extensive system require additional energy to move long distances in search of pasture and water, whereas cows in zero-grazing systems move very little and require comparatively less energy for maintenance. According to NRC (1989), the maintenance

requirement for the animals kept under extensive management systems should be increased by 3% for each additional kilometre the cow walks and by 10 and 20 percent to support grazing for a good and sparse pasture respectively. Balance experiments have indicated that the total energy required for pregnant dairy cattle is 30 percent of that required for maintenance (NRC, 1996).

The energy value of feeds for milk production is described in terms of the energy contained in the milk produced (Etherton and Bauman, 1998; NRC, 2001). The requirement therefore varies considerably depending on the level of milk produced and milk fat percentage and is set at 0.74 Mcal/kg for milk containing 4 percent milk fat (NRC, 1996). According to NRC (1989) the energy contents of intermediate milk fat percentages can be calculated using an equation:

$$\text{NEL (Mcal/kg of milk)} = 0.3512 + (0.0962(\%\text{fat}).$$

Where: NEL is Net Energy for Lactation.

In lactating dairy cattle, energy intake is driven by milk production (Bauman, 1992; Etherton and Bauman, 1998). Therefore, the period from calving until peak milk production is most critical because high producing dairy cows in early lactation are either not offered adequate amount of feed or cannot consume enough to supply the energy needed for maximum milk production, and are actually prone to negative energy balance (Allen, 1996; Garnsworthy, 1997). Energy expenditure through milk production usually peaks 4 to 8 weeks postpartum, while peak dry matter intake (energy intake) lags until 10 to 14 weeks postpartum (Figure 1).

Lactating dairy cows are either gaining or loosing body weight. A cow losing weight would be making reserves of energy available to maintain her level of milk production, whereas, the one gaining weight would divert some of the production ratio for this purpose (McDonald *et al.*, 1998). The energy value of live weight gain in dairy cow varies from 20 to 30 MJ/kg depending on body condition. NRC (1989) recommended an addition of 20 and 10 percent to support weight gain for the cows in their first and second lactation, respectively. The use of energy by lactating dairy cow, however, depends to a large extent on the microbial fermentation that occurs in the rumen, which determine the nature and amounts of the various metabolites that are absorbed from the digestive tract (Chamberlain and Wilkinson, 1998). These metabolites affect the efficiency of milk production and influence the way energy is used or partitioned for different activities.

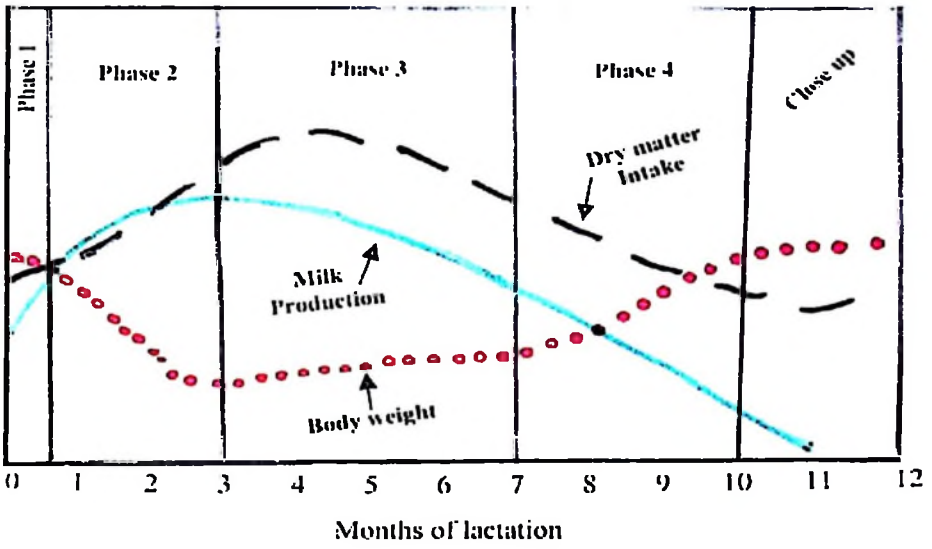

Figure 1. Dry matter intake, milk production and body weight changes in lactating dairy cow (Phase 1 = early lactation, Phase 2 = peak lactation, Phase 3 = mid to late lactation and Phase 4 = dry period).

2.2.2 Protein requirements

Proteins are principal constituents of the animal body and are continuously needed for repair and in vital metabolic processes. Protein requirement is the amount of protein required to satisfy the demands of the rumen microorganism and the demand of essential amino acid at tissue level (McDonald *et al.*, 1998; Norton, 2003). These essential amino acids are derived either from dietary protein that escape rumen fermentation or from the microbial protein produced in the rumen fermentation (Butler, 1998). The protein value of a feedstuff for ruminant is, therefore, determined by the ability of the feed to promote microbial synthesis in the rumen, the extent by which the feed protein escapes degradation by the rumen micro-organism, provide

protein and essential amino acids for absorption in the small intestines (Davidson *et al.*, 2003).

The protein requirement includes requirements for maintenance, faecal metabolic N, and production. The maintenance requirement includes urinary endogenous protein and surface protein, while the requirements for production includes the protein needed for the conceptus, growth, and lactation (NRC, 2001). Protein requirements for ruminants vary in relation to changing productive or physiological status of the animal. Ruminants require less protein for maintenance, slow growth, early pregnancy, late growth and late lactation (Kempton *et al.*, 1997). The levels of protein which are adequate for good performance differ with different physiological categories and ranges from 7-20% in the diet (McDonald *et al.*, 1998; NRC, 2001).

The requirement for protein is very critical during early lactation as the amount of body protein that can be mobilized is very limited compared with body fat (Bell *et al.*, 2000). In early lactation, dietary protein content in a range of 17-19% is normally recommended (NRC, 2001). As milk production per cow increases, it becomes more important that dietary protein escape degradation in the rumen. According to NRC (2001) about 30-35% of dietary protein should be ruminally undegradable protein, while 30% should be soluble protein. Protein requirements during mid lactation are lower than in early lactation. The ration for dairy cows in mid lactation is recommended to contain about 15-17% crude protein. However, as lactation approaches an end, protein requirement is not very critical and protein supply in the range of 13-15% is adequate (NRC, 2001). To allow for continuing growth, the

maintenance requirements should be increased by 20 percent for the first lactation and by 10 percent for the second lactation (NRC, 2001).

2.2.3 Protein and energy interaction

Protein supply and energy requirements are closely interrelated. Dietary protein may affect the energy supply by modifying dry matter intake, digestibility and energy use efficiency (Allen, 2000; Kauffman and St-pierre, 2001). Several studies (Ndemanisho, 1998; Kakengi, 2000; Katakweba, 2002; Shem *et al.*, 2001) have shown that DM intake and digestibility increase with increased intake of digestible protein in the dry matter. The utilization of nitrogen has been observed to be poor with low energy levels in the feeds, mainly due to an imbalance between the quantity of carbohydrates and protein degraded in the rumen (Poppi and McLennan, 1995; Tamminga, 1996). It has been observed that animals on high energy and low protein rations consume less feed than those on high energy and high protein rations (Pirlo *et al.*, 1997; Doepal *et al.*, 2002). Hoover and Stokes (1991) reported responses of additional energy when ration contained more crude protein (12%), but there were no responses observed by feeding additional energy when the basal diet contained low crude protein (5-8%). Similarly, Mgheni *et al.* (1993) observed that urea supplementation alone to nitrogen deficient rice straw did not improve their utilization, as there was no enough digestible carbohydrate to supply energy for synthesis of protein. On the other hand, an excess dietary protein may decrease the energy supply because the excess protein in the diet would need extra energy for the conversion of ammonia (NH_3) to urea, thereby creating a possible energy shortage (Tamminga, 1996). The energy required for the deamination process, therefore,

decreases the proportion of NEL in ME (Butler, 1998) and thus reduces milk yields. Some studies also have shown that overfeeding crude protein decreases animal fertility (Rajala-Schultz *et al.*, 2001). Therefore, the need for an adequate supply of degradable protein and energy need not to be overemphasized.

2.2.4 Mineral requirements

Mineral imbalance or deficiencies can develop into reproductive, health and milk production problems. Calcium, phosphorus, magnesium, sodium, potassium and sulphur are considered as major minerals while copper, selenium, cobalt, zinc, iodine and iron are required in much smaller, trace amount (Mc Dowell, 1992; Chamberlain and Wilkinson, 1998).

2.2.4.1 Calcium and Phosphorus requirements

Calcium is the most abundant mineral element in the animal's body, comprising 1-2% of total body composition (Jonson, 1999). About 99% of the animal body Ca is stored in bones and teeth. In the bones, Ca occurs in a molar ratio of 2:1 with phosphorus, primarily as hydroxyapatite crystals (Bondi, 1987). The remaining 1% is distributed in soft tissues and body fluids (McDonald *et al.*, 1998). Approximately 99% of the total Ca in body function as a structural component of bones and teeth, the remaining 1% is involved in such vital functions as blood clotting, membrane permeability, neuromuscular excitability, secretion of certain hormones and enzyme activation (Mc Dowell, 1992).

Calcium needed for maintenance, growth, pregnancy and lactation in dairy cattle is 4.3 to 7.7/kg DM intake depending on physiological status of the animal (McDowell, 1992; NRC, 1996). Requirements for Ca increase substantially with the onset of lactation. Milk contains a substantial amount of calcium, approximately 1g of Ca in every 1 kg of milk produced (NRC, 1996). At parturition, there is a sudden high demand for Ca since colostrum contains about 2.3g Ca per litre (McDowell, 1992). This amount is about two times as much Ca present in normal milk. The inability of high producing dairy cow to adjust rapidly to this increased Ca demand may result into parturient hypocalcaemia (milk fever) manifested by circulatory collapse, generalised paresis, depression of consciousness and often hypothermia (McDowell, 1992). As cow's DMI is limited during early lactation, it is difficult for the cow to obtain enough calcium from the diet to meet requirements unless it is supplemented. The average Ca contents in pasture grasses examined in Tanzania range from 2.6 to 7.8g/kg DM (Mwakatundu, 1977; Mtengeti 1984; Sendalo, 1986; Muhikambele, 1990). However, Ca contents decrease with advancing maturity (Underwood and Suttle, 1999) and in the dry season mature range pastures are low in calcium content (3.1-3.6g/kg DM).

Phosphorus is the second most abundant mineral element found in the body of cattle (Ternouth and Sevilla, 1990). Approximately 80% of body P is present in bones and teeth. The remainder is distributed in tissue of body fluids. Phosphorus is present as hydroxyapatite [Ca_{10} $(PO_4)_6$ $(OH)_2$] in bones (Corbridge, 1985). Phosphorus is involved in a variety of vital functions probably more than any other mineral (Corbridge, 1985). Phosphorus is involved in feed metabolism and utilization of fat,

carbohydrates, proteins and other nutrients in the body (Bondi, 1987). As a major constituent of cell wall, phospholipids are involved in maintaining the structure and integrity of all cells in the body. Furthermore, phospholipids allow fatty acids to be transported throughout the body. As part of DNA in cell nuclei, P is involved in the determination of the genetic characteristics of the animal and in the expression of those characteristics through the P in RNA. Phosphorus is involved in many enzymatic reactions involving energy metabolism in cells (e.g. in ATP, ADP, cyclic AMP and creatine Phosphate) (Wang *et al.*, 1985). Phosphorus is also important in the formation of protein, nucleoproteins and phosphoproteins (Petri *et al.*, 1989; Ternouth and Sevilla, 1990).

Phosphorus is needed for normal milk secretion. There is approximately 0.8g of P in every 1 kg of milk (NRC, 2001). Phosphorus requirement is highly dependent on the level of productivity and the physiological status of the animal (Norton, 1994a; NRC, 2001). A high yielding milking cow requires much more dietary P than do low yielding cows. Young, pregnant animals that are lactating and still growing have high P needs (Mc Dowell, 1992). The normal range recommended in dairy cattle is 2.8 to 4.8g P/kg DM intake depending on physiological functions (McDowell, 1992; Norton, 1994a). In Tanzania, the average P contents in pasture range from 0.6 to 6.7g/kg DM (Mwakatundu, 1977; Mtengeti, 1984; Sendalo, 1986; Muhikambele, 1990). However, there is a marked reduction in whole plant P as the forage matures particularly during the dry season (McDowell, 1992).

A lactating animal responds to a dietary deficiency of P by reducing its milk yield without affecting the concentration of P in the milk produced. Even in extreme deficiency in the diet, the composition of the milk remains within normal limits (Muschen *et al.*, 1988; McDowell, 1992). The animal body skeleton provides an enormous reserve for both Ca and P, which can be drawn upon during a period of dietary deficiency. This makes diets deficient in Ca and P to have no obvious detrimental effect for a considerable period (Church, 1991).

Calcium is closely associated with phosphorus metabolism. The calcium to phosphorus ratio of 2:1 is usually recommended for ruminant diets (NRC, 1996). An excess of P depresses absorption of Ca in the gut by binding to the Ca binding protein (Horst, 1986). Likewise, high levels of Ca in the diet may reduce the absorption of P when its levels are low due to either precipitation of P in non-absorbable forms within the intestine as the pH rises or due to the homeostatic mechanisms concentrating on regulating plasma Ca (Ternouth and Sevilla, 1990). However, studies have shown that dietary Ca: P ratio of between 1:1 and 7:1 result in nearly equal performance, provided the animal's phosphorus intake meets its requirements (McDowell, 1992). The amount of P absorbed by the animal depends on the source of the P, the amount of intake, the Ca to P ratio, intestinal pH, the age of the animal and dietary levels of Fe, Al, Mn, K and fat (NAS, 1988).

2.2.4.2 Magnesium, sodium, potassium and sulphur requirements

Magnesium (mg) is the most abundant intra-cellular mineral. It is primarily involved in enzyme activation and central of nervous impulses (McDowell, 1992). The total

amount of magnesium in adult cow is approximately 200g, 70% of which is embedded in the bone structure, 28% in the soft body tissue and 2% circulate in the body fluids. Daily requirements for lactation have been estimated at 0.13g/litre of milk (Chamberlain and Wilkinson, 1998). Magnesium deficiency causes grass tetany or staggers (Hypomagnesaemia).

Sodium (Na) is a major cation in the blood and is involved in the maintenance of volume of blood fluids and acid-base of the blood, transmission of nerve impulses and absorption of nutrients (especially sugars) across the gut wall into other body cells (Chamberlain and Wilkinson, 1998). Consequently, its deficiency results in low performance and slow growth rates. Potassium, like sodium, serves to maintain proper acidity levels in body fluids and pressure in body cells. It is also required in a number of enzyme reactions in carbohydrate metabolism and protein synthesis (McDowell, 1992). Forages normally contain more than adequate amount of potassium (Karanja, 1999). Supplemental potassium may be necessary for high-grain diets.

Sulphur (S), like carbon and nitrogen, is an essential nutrient for rumen macroorganisms (McDowell, 1992). It is required for the synthesis of S-containing amino acids (methionine and cysteine). Dietary requirement for sulphur has been estimated at 1.1 – 1.6g S/kg DM depending on the protein concentration in the diet, the digestibility of the diet and the level of animal production (Chamberlain and Wilkinson, 1998).

2.2.4.3 Trace minerals requirements

These are required in very small amounts or traces in the diet throughout the animal life and are involved in enzymes and co-enzyme factors (Karanja, 1999). Most dairy rations need to be supplemented with copper, iodine, selenium and zinc. However, deficiencies of cobalt, manganese and iron in dairy cattle rations are rare. According to NRC (1996) requirements for lactating dairy cattle are 0.10, 10, 0.6, 50, 40, 0.3 and 40 – 60ppm for cobalt, copper, iodine, iron, manganese, selenium and zinc, respectively (NRC, 1996). A sub-clinical trace mineral deficiencies occur more frequently but are not easily recognized because specific symptoms are not obvious, instead animal grows or continue to produce at a reduced rate, use feed less efficiently and operates with a depressed immune system (McDowell, 1992; Chamberlain and Wilkison, 1998), thus resulting in inefficient production.

2.2.5 Vitamins

These are essential organic compounds required by the animal but which the animal cannot synthesize. They often act as hormones, enzymes or co-enzymes in a number of metabolic pathways (Karanja, 1999). They are required in small amounts because they are normally recycled within the body (Chamberlain and Wilkinson, 1998). However, regularly supplementation, especially with vitamins A, D and E is recommended to meet the requirements for a wide range of physiological conditions and production levels (McDowell, 1992).

2.3 Natural pasture and crop residues as ruminant feeds

Ruminant livestock in the semi arid Western Tanzania like in many parts of the sub-sahara Africa depends mostly on natural pastures and crop residues for their nutritional requirements. Availability of feed resources is such that during the wet season there is plenty of pasture with moderate to good nutritive value while in the dry season pasture are scarce and of low quality. Crop residues, mainly maize stover and rice straws are the alternative feed resources for dry season feeding.

2.3.1 Chemical composition and nutritive value

Tropical grasses grow very fast to mature before the onset of the dry season and once they are mature they are low in digestibility (usually 30 - 50%) with a protein content of less than 5% CP (Leng, 1991). Apart from being low in nutritive value, but also the quantity is low and crop residues like maize stover are alternative source of feed for ruminant animals during the dry season (Methu *et al.*, 2001). However, crop residues are inherently low in proteins and minerals and are high in cell wall constituents (NDF and ADF) and have small fraction of cell contents (Table 1). The cell wall constituents are closely associated with lignin (Van Soest, 1994) and the degree of lignification acts as a barrier to microbial degradation of polysaccharides (Jung and Allen, 1995). In addition, shortages of essential nutrients in these feed resources limits rumen microbial activity (Ebong, 1995; Norton, 2003), leading into low digestibility and voluntary feed intake and thus limit their utilization (Abdulrazak *et al.*, 1997; Kimbi, 1997; Nherera *et al.*, 1998).

Based on the above description, nutrients requirement of a lactating cross-bred dairy cow that weigh about 400 kg live weight (like most dairy cows in the study area), in her second lactation and producing about 10 litres of milk per day would require a metabolizable energy (ME) of 45 MJ/day for maintenance and 4.9 MJ/kg DM for milk production (NRC, 2001). In addition the animal will require 408 g of crude protein, 19.21 g of Calcium and 12.98 g of phosphorus per day (ARC, 1990). In view of these requirements and the foregoing nutritive values of natural pasture and crop residues, it is obvious that the main feed resources cannot meet the requirements of the dairy cows for maintenance, growth and lactation unless they are provided with supplemental energy, protein and minerals.

Table 1. Chemical composition (g/kg DM) of crop residues and some grass species

	DM	CP	NDF	ADF	ADL	Ash	Ca	P	References
Maize stover	932	29	781	483	55	58	3.7	0.40	Kimbi (1997)
	881	26	816	538	44	64	1.7	0.54	Kimoro (2003)
Rice straw	833	39	790	469	65	146	-	-	Nguyen and Peter (2001)
	941	44	645	531	45	-	13.4	0.56	Mtamakaya (2002)
Panicum maximum	939	71	678	400	-	-	3.27	2.38	Shem *et al.*(2001)
	-	40	755	460	-	-	-	-	Bwire (2000)
Hyparrhenia spp	942	41	704	456	-	-	0.97	0.93	Shem *et al.* (2001)
Cynodon spp	949	70	689	474	-	-	0.24	2.22	Shem *et al.* (2001)
	-	54	779	432	-	95	-	-	Bwire (2000)
Cenchrus ciliaris	-	71	742	493	132	-	-	-	Mero (1997)
	-	49	794	566	-	84	-	-	Bwire (2000)
Chloris gayana	-	35	808	521	-	83	-	-	Bwire (2000)
	-	64	739	496	88	-	-	-	Mero (1997)

CP = Crude protein, NDF = Neutral detergent fibre, ADF = Acid detergent fibre, ADL = Acid detergent lignin, Ca = Calcium and P = Phosphorus.
- Not determined or reported

2.3.2 Possible strategies used to improve feeding value of low quality roughages

Intake and utilization of low quality roughages may be improved by supplementary feeding and by various pre-treatment methods, which may involve physical, chemical, physiochemical and biological means. Supplementing using commercial feeds or by products such as hominy meal and oil seed cakes (cotton and sunflower cakes) from agro-processing industries are widely used to improve growth rates and milk yields (Shem *et al.*, 2001; Kakengi *et al.*, 2001; Katakweba, 2002). However, In Tanzania and particularly in the rural areas, the use of high protein concentrates for that purpose is limited by their high cost and unavailability.

Chopping, pelleting and grinding are some of the physical treatment methods used to increase intake of low quality roughages. These methods, however, do not provide the opportunity for selection of the best parts of the plant materials, thus resulting in intake of inadequate amount of digestible nutrients. Treatment of low quality roughages using chemicals such as acid (H_2SO4 and HCl), alkalis (NaOH, KOH, CaO, NH_3 or urea) and oxidative agents such as SO_2 and sodium chlorite has been used to increase intake and digestibility of low quality roughage (Kimambo *et al.*, 1995; Chenost and Kayouli, 1997). However, chemical treatments are expensive, difficult to apply by the rural people, hazardous, require special equipment and may cause environmental pollution. Furthermore, chemicals that do not promote microbial growth have minimal effect on feed digestibility especially with roughage highly deficient in nitrogen (Rode *et al.*, 1997).

Biological treatments, which have been tested to improve the feeding value of fibrous residues are ensiling, composting and fungal growth (Dyle *et al*, 1986). The major disadvantage of silage making is the unavailability of the equipment for the ensiling process; quantity of materials required and generally tropical grass species have low water soluble sugar content for ensiling. Composting has the risk of moulding and loss of nutrients through leaching. With respect to fungal treatment, the fungi often consume the more digestible parts of the feed causing substantial organic matter loss. Furthermore, fungi may produce toxic substances, which are harmful to the animals. Multiplication of these micro-organisms under field condition has also shown to be difficult (Schiere and Ibrahim, 1989).

Supplementation using tree fodder could be an alternative option to commercial feeds, physical and chemical treatments of low quality roughages in the rural areas. Browse species have many advantages in animal production, amongst which is high feeding quality based on protein and mineral contents (Ca, P and K), tolerance to wide range of management practices, longevity and presumably because of their deep-root system, they are capable of producing fodder even during the dry season when other species are dormant (Norton, 1994b; Paterson *et al.*, 1998). Browse species also maintain high levels of protein in the dry season.

The farmers can produce tree fodder easily as there are abundant niches on small farms where fodder trees can be grown without affecting crop production. They could be introduced as fodder banks (concentrated units of forage legumes) established adjacent to rangeland or farmer's homestead or grown as an upper storey

on land used for growing arable crops (Reynolds and Jabar, 1994). They could also be grown along the contour bunds, external boundaries and as homestead hedges (Kiruiro, 1999). These can be cut and carried to the stall fed animals or grazed *in situ* as a supplement to natural pasture and crop residues.

2.4 Trees and shrubs as ruminant feed

Tropical grasses and crop residues are low in quality and therefore cannot sustain high animal productivity. Tree fodder are complementary source of quality feed for ruminant livestock that offers a sustainable and an economic way of increasing levels of animal production especially in the rural areas.

2.4.1 Chemical composition and digestibility of browse species

Tree legumes are higher in proteins (12-30%) and minerals compared to mature grass and crop residues (3-10%) (Table 2). The general acceptable levels for maintenance of ruminant are around 8% CP, while for growth and lactation is about 15% (NRC, 1996). Thus, tree fodder have potential for use as supplements to poor quality roughages or as substitutes for commercial protein supplements, especially in the small holder sector where the quality of forages is often poor, especially in the dry season (Tolera and Sundstol, 2000; Sarwatt *et al.*, 2003; Shem *et al.*, 2003). A good example of a useful browse species as a feed is Leucaena.

Leucaena species are usually high in protein contents (17.8 to 30%) and mineral contents (Table 2). However, psyllid tolerant *Leucaena species* such as *L. pallida* and *L. diversifolia* are relatively low in protein (17.5 to 22.8%) (Austin *et al.* (1992).

Another browse species being promoted is *Acacia angustissima*. Nutritive value of *A. angustissima* is not well documented. However, few available data indicate that it has high concentration of CP (18.2 to 22.5%) and adequate levels of sulphur and phosphorus (Dzowela *et al.*, 1997; Sandoval *et al.*, 2001) as shown in Table 2.

Table 2. Protein and mineral contents (g/kg DM) in the edible foliage of some tree legumes

Browse species	CP	Ash	Ca	P	S	References
A. angustissima	225	46	-	1.3	1.4	Ahn *et al.* (1989)
	182	36	11	0.7	-	Sandoval *et al.* (2001)
A. nilotica	172	-	8.9	1.3	1.6	Abdulrazak *et al.* (2000)
	172	-	7.9	0.8	1.0	Abdulrazak *et al.* (2000)
A tortilis	241	-	-	1.6	2.0	Ahn *et al.* (1989)
Albizia labberk	228	55	3.7	1.7	-	Devendra (1990)
Cajanus cajan	230	-	-	1.5	1.9	Ahn *et al.* (1989)
Calliandra calothyrsus	240	-	16	2.0	-	Devendra *et al.* (1990)
	191	138	27	2.5	-	Gunasema *et al.* (1990)
Gliricidia sepium	212	99	-	-	-	Machibula (2000)
	235	97	11	2.1	-	Kimbi (1997)
L. leucocephala	211	139	37	1.8		Gunasema *et al.* (1990)
	175	-	8.5	1.7	-	Karachi (1998)
L.diversifolia	235	97	11	2.2		Gunasema *et al.* (1990)
	191	74	12	2.1		Gunasema *et al.* (1990)
L. esculenta	175	-	10	1.8	-	Karachi (1998)
L. pallida	214	82	13	1.6		Gunasema *et al.* (1990)
Moringa oleifera	277	142	-	-	-	Murro (2000)
Sesbania sesban	263	-	28	4.3		Gohl (1981)

CP = Crude protein, Ca = Calcium, P = Phosphorus and S = Sulphur
- Not determined

Although browse trees have a high protein content, many species contain high levels of polyphenolic compounds, including tannins, which may bind protein, making it unavailable to the animal, and may have negative effect on their palatability and

digestibility (Woodward and Reed, 1997; Mupungwa *et al.*, 2000), which could result in overestimation of their true nutritive value based on chemical analysis (Dzowela *et al.*, 1995). Small quantities of tannin, however, can have a beneficial effect, possibly by increasing rumen escape protein, decreasing ammonia loss (Barry *et al.*, 2001) and suppressing bloat (Reed *et al.*, 2000).

The minimum requirement for phosphorus varies from 1.2 to 2.4g/kg feed dry matter intake depending on physiological function (Norton, 1994a). Calcium is rarely limiting in forage diet and the same is true for forage tree (Table 2) and Ca: P ration of 2:1 is generally recommended (NRC, 2001). With the possible exception of phosphorus and sodium, all tree forages have adequate levels of macro-elements for ruminant nutrition.

Results from different studies generally indicate high dry matter and nitrogen digestibility values in *Leucaena leucocephala*, Albizia, and Gliricidia while most tannin containing species are of low degradability (Table 3). However, there are great differences in digestibility and degradability values between and even within species due to presence of some secondary compounds such as tannins, mimosine and other related phenolic compounds (Woodward and Reed, 1997; Paterson *et al.* 1998; Khamseekhiew *et al.*, 2001). The presences of higher level of condensed tannins in some browse species may sometime reduce or partially shield the protein from microbial attack (Leng, 1997). However, the specificity by which phenolics interact with protein vary considerable and depends on many factors such as level of

tannins and its molecular weight, rumen environment and time available for complex formation (Hegerman *et al.*, 1992; Makkar, 2000).

Variation in fibre contents (NDF and ADL) may also account for the differences in digestibility between species. These constituents are negatively related to DM and N digestibility in browse species as has been reported by several workers. Ramirez *et al.* (2002) studied the effect of cell wall and its derivatives (Lignin and condensed tannins) upon degradability of 15 browse plants from North eastern Mexico and reported that lignin content negatively influence the effective degradability of cell wall as also reported by Maya-Rodriguez *et al.* (2002) from the same area. In Greece, Khazaal *et al.* (1993) also reported that NDF was negatively correlated ($r = - 0.80$) with potential DM degradability in browse species.

Considerable variation in the chemical components among species and even within the same browse species has been shown by various studies (Table 2 and 3). This could be attributed to factors such as climate, soil and other edaphic factors, plant parts, processing, cutting management (frequency), state of hydration (fresh, wilted or dry), drying procedure and assay used in the analysis (Palmer and Schlink, 1992; Dzowela *et al.*, 1995; Wood *et al.*, 1998).

Table 3. Fibre contents, dry matter and nitrogen digestibility, total tannin and condensed tannin of some browse species

Browse species	g/kg DM					mg/g DM		References
	NDF	ADF	ADL	*In-sacco* DMD	*In-vitro* ND	Total Tannin	CT	
Acacia angustisstma	364	179	82	551	430	66	-	El-hassan *et al.* (2000)
A. nilotica	312	217	99	530	-	109	11	Abdulrazak *et al.* (2000)
A. tortilis	296	251	110	634	-	100	28	Abdulrazak *et al.* (2000)
Albizia labberk	433	312	174	620	-	-		Ramana *et al.* (2000)
Cajanus cajan	314	292	100	-	-	-	16.8	Bamualim *et al.* (1980)
Calliandra calothyrsus	418	235	156	-	-	-	-	Salawu *et al.* (1999)
	-	-	-	480	493	-	-	Jones and Palmer (2000)
	393	175	28	-	-	-	60	Kamatali *et al.* (1992)
Gliricidia sepium	284	155	-	682	823	-	-	Jones and Palmer (2000)
	454	296	76	-	-	-	-	Machibula (2000)
	263	174	100	-	-	-	-	Kimbi (1997)
L. leucocephala	414	262	144	668	740	55	-	Jones and Palmer (2000)
	519	205	-	-	-	-	23.5	Rootheart (1999)
L. diversifolia	-	-	-	-	-	99-141	-	Castilo (1993)
	377	220	102	-	-	-	12	Kaitho (1998)
L. pallida	-	-	-	-	721	63-108	-	Jones and Palmer (2001)
	349	192	94	613	479	-	85	El-hassan *et al.* (2000)
Moringa oleifera	286	205	-	805	803	-	-	Murro (2002)

NDF = Neutral detergent fibre, ADF = Acid detergent fibre, ADL = Acid detergent lignin, DMD = Dry matter degradability, ND – Nitrogen digestibility and CT = Condensed tannins.

2.4.2 Palatability and dry matter intake of browse fodder

Palatability (or edibility) is that aspect of voluntary feed intake controlled by animal preference, and may be a major determinant of leaf intake in some fodder tree species (Norton *et al.*, 2001). Palatability of browse species has been related to both physical characteristics (e.g. thorns, hairiness, bulk density) and the presence of compounds, which may affect taste and appetite (volatile oils, alkaloids, tannins, soluble carbohydrate) (Norton *et al.*, 2001).

The presence of thorns, spines, hooks and fibrous leaf in some browse species have been shown to limit browsing and/or restrict bite size and rate at which the plant can be harvested by browsing ungulates. Sometimes the herbivores may require time to bite between thorns and very carefully manipulate the plant in their mouth to avoid the thorns and spines (Belovsky *et al.*, 1991), thus influence palatability and dry matter intake.

In most thorny species, juvenile trees and growing plant parts are physically more protected against herbivores than mature plants. For instance, in some *Acacia species*, thorns on juvenile tips are longer and more closely spaced than in mature branches (Brooks and Owen-Smith 1994; Rohner and Ward, 1997). According to Cooper and Owen-Smith (1986) many plants become less spiny as they grow out of reach of browsers, while others facultatively increase their thorniness following browsing as physical barrier against browsing mammalian herbivores. Similar observations had been reported by other workers elsewhere (Midgley and Wood, 1996; Gowda, 1997; Young and Okello, 1998).

According to Woodward and Coppock (1995) the preferences of camels, sheep and goats to 20 browse species in a densely wooded, semi-arid savannas during wet and dry season is negatively correlated to thorns, hooks and spines. Similarly, Gowda (1997) found that feeding rate of goats was negatively correlated with spine density. Cooper and Owen-Smith (1986) observed that there was a general tendency for spinescent species to be less favoured than unarmed species even if they have high nutritional value. It is obvious that the spines of cactus for example render a very succulent plant highly unpalatable (Willms, 1978).

The chemical composition of forage is perhaps the most important palatability factor. Nitrogen, fat, minerals, soluble carbohydrate and organic acids have been positively related to palatability while fibre, volatile oils and secondary compounds including tannins, alkaloids and coumarins are negatively related (Reed *et al.*, 2000). In South Africa, for example, the palatability of 14 species of woody plants to kudus, impalas and goats was related to the condensed tannin content of the leaves. All plants containing more than 5% condensed tannins were rejected as food during the wet season (Cooper and Oven-Smith, 1986).

Most *Leucaena species* are highly palatable, but psyllid resistant species such as *L. esculenta* are less palatable (Austin *et al.*, 1992), presumably due to high contents of tannins and other related phenolic compounds (Wheeler, 1994). The astringency caused by formation of complexes between salivary glycoproteins and tannins during maceration of the plant materials result into increased salivation and decreased palatability.

The main effect associated with high tannin levels is decreased DM intake due to reduced palatability or depressed ruminal digestion (Reed, 1995). Hove *et al.* (2001) reported reduced intake in goats when high level of *A. angustissima* was included in native pasture based diet and attributed this to high tannin content of the species. Minson *et al.* (1993) found a decrease in DM intake from 40 to 50% due to condensed tannins. Condensed tannins also diminish the activity of certain fiber-degrading enzymes (Mupungwa *et al.*, 2000), increasing the amount of time feed stays in the rumen and thus, decreasing DM intake (Faverdin *et al.*, 1999, Mgheni, 2000). Sometimes, volatile compounds released from the leaf surface may lower palatability and intake of some browse species. For instance, animals appear to refuse Gliricidia leaves on the basis of smell, often rejecting it even without testing (Lowry, 1990). Potential interactions of tannin with other primary and secondary plant compounds perhaps may be the key to understanding palatability and other biological functions.

Browse intake depends on the species and the type of animal. The type of animal greatly influence the degree of browse utilization. The differences can be seen when comparing the size and morphology of the mouth among animal species (Hofman, 1981) For example, the narrow and labile mouth, and long neck of goats, impala and giraffes allow discriminate selection and bite between thorns to greater degree than the wide mouth and short neck of cattle, hippos, rhinos and same grazers, thus making them better at making good use of thorny shrubs. According to Ibrahim (1981), the proportion of browse eaten by cattle and sheep varies from 2-30% of their

dry matter intake. With goats, the proportion of intake ranges from 25-50% in the rainy season and up to 75% or more during the dry periods.

2.4.4 Browse leaf meal as supplements

Forage tree leaves, particularly that from *Leucaena, Gliricidia, Sesbania* and *Calliandra species* on their own or in combination with commercial feeds have been used as supplements to a wide range of forage and agricultural by products (Karachi and Zengo, 1997; Osuji and Odenyo, 1997; Ndemanisho *et al.*, 1998; Kakengi *et al.*, 2001; Shem *et al.*, 2003). The value of browse as supplement is mainly dependent on their capacity to provide nutrients that are deficient in the basal diet. This includes their ability to provide essential nutrients to the microbial population and/or critical nutrients to meet the host animal's requirement, and thus increase efficiency of feed utilization (Tolera and Sundstol, 2000).

Forage legume serves as a source of absorbed protein (AP) to the ruminant by providing both ruminal-degraded protein (RDP) for microbial protein synthesis plus ruminal undegraded protein (RUP) that escape microbial break down (Barry *et al.* 2001; Muetzel *et al.*, 2003). Several studies including that of Abdulrazak *et al.* (1997), Bonsi and Osuji (1997), Jones and Palmer (2000), Tudsi *et al.* (2001) and Sarwatt *et al.* (2004) have shown a positive effect on dry matter intake, digestibility, and animal performance in term of live weight gain and milk production when browse fodder is used as supplements to poor quality forages.

2.4.4.1 Effect of browse fodder on DM intake and digestibility of low quality roughage

Utilization of low quality forages is often constrained by their low nitrogen content, which limits microbial activity in the rumen (Van Soest, 1994; Norton, 2003). The consequence of this is manifested in slow ruminal digestion, low passage rate and DM intake and ultimately low animal productivity (Romney and Gill 2000).

Feeding leguminous fodder to ruminants animals have been reported to improve rumen fermentation parameters, leading to increased dry matter intake and digestibility of low quality roughages (Abdulrazak *et al.*, 1997; Faftine *et al.*, 1998; Dana *et al.*, 2000). For example, Bonsi and Osuji (1997) reported DM intake increase from 53.5 to 89.1g/kg$W^{0.75}$ in sheep feeding a basal diet of rice straw supplemented with Leucaena. Similarly, Bosman *et al.*, (1995) and Stewart *et al.* (1998) observed an increase in DM intake of between 46 and 72.1g/kg$W^{0.75}$ in West African Dwarf goat fed poor quality roughage and supplemented with *Gliricidia sepium*. Muinga *et al.* (1995) observed a voluntary intake in lactating cattle of 7.8, 9.3 and 10.4kg DM/day by supplementing grass hay with 0, 4 and 8 kg DM of sole *Leucaena* forage. According to Smith *et al.* (1995) and Alayon *et al.* (1998), increasing browse supplementation (0 to 30% or above) results into linear increase in DM intake regardless of the type of browse plant used.

Low ammonia concentration in the rumen fluid is considered the primary limitation to the growth of rumen microorganisms in ruminants feeding low quality fibrous feeds (Tolera and Sundstol, 2000). Browse supplementation increases the supply of

nitrogen and essential nutrients to the rumen microbes (Dana *et al.*, 2000; Nagadi *et al.*, 2000) thus stimulate fermentation of different feed components and increase passage rates from the rumen.

According to Osuji and Odenyo (1997) browse supplementation increase DM degradation and fractional outflow rates of particulate matter by 23 – 53% per hour and liquid phase by 9 – 43% per hour. Thus Bonsi and Osuji (1997) feeding cotton seed cake, *Sesbania* or *Leucaena species* with crushed maize as supplement to teff straw reported increase in DM and OM digestibility from 50.7 and 54% to 52.8 and 53% respectively. Similarly, Abdulrazak *et al.* (1997) supplemented steers feeding maize stover with 30g/kg$W^{0.75}$ of *Gliricidia sepium* and *Leucaena leucocephala* recorded DM and OM digestibility values of 58.4 and 61.0%, respectively.

It is not always true however that browse supplementation to ruminants increase digestibility. Sometimes, supplementation does not improve the digestibility and occasionally may slightly decrease the digestibility of poor quality forage. For example, Smith *et al.* (1995) using Gliricidia as supplement to a basal diet of *Panicum maximum* recorded digestibility values of 61.8 – 66.5%, 56.5 – 58.3% and 50.3 – 52.5% for OM, NDF and ADF, respectively which were lower compared to the control group. Generally, when the herbage has 40g/kg DM or less CP content nitrogen supplementation increases both the level of digestibility and intake. At higher CP levels, little or no digestibility increase is observed (Forbes *et al.*, 1995).

2.4.4.2 Effect of browse supplements on milk yield

Feeding leguminous fodder to dairy cows impoves dry matter digestibility and intake of low quality fibrous feeds and thus improves milk production (Camero and Franco, 2001; Shem *et al.*, 2003; Sarwatt, *et al.*, 2004). Gupta *et al.* (1992) observed a net milk yield increase of 1.1 kg per day over and above the control group by feeding dairy cows with a supplementary ration containing 35% Leucaena leaf meal. Kakengi (2001) reported a net increase in milk yield of 46.2%, 77.4% and 83.8% over the initial yield by supplementing dairy cattle grazing native pasture with 1.2, 2.0 and 2.6 kg DM of Leucaena leaf meal in conjunction with cotton seed hulls. In an experiment conducted by Muinga *et al.* (1995) five dairy cows fed diet supplemented with 1 and 2 kg dried Leucaena leaf meal gave an average milk yield increase of 5.3 and 6.5 kg respectively per day. Similarly, Shem (1996) reported milk yield increase of 20% by supplementing dairy cow with 2 kg/cow/day Leucaena leaf meal. Guttridge and Shelton (1994) and Tudsi *et al.* (2001) reported milk yield increase of 14–33% by supplementing dairy cows on natural pasture or grass hay with Leucaena leaf meal.

Apart from being rich in protein, most browse species are good source of both fermentable and by-pass protein (Tolera and Sundstol, 2000). Sarwatt *et al.* (2004) reported that when cotton seed cake was substituted with *Moringa oleifera* milk yield was significantly increased. These authors recorded milk yield range of 7.84 to 9.23 with higher yields when *Moringa oleifera* was part of the diet and attributed this to the good rumen by pass characteristics of *Moringa oleifera* when compared to cotton seed cake. Paterson *et al.* (1996) also reported that milk yield was not affected by

substituting 1 kg of dairy meal with 1 kg of dried Calliandra leaves. This similar effect could be due to the effect of Calliandra tannin to complex with protein at the pH of the rumen and hence protecting them from microbial enzyme, but making protein available for digestion and absorption in the lower tract (Reed, 1995, Jones *et al.*, 2000). As milk production per cow increases, it becomes more important that dietary protein escape degradation in the rumen and thereby increases amino acid supply to the hindgut. According to NRC (2001) about 30-35% of dietary protein should be ruminally undegradable protein, while 30% should be soluble protein.

2.5 Introduced browse species in western Tanzania

In recent years, there has been increasing interest in introducing and evaluating multipurpose tree and shrub species for use in different agro-ecological zones of the country. Therefore, a number of leguminous tree species including *Leucaena leucocephala*, *Sesbania spp*, *Faidhabia albida*, *Gliricidia spp* and *Acacia* species have been introduced.

2.5.1 *Leucaena spp*

Leucaena leucocephala is one of the most widely distributed tree species in tropical and sub-tropical regions of the world (Shelton and Brewbaker, 1994). Over the years, it has been used to provide a multiplicity of basic products and services such as fodder for ruminant livestock, fuel wood, building poles, green manure and food for human consumption (Shelton and Brewbaker, 1994). The leaves of Leucaena are highly nutritious for ruminants with excellent palatability, digestibility and balanced chemical composition of protein, minerals and amino acids (NRC, 1984; Hughes,

1998). Protein concentration in Leucaena is usually high (23.5 – 31.5% CP) (Kimbi, 1997; Ndemanisho *et al.*, 1998; El-hassan *et al.*, 2000; Kimoro, 2003). Most Leucaena species have adequate levels of macro-elements for ruminant nutrition (Table 2). Calcium level ranging from 5.4 to 23g/kg DM and phosphorus concentration of 1.6 to 2.9g/kg DM has been reported in Leucaena species by several workers (Austin *et al.*, 1992; Norton, 1994; Karachi, 1998). These outstanding qualities make it one of the most demanded fodder trees for supplementation of low quality herbage, especially in the dry season.

The usefulness of *Leucaena leucocephala* however has been reduced due to psyllid attack. It is highly susceptible to psyllid (*Heteropsylla cubana*), which has become a major pest throughout the pacific, Asia and parts of Africa. Leucaena psyllid are small jumping, sucking plant lice, reminiscent of aphids (Plate 1), and native to central and South America, which is also the origin of *Leucaena leucocephala* and other species of the genus *Leucaena* (Napompeth, 1994). The psyllid damage Leucaena tree by feeding from the phloem of developing shoot and young foliage, causing leaf defoliation, deformation, stunting and dieback (Plate 2 and 3). The damaging effect of the psyllid poses serious economic threat and has halted promotion of *leucaena leucocephala* as an important fodder species.

Plate 1. Adult Leucaena psyllid (Photo by Nagamine, 1998)

Plate 2. Young Leucaena leaf with eggs of the Leucaena psyllid (Photo by Nagamine, 1998)

Plate 3. *L. leucocephala* shoot tip damaged by Leucaena psyllid (Photo by Reynolds, 1988)

In search of alternative *Leucaena* species and provenances to overcome the limitations associated with psyllid attacks, a number of *Leucaena species*, hybrids and composites believed to be tolerant to psyllid attack were introduced at the Agricultural Research Institute, Tumbi, Tabora in 1992/93 growing season. These

were evaluated for environmental adaptability, fodder production and quality, and psyllid tolerance. Preliminary results from on station trials (Table 4) indicated that *L. pallida, L. divesifolia* K156 and some of the hybrid such as L. hybrid K × 3A (original) and L. hybrid K × 2 are well adopted tree species in terms of biomass production, psyllid resistance and survival (Otsyina *et al.*, 1997). Thus, they are likely to replace *L. leucocephala* in psyllid challenged environment and used to provide supplementary fodder for cattle fed on low quality feed stuffs. However, these new Leucaena materials are largely untested for forage quality and animal production potential.

Table 4. Mean fodder production (t/ha) and psyllid damage scores of *Leucaena species*, hybrids and composites evaluated at Tumbi, Tabora, Tanzania during 1993/94 to 1996/97 growing seasons

Leucaena material	Fodder production (t/ha)		Psyllid Damage rating
	Wet season	Dry season	
L.diversifolia Acc	3.39	0.53	1.00
Leucaena K36 composite	3.50	0.33	3.35
Leucaena spp Kx2 (composite)	4.01	0.79	2.69
Leucaena hybrid (Wainamalo)	3.92	0.44	3.08
Leucaena hybrid Kx3 (Wainamalo)	4.31	0.79	2.85
L.hybrid Kx3c (Wainamalo)	3.28	0.64	3.88
L.hybrid Kx3A (Original)	3.05	0.67	1.15
L.hybrid Kx3A (Composite)	2.09	0.44	3.35
L.divesifolia K156	1.66	0.63	1.12
L.pallida	6.46	0.90	1.00
SED (±)	1.56	0.20	

Psyllid damage rating scale: 0 (no damage), 9 (very high) Source: Otsyina *et al.* (1997).

As a result of the positive results reported above, *L. pallida, L. diversifolia* and *A. angustissima* obtained from Zimbabwe were established as fodder bank plots in

farmer fields in 1996/97 growing season for further testing. Fifty-four small-scale dairy farmers were selected from the three villages (Mtakuja, Kazima and Tumbi) to take part in the fodder bank trial. Over the years, the number of participating farmers has been increasing and currently over 200 farmers in Tabora rural district alone have already established fodder bank plots of one or two of the three species.

2.5.1.1. *Leucaena pallida*

Leucaena pallida, formerly known as *Leucaena esculenta* subs. *paniculata* (Hughes 1998) is a multiple stemmed tree (2-4 stems per tree) that usually attains a height of 7-10 m. The leaves are pinnae with 15-27 pairs of pinnae bearing 39-50 pairs of leaflets (Plate 4). Flowers appear pale pink or dull purplish. Pods are slightly thickened and leathery, glossy maroon when unripe turning mid-reddish and orange brown when mature (Hughes, 1998). *Leucaena pallida* is native to mid-interior highlands of south central Mexico where its pods and seeds are preferred as human food. It grows on a wide variety of soils and in a wide range of rainfall, between 500-1,000 mm and with 5-7 months of dry season. It is moderately frost tolerant and has high growth rate (Hughes 1998).

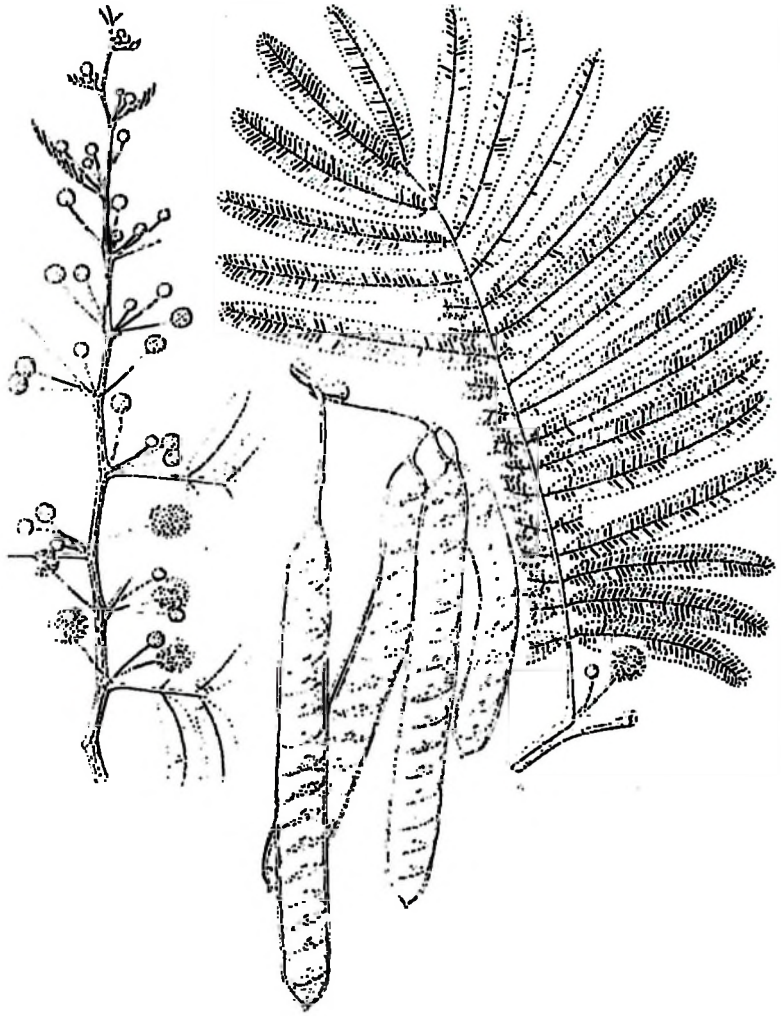

Plate 4. *Leucaena pallida* (Source: Hughes, 1998)

Productivity and nutritive value

Mawenya (1995) from Arusha and Kusekwa *et al.* (1997) from Mpwapwa, Tanzania reported fodder yield values within the range of 2.25 - 4.23 tons/hectare. Nitrogen content in the edible fractions of *L. pallida* is high and range between 27.2 and 36.5g/kg DM (Austin *et al.*, 1992; Castilo 1993, cited by Norton, 1994). However, fibre and condensed tannins are high in the edible fractions. The NDF and ADF contents vary between 36.8 – 565g/kg DM and 204 – 232g/kg DM, respectively in

different accessions of *L. pallida* (Austin *et al.*, 1992). According to Athanasladon *et al.* (2000) condensed tannins in different accessions of *L. pallida* varies from 3.8-6.1mg/g DM. However, Wheeler *et al.* (1994) reported much higher values of 54-120mg/g DM for psyllid resistant Leucaena species including *L. pallida*. However, these new Lecuaena materials are largely untested for forage quality and animal production potential. Therefore, doubts remain over the nutritive value of *L. pallida.*

2.5.2 *Acacia angustissima*

Acacia angustissima is one of the species offering promises as an alternative to *Leucaena leucocephala. Acacia angustissima* is a member of the mimosaceae family and is thought to have originated from Belize, Central America (Dzowela, 1994). The species is now commonly found in Southeast Asia, particularly Indonesia, as well as in Australia. Recently, the species has been introduced to other regions and it is now common in Southern Africa, particularly Zimbabwe where it is used as an important fodder plant. It was introduced for screening and evaluation under the Tumbi, Tabora environmental condition as one of the promising tree fodder species from Zimbabwe.

Acacia angustissima is a multi-branched, thornless shrub or small tree mostly 2-7 m high (Plate 5). Its leaves (Plate 6) are mostly asymmetric with a displaced mid-vein and 10-25 cm long, with 10-20 pairs of pinnae and leaflets without secondary venation (Turner, 1996). The inflorescences (Plate 7) are ellipsoidal with whitish head 1-1.5 cm in diameter, turning pinkish to dull orange when dried. The species flowers throughout the year in its natural range and its prolific seed producer. The

pod is oblong, 3– 6 cm long and 6 – 9 mm wide, with straight or sinuate margins. The pods are initially green, turning coffee-brown as they ripen (Dzowella, 1994).

Plate 5. *A. angustissima* whole plant
(Source: Steve Baskauf, 2002)

Plate 6. *A. angustissima* twig
(Source: Steve Baskauf, 2002)

Plate 7. *A. angustissima* flower
(Source: Steve Baskauf, 2002)

2.5.2.1 Ecology

The species is found in tropical deciduous or semi-deciduous forest. In the native range, annual rainfalls varies from 895-2870 mm, and mean temperature ranges are between 5^0 and 30^0 C. It grows from near sea level to 2600 m, but shows better growth potential at higher elevations. It tolerates cold climates (occasional temperature below freezing) and free-draining acid soils (Dzowela, 1994). It also withstands periodic drought, possibly due to its substantial taproot.

2.5.2.2 Productivity and nutritive value

Acacia angustissima retain most of its leaf during the dry season (Gutteridge, 1994), making it suitable as a dry season browse species. The crown architecture enables the tree to withstand frequent cuttings or defoliation with a high recovery and growth rate (Gutteridge, 1994). Biomass production has been shown to range from 10.3 to 11.4 t DM ha^{-1} (Brook *et al.*, 1992) at 2 m spacing. At 3 m spacing the biomass increases to a range from 11.5 to 12.4 t Dm ha^{-1} (Isaac *et al.*, 1994; Bino, 1997). These figures are based on cutting the trees back to 50 cm above ground level and on yearly cuttings taken during, and/or at the end of the wet season. Preliminary evaluation trials in Tabora, in the miombo woodlands of Western Tanzania (sandy soils, 80 to 90% sand, acidic soil, pH 4-5) excellent growth and fodder yields of up to 5.41t/ha has been shown by the species (Otsyina *et al.*, 1998) at 1 m spacing. Similarly, Dzowela *et al.* (1997) reported fodder yield range of 3.5 to 5.2 tons/ha from Zimbabwe.

Research shows that *A. angustissima* cuttings contain high levels of nitrogen and minerals, particularly, phosphorus and potassium (Gutteridge, 1994). It has a high crude protein contents about 23% (Dzowela *et al.*, 1997; Hove *et al.*, 2001; Odenyo *et al.*, 2003) and dry matter degradability in the rumen of cows after 48 hours of incubation has been shown to be 48% (Dzowella *et al.*, 1997), but due to high content of condensed tannin (23-28.8mg/g DM) as reported by Odenyo *et al.* (1997) and Sandol Castro *et al.* (2001), the protein may be less accessible to the livestock. Its high yielding ability and high protein content indicate its possible potential as a valuable fodder species for supplementation of low quality feed stuff, especially in the dry season. However, according to Ahn *et al.* (1989), its palatability and intake by livestock is low. In some areas, however, like in Indonesia *A. angustissima* leaf is reported to be eaten well and is regarded as an important source of forage (Guttredge, 1994).

2.6 Secondary compounds in browse species

Despite their potential as feed resources for ruminants, most tropical browse species contain anti-nutritional factors such as tannins, cynogenic glycosides, saponins, alkaloids, flavonoids and toxic amino acids (e.g. mimosine) which can cause a variety of effects ranging from beneficial to toxicity and sometimes death (Barry and McNabb, 1999; Reed *et al.*, 2000; Allen and Segarra, 2001).

2.6.1 Phenolic compounds (Tannins)

Tannins are water-soluble high molecular weight polyphenols and have ability to bind to carbohydrates, proteins, saliva mucoprotein and gastrointestinal enzymes

(Barry and McNabb, 1999; Allen and Segarra, 2001). Tannins are usually classified either as hydrolysable tannins (HTs) or condensed tannins (proanthocyanidins) based on their molecular structure. Condensed tannins are the most common type of tannin found in forage legumes, trees and shrubs (Barry and McNabb, 1999). The two groups of compounds may be differentiated by their structure and reactivity towards hydrolytic reagents. Structurally (Figure 2), hydrolysable tannin molecules contain a carbohydrate (generally D-glucose) as a central core. The hydroxy group (OH) of these carbohydrates are esterified with phenolic groups, such as gallic acid, ellagic acid or hexahydroxydiphenic acid. Condensed tannins (CTs) are complexes of oligomers and polymers of flavan-3-ols (catechin) or flavan-3, 4-diols (epicatechin) units linked by carbon-carbon bonds (Barry and McNabb, 1999; McSweeney *et al.*, 1999).

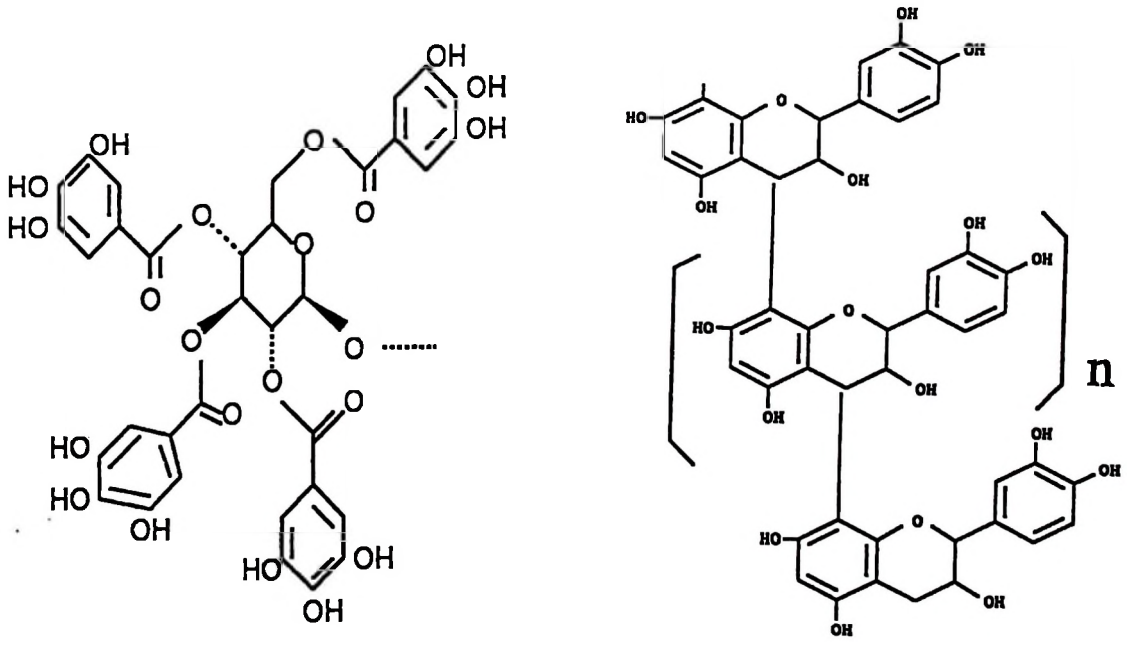

Figure 2. Chemical structure of hydrolysable (left) and condensed (right) tannins, n, repeating subunit of the polymer (McSweeney *et al.*, 1999)

Condensed tannins are present in all *Leucaena species* though in varying amounts. Among Leucaena species, *L. leucocephala* appear to have moderate tannin contents (1.4-7.9%), while *L. pallida* and *L diversifolia* have high contents (5.4-12%) (Wheeler *et al.*, 1994). It is for this reason that psyllid resistance in some *Leucaena species* is thought to be related to the presence of high tannins content (Gupta *et al.*, 1991; Hove *et al.*, 2001). *Acacia species* are widely reported to contain both hydrolysable and condensed tannins (Odenyo *et al.*, 1997; Shayo and Uden, 1998; Abdulrazak *et al.*, 2000; Rubanza *et al.*, 2003).

The amount of tannins found in foliage may vary with genotype, season, age of the plant and the age of the foliage, generally being higher in young leaves, in immature fruits and seed and low in mature leaves and pods (Paakaj *et al.*, 1995; Shelton, 2001). Browse plants tend to invest more phenolic compounds in actively growing shoots to protect herbivores from browsing these important food synthesizing and reproducing organs (Robbin *et al.*, 1987). Soil fertility also affects condensed tannin (CT) levels, with low pH associated with higher CT levels (Kelman and Tunner, 1990). The position of leaves in the canopy, browsing, ambient temperature, and sunlight can all influence CT levels in leaves. For example, high temperature stress has been shown to lead to greater level of CT in the leaves (Lees *et al.*, 1994).

2.6.1.1 Effect on dry matter Intake

Tannins may influence dry matter intake in many ways; by interfering with digestive enzymes through the formation of complexes (Miller, 1994; McMahon *et al.*, 1999), thus slow down ruminal digestion, by combining with protein in the cellular layer of

the gut and thus prevent nutrient uptake (Reed, 2001). Tannins influence hormone levels such as cholecystokinin and peptide bombesin, which are known to influence feed intake (Kumar and Vaithyanathan, 1990).

2.6.1.2 Effect on digestibility

Tannins influence plant dry matter digestibility in a number of ways. During mastication of the plant materials, tannins react by hydrogen bonding with protein to form tannins: protein complexes, upon reaching the rumen, resulting into the creation of a dynamic pool of free condensed tannins (Miller, 1994). Tannins in this pool interfere with digestive enzyme and inhibit the growth and enzyme activity of rumen fungi, protozoa and bacteria (Nelson *et al.*, 1997; Allen and Segarra, 2001). The protein: tannin complexes formed are stable and insoluble at normal rumen pH (5.5 to 7.0), resulting in reducing protein availability below what the crude protein concentrations in the diet imply. The complexes may however dissociate in the lower tract of the ruminant (pH less than 3.0 and at pH 8.0) (Jones *et al.*, 2000), thus providing additional amino acid for digestion, absorption and utilization by animals.

The tannin protein interactions are influenced by many factors, which are associated with protein and tannin structure (Makkar, 2000). Important protein characteristics include; size of molecule, amino acid composition and the molecular charge, whereas tannin characteristics include molecular size, composition, flexibility and structure (Hagerman, 1992; Makkar, 2000). In addition, tannin-protein interactions are influenced by environmental conditions such as pH, temperature, rumen content, and the amount of time available for complex formation (Hagerman, 1992). Therefore,

tannins may selectively bind specific protein even in the presence of an access of another protein (Makkar, 2000).

Tannins may have both beneficial and detrimental effect on protein availability depending on the amount, molecular weight and tannins reactivity with protein (Hagerman *et al.*, 1992, Jones *et al.*, 2000). While high tannin level (>5%) adversely affects intake and digestibility (Leng, 1997), moderate levels (20 to 40g CT/kg of DM) may have two beneficial effects in ruminant nutrition. Firstly, they may protect plant proteins from microbial degradation in the rumen (at near neutral pH, 6.0 to 7.0), but dissociate and release bound protein at pH less than 3.5 in the abomasums (Barry *et al.* 2001; Muetzel *et al.*, 2003), thereby increase amino acid supply to the abomasums and small intestine, resulting in an improved nutritional status of the animals.

The proteins in the leaves of species which do not have tannins such as *Albizzia lebbeck* and *Sesbania spp* are rapidly degraded in the rumen, providing high levels of rumen ammonia, much of which is wasted by excretion as urea (Norton, 1994). On the other hand, species like *Leucaena leucocephala*, *Moringa oleifera* and *Gliricidia sepium*, which contain some tannin, provide both degradable and undegradable rumen nitrogen and are thus more effective source of supplemental nitrogen (Jones *et al.*, 2000). Nguyen *et al.* (2002) demonstrated that low tannin levels (0.29 – 0.74% DM) do not have any effect on nutritive value of diets.

Secondly, tannins may prevent bloat by hindering the formation of stable protein foams in the rumen and control heliminthiasis (Aerts *et al.*, 1999; Reed *et al.*, 2000). Variation in tannins contents is likely to explain in part the variation recorded in digestibility across different plant species. Interpretation of the nutritional value of protein in forage tree therefore requires some knowledge on the nature and reactivity of the tannins.

2.6.1.3 Toxicity

Ruminant animals tolerate moderate levels of tannins up to 5% of dry weight, however a higher level may have adverse nutritional implications (Leng, 1997). Primary manifestation of tannins toxicity is depression of intake due to impaired rumen fermentation of structural carbohydrate resulting from shortage of rumen degradable nitrogen (Reed, 1995) and sometime animals may lose weight (Allen and Segarra, 2001). Of the two types of tannins, hydrolysable tannins are more toxic than condensed tannins. For instance, daily intake of 0.85g/BW of condensed tannins can develop Oedema in the infra mandibular region of rams after 30 days of feeding (Upadhyaya, 1985); whereas intake of 0.9g/BW of hydrolysable tannins has been reported to affect 50% of the sheep within 15 days of feeding (Dynes and Schlink, 2002). According to Murdiati *et al.* (1987), simple phenolics and the phenolic component of hydrolysable tannins may be absorbed and subsequently be excreted in the urine. However, if detoxification mechanism of the animal is insufficient to handle the absorbed phenolics, damage of the liver and kidney may occur (McSweny *et al.*, 1988). Ruminant animals are less susceptible to tannin toxicity than non-

ruminants, however domestic cows and sheep are more susceptible to tannins than are browsing ruminants.

Animals use several mechanisms to counteract the effect of ingested tannins. Some animals adapt to diet containing high level of tannins by increasing plasma growth hormone secretions, which in turn stimulates protein synthesis to replace animal protein precipitated by excess tannins (Barry *et al.*, 1999). Others, especially browsing ruminants have developed physiological defensive mechanisms against tannins. Certain animals are capable of secreting proline-rich protein (PRP) in saliva, which may combine with tannin to form PRP: tannin complexes (Robbins *et al.*, 1987; Makkar and Becker, 1998). The tannin: PRP complexes resist endogenous or microbial enzyme attack and pass intact though the gastrointestinal tract (Robbins *et al.*, 1987), thus protecting valuable protein from tannins.

The secretion of PRP however varies greatly depending on the type of animals and correlates with feeding niches. The saliva of browsing ruminants consuming tanniniferous forage such as domestic goats contain significant amount of PRP than that of grazing ruminants (Robbins *et al.*, 1987). There are some claim that during ingestion of the plant materials, saliva secreted by domestic goats can bind as much as 50% of the dietary tannins (Provenza and Malechek, 1984). Potential grazers such as cattle and sheep do not have PRP in their saliva and hence they are more susceptible to tannin toxicity than are browsing ruminants (Austin *et al.*, 1989). However, continuous production of high levels of proline-rich protein may reduce the efficiency of protein retention when animals are consuming low-tannin diets

(Robbins *et al.*, 1987). There are also some suggestions that the size of parotid salivary gland may indicate an animal ability to ingest tannins. According to Kay *et al.* (1980) paratoid salivary glands in ruminants are three times larger in browsers than in grazers and are intermediate in size in mixed feeder.

2.6.2 Mimosine

Leucaena species contain mimosine, a non-protein amino acid, degraded by the rumen microbes to form a toxic compound (3, 4 - DHP). All species of leucaena tested so far contain mimosine (Hughes, 1998). Mimosine contents vary with species, hybrids and plant fractions. Generally, there is a positive relationship between mimosine content and leaflet size (Hughes, 1998). Species with small leaflets such as *L. collinsii, L. diversifolia, L. esculenta, L. greggii,* and *L. pulverulenta* generally have lower mimosine concentration than the large leaflet species such a *L. macrophylla, L. lanceolata* and *L. trichodes. Leucaena leucocephala* has intermediate level of mimosine (Hughes, 1998). According to Bray (1995) non-genetical factors which affect mimosine concentrations include, plant growth rate, stage of development, plant part, season and plant responses to stress and treatment such as drying. The mimosine concentration is generally high in active growing shoots (8 to 12%), moderate in young leaves (4 to 6%) and moderate to low in young pod and seed (4 to 5%) (Norton *et al.*, 1994).

2.6.2.1 Mimosine toxicity

Mimosine toxicity is caused by 3, 4-DHP which is a potent goitrogen, a breakdown product of the toxic amino acid mimosine. During maceration of the leaf tissue,

mimosine is converted to 3–hydroxy-4 (H)-pyridone (3,4-DHP) by the enzyme, which is present in plant materials (D'mello, 1995). However, further conversion occurs in the rumen by the rumen bacteria (Jones, 1994). When the animals are fed dried Leucaena materials (leaf meals), enzymatic conversion of mimosine to DHP does not take place in the mouth because the enzyme in the plant is rendered inactive by heating (drying) process, instead conversion of mimosine to DHP take place only in the rumen. The DHP circulates in the blood and is excreted in the urine of animals, which do not have DHP-degrading bacteria (Jones, 1997).

The symptoms of mimosine toxicity include excessive salivation, goitre, depressed serum thyroxine levels, depressed appetite, poor live weight gains, ulceration of the esophagus and rumen, hair loss, lesion on the body, poor breeding performance and the production of weak, goitrous, light weight calves and even death (NRC, 1994; Hammond, 1995; Nherera *et al.*, 1998). However, prolonged feeding may sometime be necessary to elicit symptoms of mimosine toxicity (Semanye 1990).

The severity of mimosine toxicity is related to the level of Leucaena consumed. In cattle for example, the normal thyroid weight is about 20 g. However, with high Leucaena intakes, thyroid gland may attain weight of up to 500 g over a twelve-month period (Jones, 1994). In an experiment in which sheep were fed lucerne chaff and infused with DHP into the rumen, feed intake declined from about 1 kg per day of lucerne chaff to 0.2 kg per day over a 6 days period (Bamumalin, 1984).

The susceptibility of animals to mimosine toxicity however varies with factors such as animal species, diet, duration of feeding and geographical differences in rumen microbial ecology (D'mello, 1995). Although quite toxic to non-ruminant animals, the DHP is normally broken down by rumen microorganisms to non-toxic compounds and excreted in the faces and urine. In Australia for example, goats have been reported to excrete large amounts of DHP after grazing *Leucaena* without symptoms of toxicity (Jones, 1994). The microbes are naturally present in ruminant animals where animals have been grazing naturalized leucaena for a long time. In other countries however the appropriate rumen microorganisms are lacking, thus leading to an accumulation of DHP if Leucaena constitutes a high proportion (>30%) of the animal diet for an extended period (Shelton and Brewbaker, 1994).

2.6. 3 Cyanogenic glycosides and Saponins

Cyanogenic glycosides (CNG) are esters of an aglycone and sugar (generally D-glucose), which are important in many acacias and other tropical browse plants (Kumar and D'mello, 1995; Ngwa and Nsahlai, 2004). Generally, the young rapidly growing portion of the plant and the seeds contain the highest concentration of CNG than other plant parts. The concentration of CNG in plants varies with the stage of growth, time of year, soil mineral and moisture content, and time of the day (Knight and Walter, 2002).

The CNG in the leaves and stems of plants are not toxic unless acted on by the plant or rumen microorganism enzymes (b-glucosidase and hydroxynitrile lyase) to form a toxic hydrogen cyanide (HCN) or prussic acid (Cheeke, 1997; Knight and Walter,

2002). Enzymatic convertion of the glycosides to HCN is enhanced when plant cells are damaged or stressed as occurs when plants are chewed, crushed, droughted, wilted or frozen (Pickerel *et al.*, 1991). When HCN is absorbed from the stomach, it combines with hemoglobin in blood and inhibits respiratory enzymes such as cytochrome oxidase, resulting in cessation of eating, depression, staggering, collapse, chronic convulsions and ultimately death due to inhibition of cellular respiration (D'mello, 1995).

Toxicity problems caused by HCN depend upon the concentration of glycosides in the plant and the rate of release of HCN from the glycoside. According to Everist (1981), only plants with more than 2% glycoside as fresh weight are considered deleterious. Acacia species associated with livestock loses due to cyanide poisoning includes, *Acacia cunninghamii, A. leucophloea, A. sieberiana* and *A. sparsiflora* (Kumar and D'mello, 1995; Ngwa and Nsahlai, 2004).

Saponins are glycosides of steroid (triterpenoid compounds) and are widely distributed in plant kingdom (Paterson *et al.*, 1998; Reed *et al.*, 2000). They have a characteristic bitter taste, detergent action and pronounced irritation effect on the membranes of the mouth and throat (Kumar and D'mello, 1995), thus may result in reduced feed intake (Small, 1996; Oleszek *et al.*, 1999). In ruminants, saponins can cause haemolysis of the red blood cells and they have been implicated in causing bloat because of their foaming properties (Harbone, 1991; Francis *et al.*, 2002). Some *Acacia species* contain saponins with the developing seedpods, where they presumably protect the seeds from predation (Dixon and Sumner, 2003). According

to Acamovic *et al.* (1986) Leucaena leaf meal and seeds contain saponins to the level comparable with soybean meal.

2.6. 4 Other inhibitors

Other important inhibitors which have been implicated in causing toxicity to ruminant livestock include; canavanine, fluoroacetic acid (FA), alkaloids and indospicine (Rosales and Gill, 1997). Canavanine is water-soluble, heat resistant, free non-protein amino acids, which occurs in some species of *Canavalia*, *Sesbania* and *Gliricidia* (Paterson *et al.*, 1998). Canavanine interferes with metabolic pathways of livestock. Symptoms of toxicity include low body temperature, a clear nasal discharge, frequent passing of clear urine, lameness, prostration and death. Cattle consuming in excess of 30% of their diet as seed or meal of *Canavalia ensiformis* are at risk (Skerman *et al.*, 1988). Fluoroacetic acid (FA) is an organic acid found in a range of plant species such as *Dichapetalum*, *Castrolobium* and *Spondonthius*. The FA inhibits the Krebs cycle by formation of fluorocitrate (Norton, 1994). Fluorine is a cumulative poison and its effect is often seen only after long grazing time. FA has been responsible for heavy stock losses in part of Australia (D'mello, 1992)

Alkaloids and indospicine are heterogonous group, with diverse chemical structures and occurs in many forage tree species (Winks and Schimmer, 1999; Dixon and Sumner, 2003). Alkaloids are found in about 5-10% of all plants, being more common in tropical than in temperate species (Paterson *et al.*, 1998). Plant families such as Leguminosae, Amarythidaceae and Compositae are noted for their high levels of these compounds (Paterson *et al.*, 1998). The alkaloids content of a plant is

usually a feature of the cultivars, varying little with ecological factors such as climate, season and moisture stress. Unlike other anti-nutritive factors such as tannins, which tend to be concentrated in certain plant parts, alkaloids are often uniformly distributed throughout the plant, all parts being equally dangerous to livestock (Paterson *et al.*, 1998). Many *Indigofera species* appear to be suitable for livestock feeding however some are known to be toxic by virtue of their content of the amino acid indospicine, which can cause liver damage (Aylward *et al.*, 1987). The indospicine is usually present in seeds in high concentrations, sometimes up to 2% (D'mello 1992). The occurrence and toxicity of tannins, mimosine, hydrogen cyanide (HCN) and saponins have been discussed above.

2.7 Quantification of tannins and other related phenolic compounds in forages

A number of methods are available for the analysis of tannins and other related polyphenolic compounds. These include primarily colorimetric, gravimetric-protein precipitation and mixed assays (Giner-Chavez, 1997, Makkar, 2000). The colorimetric assays include Vanillin-HCl (Price and Butler, 1978), the Butanol-HCl (Porter *et al.*, 1986) and Wilson and Hegerman assays (Waterman and Mole, 1994). Tannins can also be assessed by simple bioassays based on *in-vitro* rumen fermentation coupled with the use of tannin-complexing agents such as polythene glycol (Ammar *et al.*, 2003). These assays however do not provide satisfactory results because the amount and type of tannins present in plants varies considerably depending on plant species, plant parts, stage of development, and environmental conditions (Lees *et al.*, 1994; Makkar, 2000). Furthermore, most methods are not

very specific and/or quantify only a fraction of the tannins or polyphenolics compound present in the forage samples.

Tannins and other related polyphenols are polar compounds and are predominantly extracted with aqueous organic solvents such as methanol, ethanol or acetone (Makkar, 2000; Capetillo, 2003). However, polarity and easiness of extraction with different solvents vary between tannins depending on their chemical nature and how tightly they are bound to protein and/or fibre components, which vary considerably between and within forage species. This leads to wide variation in the results and making it difficult to compare results from different analytical assays. For instance, the Vanillin-HCl method used for determination of condensed tannins is not specific as it measures condensed tannins as well as simple flavanoids (Makkar, 2000; Ammar *et al.*, 2003). The Folin Ciocalteau reagent is specific for phenolic compounds but it does not differentiate between tannin and non-tannin phenolics (Muetzel *et al.*, 2003).

The Butanol-HCl is the preferred method for analysis of condensed tannins (Norton, 1994), and is based on depolimerization of condensed tannins in butanol to yield a red anthocyanidin product that can be detected specrophotometrically. However, tannin polymers are cleaved into dimmers or trimmers instead of monomers and this leads to underestimation of CT. The gravimetric assays with ytterbium (Reed *et al.*, 1985) or with PVP (Makkar *et al.*, 1995) determine only soluble tannins present in plant extracts, but insoluble tannins are not measured.

Due to the complexity and diverse nature of tannins, no single method can therefore quantify the exact amount of tannins or polyphenolic compounds present in forage materials and give results that are satisfactorily related to nutritional effects. The use of a specific 'internal standard' isolated and purified from the plant materials under study has been suggested for the accurate quantification of tannins (Giner-Chavez, *et al.*, 1997). However, the isolation and purification of CT from each species are expensive and time consuming, and hence cannot be accepted as routine procedures in most laboratories.

Knowledge of the type and amount of tannins present in forage materials is, therefore, of little value without knowing their biological influence on rumen fermentation and microbial growth. The gas production techniques combined with the use of PEG could be complementary to some analytical methods in studying the biological activity of tannins and would predict, more accurately, their adverse effects on rumen fermentation (Khazaal *et al.*, 1993; Rubanza *et al.*, 2003).

2.8 Management of anti-nutritive factors

Several methods have been used to overcome the deleterious effects of known anti-nutritive factors. Some of these includes; mineral supplementation to dilute the effects of anti-nutritive factors (Sahlu and Smuts-Ayers, 1996), addition of chemicals such as polythene glycol (PEG) to reduce problems associated with tannins (Getechew *et al.*, 2001; Merkel *et al.*, 2003), introduction of microbes to the rumen of ruminant animals to detoxify the compounds (Jones, 1994, 2001), inclusion of other feed ingredients to reduce the proportion of the problem feed in the diet

(Rosale, 1996) and avoiding feeding the plant when the levels of the anti-nutritive compounds are high (Lowry, 1996).

Addition of metal ions, for example ferrous sulphate at a rate of 1-2 % dietary level to rations containing Leucaena leaf meals reduces or completely counteracts the toxic effects of mimosine (Sahlu and Smuts, 1996). Polythylene glycol (PEG) can improve intake of tanniferous forage by decreasing the astringency caused by the interaction of tannin with salivary glycoproteins and hastening rumen digestibility flow by increasing levels of available protein (Reed, 1995). For example, Pritchard *et al.* (1992) showed that dosing sheep with polythylene glycol (PEG) increased both intake and wool production in sheep fed with *A. aneura,* a tannin-containing shrub legume. Jones and Palmer (2000) reported that feeding PEG increased *in-vitro* nitrogen degradability by approximately 30% units (49.3 to 80.7% and 53.1 to 85.5%) in *Calliandra calothyrsus* and *L. pallida,* respectively. However, economically, supplementation with PEG may not be viable.

Some specific rumen bacteria are known, which convert the toxic to non-toxic metabolites. A classic example is that of rumen bacteria *Synergistes jonesii,* which degrade 3,4 DHP to a non-toxic compounds (Jones, 1994). The transfer of DHP-degrading bacteria has overcome the problem of mimosine toxicity in *Leucaena leucocephala* in countries such as Australia (Jones, 1994) and South Africa (Morris and Toit, 1996). Microbial ecology studies show that diverse population of tannin degrading bacteria are found in a wide range of animals that naturally browse on

tannin-containg feeds (Jones, 2001). These organisms can be isolated and transferred between animals to enhance utilization of tanniferous forages.

Feeding mixtures of browse species have been reported to improve feeding value (dry matter intake and digestibility) of browse fodder than when single species is fed alone (Phiri *et al.*, 1992; Bosman *et al.*, 1995; Rosale, 1996). This is possibly due to dilution of toxics associated with different browse species below their threshhold levels (possitive associative effects, synergistic). Other simpler methods including wilting, sun drying and soaking in water have been used elsewhere with some encouraging results (Ahn, 1990; Simon and Stewart, 1994; Peneflorida *et al.*, 1995).

2.8.1 Wilting and sun drying of forage materials

Pre-wilting and sun drying are simple and effective means of reducing some of the plant metabolites. Wilting *Gliricidia* leaves for 12-24 hours before feeding have been found to reduce smell and improve palatability and intake (Hawkins *et al.*, 1990; Simon and Stewart, 1994). Sun drying has been found to be effective in reducing HCN in cassava (*Manihot esculenta*) to an acceptable level for feeding to ruminant (Devendra, 1977). Padamaja (1989) found that wilting cassava leaves under shade for 16 hours followed by drying the detached leaves at 60° C was more effective in reducing assayable tannin than drying alone.

Increased voluntary intake and digestibility by sheep have been observed when dried Gliricidia and *Calliandra calothyrus* were offered as supplements (Ahn *et al.*, 1990). Gomez and Valdivieso (1985) found that sun drying eliminated between 82 to 94%

the initial total cyanide found in fresh cassava forage. Ahn (1990) reported that drying removed all extractable tannins from Gliricidia, increased straw intake, dry matter and N digestibility and N-balance in sheep. According to Azaryan (1985) drying reduced tannin content in fresh *H. perforatum* herbage between 5 to 6.6%. Sun drying has also been reported to reduce mimosine content in *Leucaena leucocephala* leaves between 7.2 - 40% (Jones, 1980). Drying however, can greatly reduce feed intake, and both the *in-vitro* and *in-vivo* digestibility of tree legumes, especially in species containing high levels of tannins (Malyuddin *et al.* 1988; Ahn *et al.*, 1989). For example, Palmer and Schlink (1992) have reported that wilting *Calliandra calothyrsus* at 25^0C for 24 hours depress feed intake in sheep when given as a sole diet over 8 days period.

2.8.2 Soaking treatment

Soaking in water is another way of reducing mimosine content in Leucaena leaves. Detoxification of mimosine by soaking the leaves in fresh water and then drying has been worked out by various researchers (Schuke *et al.*, 1985; Wee and Wang, 1987; Hasan *et al.*, 1994; Soedarjo and Barthakur, 1996; Mondal and Ray 1998). Schuke *et al.* (1985) observed that mimosine content decreased with duration of soaking Leucaena leaves in water, the decrease being most rapid in the first 6 hours. According to Soedarjo and Barthakur (1996) soaking in water for 24 hours eliminated 97% of mimosine from young leaves, pods and split seeds of leucaena without significantly reducing the soluble protein content. Wee and Wang (1987) detected no mimosine in 48 hours soaked leaf, whereas, Hassan *et al.* (1994) reported reduction of mimosine concentration from 2.4% to 0.40%, and Mondal and Ray

(1998) reported the reduction from 2.5% to 0.08% on dry matter basis in 48 h soaked Leucaena leaf meal. Similar findings were reported by Peneflorida *et al.* (1995) who observed that 90% of mimosine was extracted by soaking in water for 30 - 48 hours.

The effect of soaking treatment on the levels of tannins in tree foliage is not well documented. However, few available data indicate that soaking in water could reduce tannin content by 35 to 70% (Mulchopadhyay and Ray, 1997; Peneflorida, 1995). The later author observed that soaking in water could reduce 50% of tannins in *Carica papaya* and *Ipomea batatas*. According to Mulchopadhyay and Ray (1997), tannins could be reduced from 34 to 7g/kg DM (70%) by soaking in water for 16 hours at room temperature. However, the effectiveness of soaking treatment on tannin reduction depends on the duration of soaking and the chemical nature of tannins present in the plant materials (Giner-Chavez, 1997).

2.9 Cutting management of browse plants

Cutting management has a very important influence on the productivity and quality of browse species. The management of tree fodder for maximum fodder production depends upon several factors such as time of the initial cutting, frequency and intensity of defoliation (Paterson *et al.*, 1998). According to Stür *et al.* (1994) the regrowths after defoliation is influenced by a number of factors including tree size, time of defoliation, availability of active meristematic tissue (buds), the amount and photosynthetic capacity of residual leaf area and mobilization of carbohydrate and other nutrients reserves. Replenishment of carbohydrate reserves must therefore be considered when determining cutting intensity and time of defoliation.

2.9.1 Age at first cutting and cutting interval

Recommended age at first cutting vary with tree species and depend more on physiological rather than chronological age. Cutting or defoliation at 12 months after planting and/or when the thickness (diameter) of the stem at 50 cm above the ground level is 8 – 10 cm is generally recommended for most forage tree species (Paterson *et al.*, 1998; Andre, 2004), except when early or late cutting will affect tree survival.

Investigations on the effect of cutting frequency on Leucaena yield shows widely varying results. Guevara *et al.* (1978) in Hawaii and Ferraris (1979) in the wet tropics of Queensland found that longer cutting intervals with low cutting height gave the best yields. However, Perez and Melendez (1980) and Pathak *et al.* (1980) found that the yield was maximized when a high cutting height was employed at shorter interval of cutting. In Kenya, increasing the cutting frequency from two to six cuts over a six months period was found to reduce dry matter yields from 2,283 to 1,637 kg/ha (Otieno and Heineman, 1992).

Shelton and Brewbaker (1994) observed that the optimum-harvesting interval for *L. leucocephala* might be 6-8 weeks at a spacing of 25-50 m between plants. However, at Tumbi, Tabora, Western Tanzania, cutting height of 50 cm above ground at an interval of 60-90 days have been found to be suitable for most Leucaena including *L. pallida* (Otsyina *et al.* 1997).

According to Paterson *et al.* (1998) and Duguma *et al.* (1988) longer intervals between cuttings increase total yield because trees accumulate adequate carbohydrate

reserves to support more foliage regrowths. However, the proportion of inedible wood may also increase, leading to decline in foliage quality (Ivory, 1990; Shelton and Brewbaker, 1994). Leafiness has been used as an indicator of optimum cutting interval. Cutting tree fodder at a time when the proportion of edible materials falls to 50% has been found to maximize yield of edible forage in some browse species like *Calliandra calothyrsus* (Stür *et al.*, 1994).

2.9.2 Effect of cutting height on fodder yield

Forage trees are usually cut to a certain height to maximize fodder production. A standard cutting height of 50–150 cm is normally recommended (Winrock International, 1994), however, there is wide variation between forage tree species. Besides fodder production, these heights retain adequate foliage to ensure rapid regrowth and plant longevity (Stür *et al.*, 1994). Cutting height of 50-100 cm at frequency of 8-10 weeks has been used for *Acacia angustissima* in a number of regions and leaf yields of up to 5 tons/ha/year have been reported (Benjamin, 1988; Dzowela, 1997; Otsyina *et al.*, 1997). In an experiment in which *A. magnum* was grown at a spacing of 2 m between rows and 1.0 m between plants and harvested at an interval of 42, 63 and 84 days and at cutting heights of 50, 75 or 100 cm, dry matter yields increased with length of time between cuttings. However, yield differences with cutting height were not significantly different for the 63 and 84 days cutting frequencies, but yield was significantly greater at 75 cm height for the 42 days cutting frequency (Rodniquez *et al.* 2001).

Some studies have shown that higher cutting height produce higher yields with Leucaena (Krishna Murthy and Munegowale, 1982; Isarasenee *et al.*, 1984). On the other hand, Ferraris (1979) found no difference in the yields of Leucaena cut at 10 or 30 cm. Similarly, Pathak *et al.* (1980) found little difference in Leucaena yields when cut at 10, 20 or 30 cm. According Jama and Nair (1989) a wider range of cutting height (30, 60 and 90 cm) for Leucaena also did not affect yield. In an experiment reported by Karachi and Shirima (1997) in Tumbi, Tabora, Western Tanzania, responses of 11 Leucaena lines to cutting heights was quite variable. Six lines gave the best yields at low cutting height (25cm), whereas four lines maximized yields at 75 cm cutting height and only one performed better when cut at 50 cm above ground. Overall, if sufficient buds are available, cutting interval has a more dominant influence on total yield than cutting height.

In areas with unmodal rainfall pattern, hot and long dry season like Tabora, moisture stress and leaf senescence can lead to physical loss of fodder during the dry season. On-station and on-farm evaluation of some promising browse species at Tabora has shown that the final wet season cut of most tree species should be made one or two months earlier in April or early May before the onset of the dry season in late June. Late wet season cutting result in low fodder yields due to leaf senescence and poor survival and recovery at the end of the dry season (Otsyina *et al.* 1997). Therefore if the aim is to maximize fodder yields at the peak of the dry season, cutting times needs to be planned carefully. This requires further research.

It is particularly important however to note that cutting frequency is influenced by the needs of the farmer to maximize fodder yield or other products such as fuel wood depending on the primary objective for growing the trees. This consideration has important implications on the availability and nutritive quality of fodder produced under different situations. Comparison of herbage dry matter yields between sites is therefore difficult because fodder yield is confounded, not only by differences in agro-ecological conditions, but also by differences in cutting management which in most cases is influenced by the needs of the farmers.

2.10 Evaluation of forage tree with reference to ruminant animals

The actual value of the feed 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.*, 1998). The digestibility of a feed is defined as that portion which is not excreted in the faeces and which is, therefore, assumed to be absorbed by the animal (McDonald *et al.*, 1998). Algebraically represented as:

$$D = (Q_i - Q_r)/Q_i$$

Where: Q_i is the average daily dry matter intake and Q_r is the average quantity of undigested dry matter voided daily and D is the feed's apparent digestibility.

In a digestibility trial, the feed under evaluation is given to a group of animal for a specific period of time in which known amount of the feed are fed to the animals and output of faeces measured. Usually, 3 to 4 animals are desirable because of differences in the digestive abilities of individual animals. Breed, age, size, weight and health condition of the animals are other factors that need to be standardized. A

standard period of 21 days, divided into 14 days preliminary and 7 days data collection period is recommended. Longer period, however, give greater accuracy (McDonald *et al.*, 1998).

The assumption that the proportion of feed digested and absorbed can be determined by subtracting the part excreted in the faeces has some weaknesses. In ruminant animals, the methane arising from the fermentation of carbohydrates is lost by eructation and not absorbed. This loss leads to overestimation of the digestible carbohydrate and digestible energy contents of ruminant feeds. Besides, not all the faeces are actually undigested feed residues. Faeces contain metabolic products including enzymes and other substances secreted into the gut and not reabsorbed, cellular materials abraded from lining of the gut, ether extractable substances and minerals which are of metabolic origin (McDonald *et al.,* 1998), consequently, all these excretions leads to underestimation of the proportion of the feed actually absorbed by the animal. Thus most digestibility values are termed as being " apparent digestibility values". The metabolic and endogenous substances constitute the differences between true and apparent digestibility. True digestibility is therefore larger value than the apparent digestibility value (Van Soest, 1994).

In practice, true digestibility coefficients are difficult to determine, because the fractions of the faeces attributable to the feed and to the animal are in most cases indistinguishable from one another (McDonald *et al.*, 1998). *In vivo* digestibility trials are however expensive and time consuming. Other simpler and quicker

biological methods of estimating digestibility are available. These include *in-vitro* digestibility techniques and the nylon bag (*in-sacco*) degradability.

The two stage *in-vitro* technique of Tilley and Terry (1963) involves incubation of feed samples in rumen liquor followed by digestion with pepsin. During the first stage, a finely ground sample of the feed is incubated at 38^0 C for 48 hours with buffered rumen liquor under anaerobic conditions. The second phase is that of pepsin digestion for 48 hours to remove undigested protein from the digested products. The residue organic matter is subtracted from that of the feed to provide an estimate of digestible organic matter. *In-vitro* digestibilities values are generally slightly lower than that determined *in-vivo,* hence the needs for corrective equations. *In-vivo* and *in-vitro* methods are suitable for estimating the extent to which feeds are digested but do not show the rate at which different feeds are degraded.

The nylon bag technique (*in-sacco* method) was therefore adapted to describe the rate and potential degradation of feedstuffs in the rumen (Ørskov, 1981; Stensig *et al.*, 1994). The method provides a means of ranking feeds according to the rate and extent of degradation of dry matter, organic matter, nitrogen or other nutritional parameters (Osuji *et al.*, 1993; Stensig *et al.*, 1994). It involves incubating feed samples in the rumen of fistulated animals for various time intervals (0, 6,12, 24, 48, 72, 96 and 120 hours for forages and up to 48 – 72 hours for concentrates) and subsequently determination of the disappearance of the different feed components. A sample of known weight (2-5 g of dry matter) is tightly sealed in the synthetic nylon bags (30 - 50 μm pore size) and placed in the rumen of a fistulated animal. After the

required period of time, the bags are removed, washed, dried and weighed. Degradability (or disappearance) of the substrate is determined by the weight loss during the incubation periods. The efflux of feed particles from the bags without breakdown by rumen microbes is corrected for by using zero hours bags. These bags are filled with the samples but are not incubated in the rumen; instead they are washed and dried in the same way as the incubated bags. Furthermore, the zero hours bags are used to correct for passage of materials from pressure applied to the nylon bags during washing (Osuji *et al.*, 1993). The rumen degradation of feed sample in bags incubated in the rumen is described by exponential equation: $\mathbf{P = a + b\ (1 - e^{-ct})}$ (Ørskov and McDonald 1979). Where **p** is the percentage disappearance of the material from the bags. The **a** represent the zero time intercept, **b** the asymptote of the exponential equation, **c** is the rate constant. The **(a + b)** represents the maximum digestistible potential of the feed and **t** is the time of exposure.

The basic assumption that the disappearance of a nutrient in the bags is synonymous with degradation is not always true especially with highly soluble feeds (Ørskov, 1992). Small amounts of solubilized feed protein may leave the rumen without being degraded. Acid detergent insoluble nitrogen, which is known to be undegraded, may also disappear during incubation (McDonald *et al.*, 1998). Degradation profiles are thus over-estimated if not corrected for particle losses (Weisbjerg *et al.*, 1990). The method is also subjected to several sources of error including sample size, bag size, porosity of the bag material, particle size of sample, method of washing, the rumen environment in which degradability is determined and treatment of the bags following removal from the rumen (Osuji *et al.*, 1993). All these sources of variation

need to be controlled and standardized if reproducible results are to be obtained (AFRC, 1992).

Nutritive value of tree foliage is not easily predicted by content of nutrients or chemical analysis. Analysis for chemical composition such as protein and mineral contents usually overestimates nutritional value of tree and shrub fodder because of the failure to account for secondary plant metabolites which may reduce nutrients availability and utilization below what their concentration imply (Reed *et al.*, 2001).

The digestibility of crude protein does not always match with the high CP content, which characterizes fodder trees and shrubs. For example, Wilson (1977) found an apparent digestibility as low as 14% for *Heterodendrum ploifolium* containing 12.5% of CP while *Atriplex vesicaria*, also with 12.5% CP had a nitrogen digestibility of 71.4%. In most cases, there is always no correlation between intake and digestibility. Sometimes highly digestible fodder materials may be poorly consumed and vice versa. Sheep have been reported to consume significantly more fallen leaf of *Albizia lebbeck* (DMD 43%) than fresh leaf (DMD 64%) (Robertson, 1988). Conversely, goats appeared to consume similar amounts of Leucaena (35.6 g/kg/LW) and Gliricidia (32.6 g/kg/LW) despite large differences in digestibility (68.0 and 56.3%), respectively.

The two stage *in-vitro* techniques (Tilley and Terry, 1963) and the *in-sacco* method (Øskov, 1981) are useful in estimation of feed digestibility and in prediction models or equations of VFI for predominant grazers such as sheep and cows (Mgheni, 2000).

However, they cannot be used for mixed feeders and browsers because tannins affect less cell wall digestion in ruminants that commonly consume tanniniferous forages than in predominant grazers (Robbins *et al.*, 1987).

There are some factors other than the rate of digestion in the rumen that determines the voluntary intake of tree foliage by ruminants. Low intakes may sometimes relate to the presence of compounds, which are appetite depressants such as tannins and alkoloids (Paterson *et al.*, 1998; Reed *et al.*, 2001). Furthermore, the presence of physical defensive structures such as thorns, spines, hooks and fibrous leaf in some browse species may render highly nutritious tree foliage quite unpreffered to browsing ruminants (Woodward and Coppock, 1995; Gowda, 1997). The form in which the fodder is fed (fresh, wilted or dry) is also known to affect intake and digestibility in some species (Palmer and Schlink, 1992). The screening of foliage trees for nutritive values by quantitative methods only may therefore lead to some erroneous conclusion if not supported by feeding trials. Feeding trials have the added advantage of providing information on animal health and productivity such as live weight gain and milk production.

CHAPTER THREE

MATERIALS AND METHODS

Four experiments were conducted in this study. The first experiment involved the assessment of the yield and nutritive value of *L. pallida* and *A. angustissima* as related to cutting management. In the second experiment, the effects of post-harvest physical treatment methodss on the levels of secondary compounds were assessed. Experiment three investigated the effect of supplementing *L. pallida* and *A. angustissima* leaf meals to dairy cows on voluntary feed intake, milk yields and quality. Experiment four was an *in-vivo* digestibility study undertaken to determine the effect of supplementary feeding of the two-browse leaf meals on dry matter (DM) and organic matter (OM) digestibility and nitrogen utilization by cattle.

3.1 Experiment 1. Effect of cutting management on fodder production and quality.

Leucaena pallida and *A. angustissima* are among the most promising fodder species for dairy cattle production in the study area. These fodder materials are intended to alleviate the feed shortage constraints, especially in the dry season and consequently increase and sustain milk production. However, farmers lack information on the feeding value of the browse materials and appropriate cutting management. This experiment was therefore initiated to determine appropriate cutting regime that will optimize fodder yield and quality as well as determining feeding values of the edible fractions in terms of chemical composition and degradability in the rumen.

3.1.1 Study area

The experiments was conducted at the Agricultural Research Institute (ARI), Tumbi, Tabora, Tanzania (Latitudes $5^0$02' – $5^0$05' and Longitudes $32^0$39'E) and in three villages of Tumbi, Kazima and Mtakuja in Tabora municipality. Tabora region is located in mid-western part of Tanzania on the central plateau between latitude 4-7^0 South and Longitude 31-34^0 East.

3.1.1.1 Ecological characteristics and vegetation

The altitude of the area varies between 1000 and 1200 meters above sea level. Soils vary widely, ranging from sandy to sandy loam on the upper slopes to heavy black soils in the poorly drained lowlands (Mbugas). In general, soils are sandy (80 to 90%), mostly ferric Acrisoils (FAO system), slightly acidic (pH in water 5.7 to 6.1), low in organic carbon (0.4 to 0.8%), total nitrogen (0.01 to 0.03%), available phosphorus (3 to 12 mg/ kg) and low in exchangeable bases (Otsyina *et al.*, 1998).

The study area has a unimodal rainfall pattern with a long, (5-6 months), hot dry season. Annual rainfall, mainly from November to May, ranges between 700 – 1000 mm, with an average of 880 mm. Rainfall patterns are extremely variable and unreliable both within and between seasons. Showers are often very localized and long dry spell can occur at any time during the rainy season. The rate of evapotranspiration exceeds the monthly rainfall almost every month, thus resulting in moisture deficits throughout the year. Rainfall amount and distribution during the course of the study are presented in Figure 3. During 1999/00, 2000/01 and 2001/02

rain seasons, the study area received 624.3 mm, 1204.4mm and 933.2 mm of rainfall, respectively.

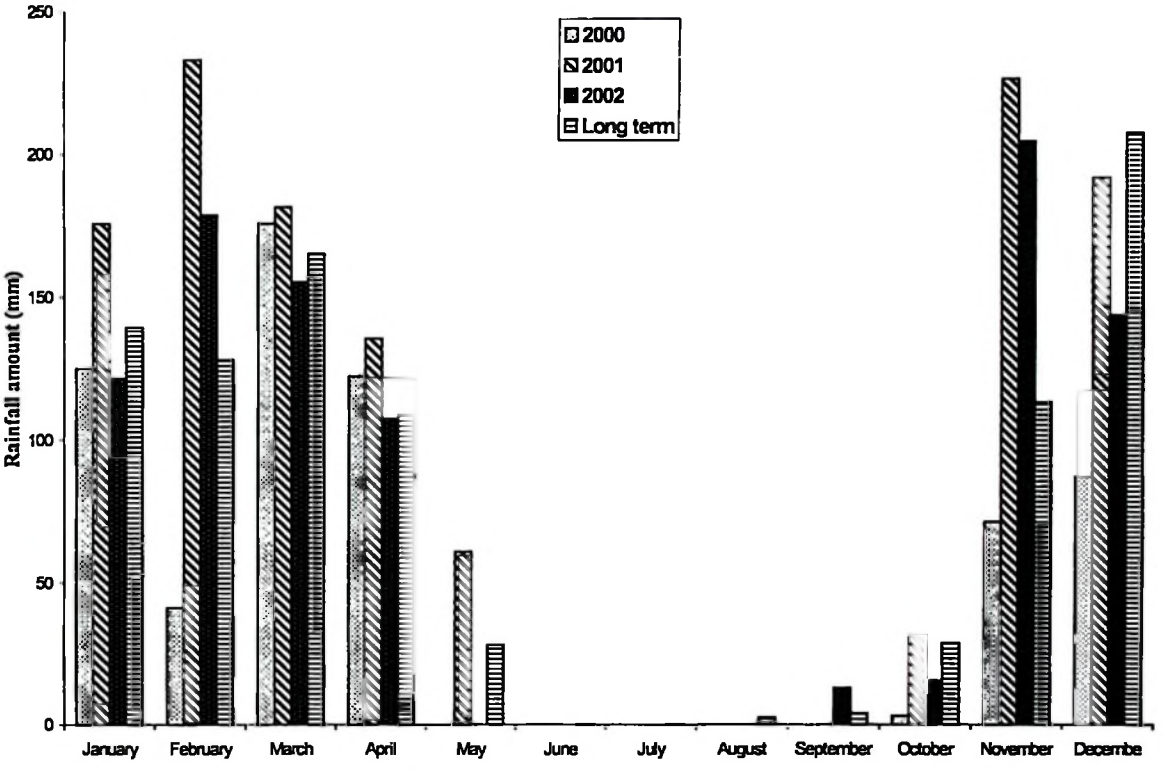

Figure 3. Mean monthly rainfall (1999/00, 2000/01 and 2001/02 growing seasons) compared to 20 years (1981 – 2000) average records at Tumbi Agricultural Research Institute, Tabora, Tanzania

Temperatures are uniformly high, with peaks in September to October just before the onset of the rainy season. However, there is a slightly cooler period from May to July, marked by onset of dry winds, which continue until October. Temperatures range from a mean minimum of 13.6^{O} C in June-July to a mean maximum of 32.5^{O} C in September-October.

The area supports vegetation typical of the deciduous Miombo woodland occurring throughout the southern interior of Africa. *Brachystegia* and *Julbernadia* tree species are the commonest genera in this kind of woodland. *Julbernadia species* make up more than half of the tree in any one area. The dominant species of *Brachystegia* are *B. boehmis, B. speciformis* and *B. microphylla. Brachystegia speciformis* is more and widely spread than the other two species. Other frequently encountered tree species are *Burkea africana, Erythrophloem africanum, Albizzia antunesiana, Pterocarpus angolensis, P. chysothrix* (Lind and Mirrison, 1984). The dominant grasses are *Hyperrhenia, Themeda, Eragrostis* and *Sporobolus species* with some pockets of *Panicum* and *Setaria species* on well-drained fertile sites (Karachi, 1998). The lowland consists of tall coarse grasses with open woodland dominated by *Acacia, Combretum* and *Terminalia* tree species. The Mbugas, which are invariably flooded for long periods during the wet season, are the natural dry season grazing areas for both game and domestic animals.

3.1.2 Planting and management of the fodder banks

The study was carried out using fodder bank plots already existing in farmers' fields as part of an on-going on-farm study aimed at evaluating the potential of psyllid tolerant *Leucaena species* (*L. pallida* and *L. diversifolia*) and a shrub legume, *A. angustissima* in an attempt to boost the quality of available feed resources for dairy cattle production in Tabora Region. The fodder plots were established in the 1997/98 growing season in three villages of Tumbi, Kazima and Mtakuja, all located in Tabora municipality. The trees were planted on ridges at a spacing of 0.75 m within

the ridges and 1.0 m between ridges. The farmers did all field operations including land preparation, ridging, planting and weeding of the fodder bank plots.

3.1.3 Cutting regime

In each of the three villages, two fodder plots, one of *L. pallida* and another for *A. angustissima* were randomly selected for the study. The fodder plots (approximately, 800 m^2) were divided into 4 sub-plots consisting of 4-6 rows each with 20-30 plants. Four cutting regimes: one, two and three monthly interval and control were applied on the respective sub-plots in the wet season. The control sub-plots were cut when the coppice regrowths reached about 1 m high, which is the normal farmer practice. Farmers in the area normally cut their fodder trees at one and a half month interval. These cutting intervals were therefore chosen above and below the farmers practice. All fodder plots were cut at 0.5 m above the ground at the end of the dry season in November of 2000, 2001 and 2002 so as to obtain uniform regrowth in the beginning of wet season.

3.1.4 Fodder production measurements

Estimates of forage yield for each browse species was done by harvesting 6 plants, marked and tagged in the middle rows of each sub-plots. At each cutting time, plants were cut back to 0.5 m above the ground. The fodder materials were separated into three components (Plate 8) including mature leaves, young leaves together with tender twigs (less than 5 mm in stem diameter) and whole edible factions (representing the fodder material as fed to the animals). Two most upper leaves starting from the branch tip were considered as young leaves and rest as mature

leaves. Total fresh and a sub-sample fresh weight for each of the three components were taken in the field for yield determination using spring balance.

Plate 8. Partioning of fodder materials into mature leaves, young leaves and tender twigs and whole edible fractions

Subsequent to yield determination, two samples for each of the three components of *L. pallida* and *A. angustissima* were taken. One of the samples was for dry matter (DM) and nutritive value determination and the other sample was for the determination of secondary compounds. Samples for DM determination were immediately taken to the laboratory at ARI Tumbi, Tabora and dried to constant weight in a forced air oven at 60^0 C. The dry samples were then ground in a Wiley mill to pass through a 2 mm sieve and then mixed thoroughly. A minimum sample of 200 g of each of the milled sample for each fraction was packed in labelled polythene

bags before they were shipped to the Department of Animal Science and Production (DASP), Sokoine University of Agriculture (SUA), Morogoro for nutritive value evaluation. Samples for secondary compounds determination were chopped into small pieces, frozen at -27^0 C and transported to SUA for freeze-drying and later analysed for anti-nutritive factors.

3.1.5 Sampling for chemical analysis

Fodder yield measurements were carried out for three subsequent years starting from January 2000 to November 2002. For each year, samples were collected during both the dry and wet seasons. The dry season samples were collected in November at the end of the dry season, while wet season samples were collected from December to May when the coppice regrowths length were at least 30 cm long. The wet and dry season samples were bulked separately for the cutting regimes (one, two and three monthly interval and control) to form a single bulk sample for each of the three fractions for each browse species from which representative samples were taken for chemical analysis.

3.1.6. Chemical analysis

Total nitrogen in the samples was determined by the Kjeldahl technique (AOAC, 1990), using a semi-automated N-analyser (2200 Kjeltec Auto Distillation, Foss TECATOR). Neutral detergent fibre (NDF), Acid detergent fibre (ADF) and Acid detergent lignin (ADL) were analysed according to the procedure of Van Soest *et al.* (1991). Hemicellulose was calculated as the difference between NDF and ADF, while cellulose was presented as the difference between ADF and ADL. The content

of ash was determined by incinerating the samples in a muffle furnace at 550 ^{0}C for three hours.

Contents of phosphorus, potassium, sodium and calcium were determined using methods recommended by AOAC (1990). Approximately, 2 g samples were incinerated at 550 ^{0}C for three hours and the ash digested using concentrated hydrochloric acid (1:1 ratio) for 24 hours to liberate the minerals. Phosphorus was determined calorimetrically using spectrophotometer (Model PU 8620, Philips, Pye Unicam, UK) set at 420 ηm as recommended by AOAC (1990) and described by Helrich (1990). In this method phosphorus is brought into the form of orthophosphate, which is determined calorimetrically after complex formation with Vanado-molybdate. The Na and K contents were determined using flame photometry (Corning, M410, UK). Calcium was determined as recommended by AOAC (1990) and as described by Milner and Whiteside (1984) using atomic absorption spectrophotometer (Pye Unicam 919, UK).

3.1.7. *In sacco* DM and N degradation

The DM and N degradation were determined using the nylon bag technique (Ørskov *et al.*, 1980). Three cows (Friesian x Boran) fitted with permanent rumen cannulae were used. Each cow was penned individually and water was freely available. The cows were fed grass hay and 2 kg/day of concentrate mixture of 65% cotton seed cake, 33% homily meal and 2% mineral mixture to ensure a stable rumen environment for microbial activity. Nylon bags measuring 12 × 10 cm with a pore size of 40 to 50μm were used. For each sample, six sub-samples of 2 g were

weighed into six nylon bags (two for each cow) for each incubation period. The bags were then incubated in separate batches for 6, 12, 24, 48, 72 and 96 hours to obtain complete degradation curves starting with the 96 hours incubation and 6 hours incubation last. That way, all the bags were eventually taken out at the same time (sequential addition).

The bags were removed from the rumen and hand washed under running tape-water and rinsed until the rinse water was clear. In addition, two samples from each of the three fractions for each browse were soaked in warm water for 1 hour and then washed to determine particle-washing losses (zero hours incubation period). All the bags were then dried in an oven at 60^0 C to constant weights. They were then weighed and the dry matter loss was calculated from the residue weight as the difference between DM before and after incubation. The residues were reground to pass a 1 mm screen for nitrogen determination.

Degradation characteristics (**a, b**), potential degradability (**a + b**) and degradation rate constant **c** (h^{-1}) of DM and N were calculated using NAWAY programme according to the non-linear model equation $\mathbf{p = a + b\ (1 - e^{-ct})}$ (McDonald, 1981) as illustrated in Figure 4 below.

p. Percent degradation at time **t**.

a. **Zero time intercept:** Obtained by extrapolation of the exponential to zero time. It is a constant because it is an extrapolation to zero time. '**a**' can be negative. It is not the soluble component. '**a**' represents the distance between the line **a..a**^{1} and the x - axis of the graph in the diagram.

b. **Degradability constant:** Includes the material, which will be degraded with time, plus a portion of the zero time washing losses (i.e. $A^0 - a$). Therefore it is usually greater than the material, which with time will be degraded (**B**). 'b' will only equal to 'B' when there is no lag phase and $t_L = t_o$ ($a = A^0$ in this situation).

c. **Degradation rate constant:** Defines the rate of change of 'b' (and 'B') with time (t).

$A^{0=A}$. **Zero time washing loss:** Material that can be lost from the bag by washing without incubation in the rumen. Includes the water-soluble materials, plus small particles capable of leaving the bags without degradation.

B. **Fraction degradable with time:** Excludes zero time washing losses.

$$B = (a + b) - A^0 \text{ or } B = (A + B) - A^0.$$

(a + b) **Potential degradability:** Also given by **(A + B)**. It represents degradation when 't' is infinite, and the expression 'e^{-ct}' becomes zero. Thus the degradation equation then becomes $\mathbf{p = a + b\ (1 - 0)}$. In practice this value is very nearly achieved after about 70 – 80 hours with forages (hence incubates to 96 hours to define asymptote), and 40 – 50 hours with protein concentrates (hence incubate to 72 hours).

t_0 **Zero time:** The time at which the bags were introduced into the rumen.

t_L **Lag time:** The time at which the curve a..b crosses the line $A^0 ..A_1$

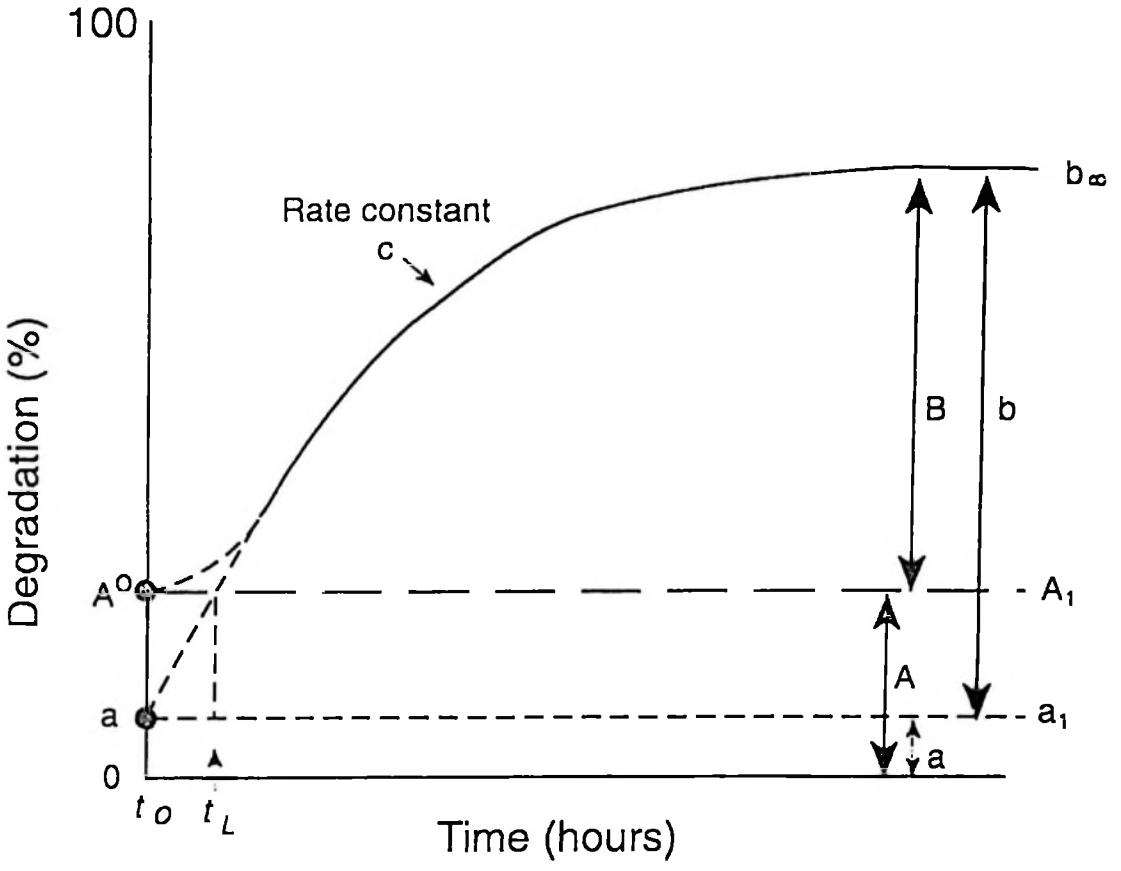

Figure 4. Description of degradation curve described as $\mathbf{p = a + b\ (1 - e^{-ct})}$

3.1.8 Determination of total extractable phenolics, extractable tannins and extractable condensed tannins

The freeze-dried fodder samples were grounded to pass through 0.5 mm screen and further grounded into fine powder in a motor using a pestle. The samples were packed in labeled black nylon bags and stored in cool place before they were analyzed for total phenolics, tannins and condensed tannins.

3.1.8.1 Extraction of tannins

Tannins were extracted from the samples with 70 % aqueous acetone as described by Makkar (2000). About 200 mg of the finely ground fodder samples were weighed into glass beakers (25 ml capacity) and 10 ml of aqueous acetone (70%) were then added to all the beakers, which were subsequently suspended in an ultrasonic water bath for 20 minutes at room temperature. The contents were then transferred to centrifuge tubes and centrifuged for 10 minutes at approximately 3000 rpm. The supernatants were collected and kept on ice. The remaining pellets were transferred to the beaker using two portions of 5 ml each of 70% aqueous acetone and subjected to ultrasonic water bath for 20 minutes, centrifuged for 10 minutes at 3000 rpm and the supernatant collected as described earlier. The two extraction steps were used for determination of total phenolics in two supernatants. However, if the recovery of total phenols in the second supernatant was less than 5% of that in the first supernatant, the second extraction step was omitted.

3.1.8.2 Preparation of calibration curve

Calibration curve was prepared according to Makkar *et al.* (1993) using tannic acid powder from Merck, Germany. Various amounts (0.00 – 0.10 ml) of tannic acid (0.1mg/ml; obtained by dissolving 25 mg tannic acid in 25 ml distilled water and then diluted 1:10 in distilled water) standard solution were made up to 0.5 ml with distilled water (Table 5). Then 0.25 ml of Folin Ciocalteu reagent (1N) was added to all tubes, which were subsequently vortexed, followed by addition of 1.25 ml Na_2CO_3 (20%) and vortexing all the tubes again. After 40 minutes, the absorbance was read at 725 ηm using a normal spectrophotometer (Model PU 8620, Philips, Pye

Unicam Ltd, Cambridge, England). The absorbance readings and tannic acid concentrations (Table 5) were used to develop regression equation that was used in the determination of the tannic acid concentration (μg) of the sample extracts.

$$Y = 3.1036x + 0.0016$$

Where: **x** is the tannic acid concentration (μg) and **Y** is absorbance of the sample extracts recorded at 725ηm.

Table 5. Absorbance readings of the various concentrations (μg/ml) of standard tannic acid solution

Tube	Tannic acid solution (0.1ml/ml)	Distilled water (ml)	Folin reagent (ml)	Sodium carbonate solution (ml)	Absorbance at 725ηm
Blank	0.00	0.50	0.25	1.25	0.000
T1	0.02	0.48	0.25	1.25	0.065
T2	0.04	0.46	0.25	1.25	0.124
T3	0.06	0.44	0.25	1.25	0.196
T4	0.08	0.42	0.25	1.25	0.246
T5	0.10	0.40	0.25	1.25	0.312

T1 – T5 represents various concentrations of standard tannic acid solution against absorbance readings

3.1.8.3. Analysis of total extractable phenols

Total extractable phenols were determined in the extracts according to the method of Julkunen-Tiitto (1985) with the modification of Makkar (2000) using Folin-Ciocalteua and sodium carbonate (20%) as reagents and tannic acid as the standard. Tannin containing extracts (0.02 ml) were measured into the test tubes and the extracts were brought to 0.5 ml with distilled water. Subsequently, 0.25 ml of Folin reagent and 1.25 ml of sodium carbonate solutions were added to the extracts, mixed thoroughly and after 40 minutes the absorbance was read in a spectrophotometer at a

wavelength of 725 ηm. The concentration of tannic acid (μg) on the samples were calculated based on the tannin standard regression curve (**Y = 3.1036x + 0.0016**) and expressed as % tannic acid (TA) equivalent in dry matter basis.

TA (mg/ml) = (TA calculated from the standard curve) / (Volume of the extract)

Percentage total phenolics (TP) in the fodder samples were then calculated as follows: **% TP (DM) = [TA (mg/ml) × 5] × [% DM of the sample]**

3.1.8.4 Determination of total extractable tannins

Total extractable tannins were estimated indirectly after being adsorbed to and precipitated with insoluble polyvinylpyrrolidone (PVPP). The remaining total phenols in the supernatant were measured as described by Makkar *et al.* (1993). A 100 mg of insoluble PVPP obtained from Merck, Germany, binding tannin-phenolics matrix were weighed into glass test tubes followed by addition of 1.0 ml of distilled water and 1.0 ml of the tannin extracts. The tubes were vortexed and kept in a refrigerator at 4° C for 15 minutes. After centrifugation at 3000 rpm for 10 minutes the supernatants (containing only simple phenolics other than tannins, the tannins precipitated along with PVPP) were collected and measured for phenolic contents as described earlier by taking three times of the volume (0.02 ml) used for total phenol estimation. The percentage of total tannins as tannic acid equivalent on dry matter basis was expressed as the difference between total phenolics and non-tannin phenols using the following equation:

% Tannin = X – Y

Where: **X** is total phenolics on DM basis and **Y** is non-tannin phenolics.

3.1.8.5 Determination of condensed tannins

Extractable condensed tannins were measured using the butanol-HCl (95:5 v/v) assay reported by Porter *et al.* (1986) with the modification of Makkar (2000). Tannin extracts (0.1 ml) were measured into test tubes and brought to 0.5 ml with 70% acetone. The quantity of acetone was made to be large enough to prevent the absorbance (550 ηm) in the assay from exceeding 0.6. Subsequently, 3.0 ml of butanol-HCl reagent and 0.1 ml of ferric reagent were added to extract aliquots of 0.5 ml. The tubes were then vortexed and covered with a glass marble and placed in a boiling hot water bath adjusted at 100° C for 60 minutes. The tubes were removed, cooled and absorbance recorded using a spectrophotometer (model PU 8620, Philips, Pye Unicam Ltd, Cambridge, England) at 550 ηm after 40 minutes. Condensed tannins (%) on dry matter basis as leucocyanidin equivalent was calculated using the following formula described by Makkar *et al.* (1993).

% Condensed Tannins = (A550 ηm × 78.26 × Dilution factor) / (% DM of the sample)

3.1.9 Determination of mimosine

The concentrations of mimosine in the fodder samples were determined using the procedure described by Matsumoto and Skerman (1951) with the modification of Okot (1998). The freeze-dried fodder samples were ground as described earlier (section 3.1.7). Approximately 200 mg of the sample were measured into test tubes in duplicate. Then, 10 ml of 1.5g activated carbon suspensions in $Na_2EDTA.2H_2O$ of 1g in 410 ml of 0.1NHCL diluent was then added into each tube and mixed thoroughly. The test tubes containing the samples were placed in a boiling water bath

for 15 minutes and repeatedly shaken to ensure even heating of the samples. After which the contents were filtered through Whatman No.2 filter paper and the filtrates stored in capped glass test tubes before they were analyzed for mimosine contents.

Mimosine extracts, 1.0 ml and mimosine standard (Calbiochem A grade obtained from Sigma Company) solution in serial concentrations ranging from 3-150μg/dl were measured into pre-labelled test tubes. Then, 2 ml of iron II reagent (1.2g $Fecl_3.6H_2O$ dissolved in 500 ml of 0.05NHCL) was added into each tube, mixed thoroughly and left to stand at room temperature for 10 minutes to allow colour development. Absorbance of the sample and standard were read using a normal spectrophotometer (model PU 8620, Philips, Pye Unicam Ltd, Cambridge, England) at 530ηm against Iron 11 reagent as blank. Mimosine concentrations for the samples were obtained using a standard curve ($\mathbf{Y = 22.65X}$, $R^2 = 0.9947$) and expressed in dry matter percentage.

3.1.10 Experimental design

The experimental design used was 2 (browse species) × 3 (fractions) × 4 (cutting regimes) factorial arrangements of treatments in a randomized block design using village as blocks and individual plots as replicates.

3.1.11 Data analysis

General Linear Model (GLM) procedure of Statistical Analysis System (SAS, 2000) was used in data analysis. Fodder yields, nutrient contents, secondary compounds, *in-sacco* and N degradation data were subjected to analysis of variance using models 1-

5 as shown below. The tables for the analysis of variance (ANOVA) for the parameters analysed are shown in Appendix 3 for experiment one. The Least Significant Differences (LSD) test was used to compare the treatment means. Differences between parameters analysed were considered to be significant at $P < 0.05$. When there was no significant interaction between given parameters the data were analysed by considering the main effect only in a reduced model.

Model 1: Dry matter yield per cut

The effect of cutting regimes was compared using the following reduced model:

$$\mathbf{Y_{ij} = \mu + CR_i + \Sigma_{ij}}$$

Whereby:

Y_{ij} = General response of the j^{th} edible fraction (young leaves, old leaves or whole edible fraction) subject to the i^{th} cutting regime.

μ = Overall mean

CR_i = Effect of ith cutting regime on the jth edible fraction

Σ_{ij} = An error term

Model 2: Mean fodder DM yields and N contents.

The model for Mean DM yield and N content included cutting regime, season and cutting regime by season interaction as follows:

$$\mathbf{Yijk = \mu + CR_i + SS_j + (CR*SS)_{ij} + \Sigma_{ijk}}$$

Whereby:

Y_{ijk} = General response (Fodder yield or N content) of the i^{th} cutting regime and j^{th} season

μ = Overall mean response

CR_i = Part of the mean that is due to cutting regime

SS_j = Part of the mean that is due to season

$(CR*SS)_{ij}$ = Interaction between cutting regime and season

Σ_{ijk} = Residual effect (an error term)

Model 3: Mineral concentrations in the edible fractions

The model for mineral concentrations in the edible fractions included cutting regime, plant fraction and cutting regime by plant fractions as indicated below:

$$\mathbf{Y_{ijk} = \mu + CR_i + P_j + (CR*P)_{ij} + \Sigma_{ijk}}$$

Whereby:

Y_{ijk} = General response (mineral content e.g. P) of the j^{th} plant fraction (young leaves, old leaves and whole edible) on the i^{th} cutting regime.

μ = Overall mean response

CR_i = Effect of i^{th} cutting regime on the j^{th} plant fraction

P_j = Part of the mean that is due to plant fraction

$(CR*P)_{ij}$ = Interaction between cutting regime and plant fraction

Σ_{ijk} = An error term

Model 4: Fiber and secondary compounds contents in the edible fractions

$$\mathbf{Y_{ijkl} = \mu + CR_i + PFj + SS_k + (CR*PF)_{ij} + (CR*SS)_{ik} + (CR*PF*SS)_{ijk} + \Sigma_{ijkl}}$$

Whereby:

Y_{ijkl} = General effects of the k^{th} season on j^{th} plant fraction assigned to the i^{th} plant fraction

μ = Overall mean effect

CR_i = Part of the mean due to i^{th} cutting regime

PF_j = Part of the mean due to j^{th} plant fraction

SS_k = Effect of the k^{th} season

$(CR*PF)_{ij}$ = Interaction between cutting regime and plant fraction

$(CR*SS)_{ik}$ = Interaction between cutting regime and season

$(CR*PF*SS)_{ijk}$ = Interaction between cutting regime, plant fraction and season

Σ_{ijkl} = Residual effect

Model 5: *In-sacco* and N-degradation

Mathematical model used to analyse *in-sacco* and N-degradation data was as follows:

$$Yijk = \mu + \lambda_i + \beta_j + (\lambda\beta)_{ij} + \Sigma_{ijk}$$

Whereby:

Y_{ijk} = General effect on incubation time (k^{th} time) on the j^{th} plant fraction of the i^{th} browse species

μ = Overall mean

λ_i = Effect due to browse species (i^{th} browse)

β_j = Effect due to plant fraction (j^{th} fraction)

$(\lambda\beta)_{ij}$ = Interaction between browse species and plant fraction

Σ_{ijk} = Residual effect

3.2 Experiment 2: Effect of different post-harvesting treatment methods on the levels of anti-nutritive factors in the two browse species.

The effects of different post-harvesting processing techniques on the levels of anti-nutritional factors present in the edible fractions of the two browse species (*L. pallida* and *A. angustissima*) were investigated in this experiment. The processing methods included drying (under shade or in the sun), soaking and wilting.

3.2.1 Sampling

Fresh fodder samples of *L. pallida* and *A. angustissima* coppice regrowths were collected after two months from separate plants within the plots used in experiment one. The fodder materials were then separated into three fractions (young leaves with tender twigs ≤ 5 mm stem diameter, mature leaves and whole edible fractions) and bulked into one representative sample of 12 kg. The bulk sample was packed in cool boxes before they were shipped to Tumbi Agricultural Research Institute field laboratory for subsequent treatments. At Tumbi, the fresh samples were chopped into small pieces using kitchen knives, mixed thoroughly and subjected to the various treatments as indicated below.

3.2.2 Drying in the sun and under shade

For each plant fraction from the two browse species, three representative samples of 0.5 kg each were weighed and spread on a tarpaulin to dry in the sun or under open shade. Temperature and relative humidity throughout the drying period were measured using thermometer and hydrometer. The fodder materials were dried until it was crispy between a thumb and the index finger rubbing and then sampled for

DM determination and subsequent analysis for tannins and mimosine contents as described earlier in experiment one.

3.2.3 Soaking

Representative fodder samples were soaked in still water to determine the extent of elimination of the secondary inhibitors from the fodder materials. Three samples of 0.5 kg for each plant fractions from the two browse species were weighed before being soaked for 24 and 48 hours as described by Soedarjo and Burthakur (1996). Samples were removed from water and spread onto wire meshed-bottom trays and dried under open shade to at least 90% DM and subsequently analysed for secondary compounds as described in experiment one.

3.2.4 Wilting

For each plant fraction of the two browse species, six representative samples (from the samples collected in 3.2.1) of 0.5 kg each were wilted in the sun to about 50% and 75% of their original weights. The samples were weighed every quarter or half hour depending on the prevailing weather conditions (Temperature and relative humidity) using a digital electronic balance to determine moisture losses.

3.2.5 Control treatment

For each plant fraction of the two browse species, three fresh representative fodder samples of 0.5 kg each were chopped with a kitchen knife into small pieces, packed

in labelled plastic bags and frozen at -27^0 C for later analysis of condensed tannins and mimosine as described in experiment one.

3.2.6 Experimental design

The experimental design used was 2 (browse species) × 3 (plant fractions) × 4 (post-harvesting treatments) × 2 (levels) factorial arrangement of treatments in a randomised block design with 3 replications.

3.2.7 Statistical analysis

Treatment effects (control, wilting, drying and soaking) were statistically analysed using the General Linear Model (GLM) procedure of SAS (2000). The data were analysed by considering the main effect only using the following reduced model.

$$Y_{ij} = \mu + Pi + \Sigma ij$$

Whereby:

Y_{ij} = General treatment effect on the concentration of the j^{th} edible fraction (young leaves, old leaves or whole edible fraction) subjected to the i^{th} treatment method (soaking, wilting or drying).

μ = Overall mean response

Pi = Effect of i^{th} treatment method on the j^{th} edible fraction

Σij = Residue effect or error component.

Treatment means, which showed significant difference, were compared using probability of difference based on Least Significant Differences (LSD) at $P < 0.05$.

3.3 Experiment 3: The performance of lactating dairy cows fed low quality grass hay supplemented with *L. pallida* and *A. angustissima* foliage

Anti-nutritive factors such as tannins present in tree foliage may limit nutrients availability and utilization by the host animals below what their concentration imply from the laboratory chemical analysis. A more accurate evaluation of foliage tree species for nutritive value can be obtained only if it is supported by feeding trials. This experiment was therefore carried out to investigate the effect of supplementing *L. pallida* and *A. angustissima* leaf meals to dairy cows on voluntary feed intake, milk yield and milk composition (quality) and the relative profitability of the browse leaf meals compared to commercial protein supplements.

The experiment was conducted at Magadu dairy farm of the Department of Animal Science and Production (DASP) of Sokoine University of Agriculture (SUA), Morogoro, Tanzania between March and September 2003. The experiment was carried out to mimic small-scale dairy cattle production in the semi arid areas during the dry season. It was conducted in Morogoro because of easily availability of the laboratory equipments at SUA.

Morogoro is located between latitude 6 and 7^0 South and 37 and 38^0 East Longitudes. Magadu Farm is situated at the foot of the Uluguru mountains on the Northwestern slope at an elevation of approximately 600 meters above sea level. The rainfall pattern of the area is bimodal with an average annual rainfall of between 600 to 800 mm. Short rains fall during November to January and long rains during March to

May. Peak rainfall is normally received in April. The daily temperature ranges between 20–27^0 C in the coolest months in April to August and 30–35^0 C during the hottest months in October to January. Average monthly relative humidity is about 46% during the dry season and 66% during the wet season. Day length ranges from 11 to 13 hours.

3.3.1 Feed preparation

The grass hay used for the feeding trial was a mixture of grasses comprising of *Chloris gayana*, *Bothriochloa insculpta* and *Branchiaria brizantha* from the university farm. The grass were cut in late July 2002, the second month of dry season and at the late stage of maturity, sun dried in the field for 3 days and stored in an open shed. *Leucaena pallida* and *A. angustissima* leaf meals were obtained from on-station fodder bank plots at the Agricultural Research Institute, Tumbi, Tabora. Leaves and tender twigs were harvested from the 2 months coppice regrowths, dried in the sun on a concrete floor to minimize leaf loss, contamination, spoilage and reduce the effect of secondary compounds before they were fed to cattle. After drying, the fodder materials were separated from the stems by threshing. The dry leaf materials were further sorted to remove pieces of stem and leaf raches, and then packed in polythene bags before they were shipped to Sokoine University of Agriculture (SUA), Morogoro for the feeding experiments.

3.3.2 Animals and their management

Four dairy cows (2 Friesian and 2 Ayrshire crosses) in their second months of lactation and in their second to third lactation weighing 351± 30 kg live weight were

used in the experiment. There were no animals of the same breed and on the same lactation and thus two different breeds were used. The assumption made is that the animals will be in the same nutrient requirements as they were not different in body mass and milk production.

The animals were housed in individual pens in a well-ventilated shed and allowed free access to water. Deworming of the animals was done using Milsan, a broad-spectrum anti-helminthic according to the manufacturer instructions. External parasites, mainly ticks were controlled using Ectopor, a pour-on acaricide once every four weeks.

3.3.3 Treatment diets and feeding

Four diets comprising of grass hay as basal feed, cotton seed cake or browse leaf meals as sources of protein and hominy meal as energy source were formulated based on the nutrient requirement of the experimental animals. The treatment diets were as follows; T_1 = basal feed and *L. pallida* leaf meal, T_2 = basal feed and *A. angustissima* leaf meal, T_3 = basal feed, 50% *L. pallida* leaf meal and 50% *A. angustissima* leaf meal and T_4 = basal feed and standard dairy supplement as a control (Table 6). The four dietary treatments were formulated to have similar protein and energy levels based on prior analysis of the feeds for CP and *in-sacco* dry matter digestibility. The calculations of energy and protein requirements of the animals were based on the NRC (1989) feed tables for cows weighing between 350 and 400 kg of live weight and producing 8 litres of milk per day.

Table 6. Composition of experimental diets

Treatment diet	Supplement (kg DM)				Mineral mixture
	LP	AA	CSC	HM	
T_1	2.28	-	-	2.37	0.09
T_2	-	2.07	-	2.40	0.09
T_3	1.09	1.09	-	2.30	0.09
T_4	-	-	1.21	3.20	0.09

LP = *L. pallida*, AA = *A. angustissima*, CSC = Cotton seed cake and HM = Hominy meal. - Not included in the ration

The experiment was done in two phases: the adaptation and actual experimental periods. A preliminary period of 14 days was allowed for the animals to acclimatize to the diets followed by 10 days of data collection during which feed on offer, refusal and milk yield were recorded. The basal feed was offered to the animals *ad libitum* in two equal portions at 0800 and 1500 hours by allowing about 15 to 20% excess above appetite. The supplements were offered twice daily at milking time, in the morning at 0700 hours and evening at 1800 hours. All the cows were fed 90g/cow/day of mineral mixture (Maclicksuper) manufactured by Welcome Tanzania Limited and with the following chemical composition (%): Ca 19.95, P 11.76, Na 10.26, Cl 15.83, Mg 1.1, Cu 0.16, Co 0.02, Fe 0.05, K 0.006, I 0.02, Zn 0.5, Mn 0.4, S 0.33 and Se 0.001.

3.3.4 Experimental design

The experiment was carried out in 4 × 4 balanced Latin square design, using individual cow as a replicate and period as blocks. Treatment diets were assigned to each milking cows in each period at random (Table 7). In that way, each treatment diet was tested 4 times.

Table 7. Arrangement of treatment diets in 4 × 4 Latin square design

Period	Animal			
	1	2	3	4
1	LP	AA	LPAA	CSC
2	AA	LPAA	CSC	LP
3	LPAA	CSC	LP	AA
4	CSC	LP	AA	LPAA

Treatment consisted of basal feed + LP = *L.eucaena pallida* dried leaf meal or AA = *Acacia angustissima* dried leaf meal or LPAA = 50% *L. pallida* and 50% *A. angustissima* dried leaf meal or CSC = cotton seed cake.

3.3.5 Data collection and analysis

3.3.5.1 Dry matter intake (kg/day)

The amounts of feeds offered and the refusals were recorded daily. Representative sample of each feed was taken at weekly interval for DM determination and chemical analysis, upon which amount of basal feed offered was adjusted accordingly. Before each meal, refusals from previous meals were removed from the feeding troughs and weighed. The difference between amount offered and amount refused was regarded as the quantity consumed. Refusals for each animal were taken daily and added to the

previous day sample for each period, after which all refusals were mixed and sub-sampled to obtain a representative sample for each treatment feed. The samples were then stored at room temperature in well-labelled plastic bags for chemical analysis.

3.3.5.2 Milk yield and quality

The cows were hand milked every morning and evening and daily milk yield recorded. The same person was used in the whole experimental period to ensure that style of milking was not a factor in determining milk yield. Aliquot milk sample (200 ml) from each cow was taken daily and frozen at $-27^{O}C$. At the end of the experiment, samples were thawed, bulked for each cow and period, shaken thoroughly and representative samples (500 ml) taken for subsequent analysis for butter fat content, protein, total solids and solids not fat.

3.3.5.3 Simple economics of the experimental rations

Realized profit for each ration was calculated to obtain an indication of the relative profitability of browse foliage in comparison to cotton seed cake. All inputs and costs incurred in the formulation of different rations were recorded. The following information was considered in the analysis: (a) quantities of input required to prepare different rations such as amount of browse leaf meals, cotton seed cake and hominy meal. (b) the price of variable inputs or services such as labour for management of the nursery and fodder bank plots, cutting and processing of the leaf meals, and (c) price of cottonseed cake including transportation costs. Price of milk and cost of production per litre were used to calculate net returns.

3.3.5.4 Chemical analysis

Chemical analysis of feed on offer and refusals were analysed as described in experiment one. The frozen milk was thawed, mixed thoroughly and analysed for butter fat content, protein, total solids and solids not fat. Butterfat content was determined using the standard Gerber method according to Marth (1978) and milk protein by Kjeldahl method using a semi automated N analyser (AOAC, 1990). Total solids was calculated using the Richmond formula as shown below:

$$\mathbf{TS = 0.25LR + (1.22\%\ BF) + 0.72}$$ (O'Mahony, 1988).

Whereby: **TS** = Total solids, **LR** = Lactometer reading and **BF** = Percent butter fat in the milk. Solids not fats (SNF) were calculated as the difference between the total solids (TS) and fat content of the milk.

3.3.6. Statistical analysis

3.3.6.1 Dry matter intake

Data for voluntary feed intake were analysed according to the General Linear Model (GLM) procedures of the Statistical Analysis System (SAS, 2000). The statistical model used was as follows:

$$Y_{ijk} = \mu + P_i + \beta j + \lambda_k + \delta_l + \Sigma_{ijkl}$$

Where:

Y_{ijk} = DM or OM intake of k^{th} animal assigned to i^{th} treatment over j^{th} period.

μ = Overall effect

P_i = Treatment effect

β_j = Period effect

λ_k = Animal effect

δ_l = Breed effect

Σ_{ijk} = Error effect

The differences between treatment means were compared using probability of difference based on Least Significant Differences (LSD) at $P < 0.05$.

3.3.6.2 Milk yields and milk composition

Data for milk yield and composition were analysed according to the General Linear Model (GLM) procedure of the Statistical Analysis System (SAS, 2000). Mathematical model used for the analysis was as follows:

$$\mathbf{Yij_k = \mu + T_i + P_j + \lambda_k + b\ (x_{ij} - x) + \Sigma_{ijk}}$$

Whereby:

Y_{ijk} = General response in milk yield due to treatment effects

μ = Overall effect (mean)

T_i = Effect of i^{th} dietary treatment on milk yield.

P_j = Effect of j^{th} period

λ_k = Breed effect

b = Regression of milk yield changes on initial milk yield

x_{ij} = Initial milk yield of an individual cow

x = Overall mean of initial milk yield

b $(x_{ij} - x)$ = Covariance factor for adjustment of initial milk yield of the cow.

Σ_{ijk} = Error term

The differences between treatment means were compared using probability of difference based on Least Significant Differences (LSD) at $P < 0.05$.

3.4 Experiment 4: *In-vivo* digestibility and nitrogen balance experiment

This experiment was undertaken to determine the effect of supplementary feeding of *L. pallida* and *A. angustissima* leaf meals to dairy cows on dry matter and organic matter digestibility and nitrogen utilization. In this particular study, the nitrogen consumed in the feed (basal diet and supplements) was measured parallel to that voided in the faeces, urine and milk. Finally, differences in nitrogen intake and output were calculated to obtain the nitrogen balance. The data of this experiment were collected at the end of each experimental period of the 3rd experiment using the same animals. Treatment diets, feeding and management of the animals and experimental design were similar to those of the previous experiment.

3.4.1 Dry matter and organic matter digestibility

Faeces from each cow were collected in separate 20 litres plastic buckets. Faeces were collected from the floor using a shovel after defecation (Plate 9), measured for each cow once daily every morning at 0900h using spring balance. The collected faeces were then mixed thoroughly (Plate 10) and 10% aliquot samples taken and frozen at -50^0C for chemical analysis. At the end of the experiment, the frozen samples were thawed, bulked by cow for each period, mixed thoroughly and representative samples taken for faecal DM and nitrogen determination.

Plate 9. Faecal collection from the floor using a shovel

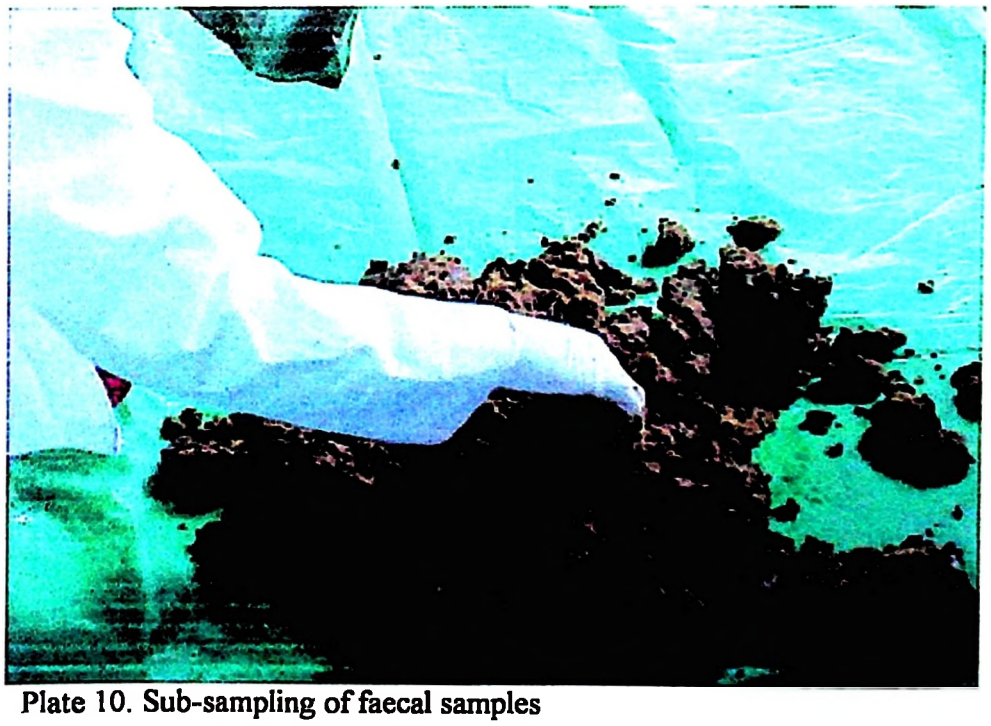

Plate 10. Sub-sampling of faecal samples

Apparent digestibility of the diets was estimated. as the proportion of the feed consumed not excreted in the faeces and which is. therefore. assumed to be absorbed by the animal. Algebraically represented as:

$$D = (Q_i - Q_r)/Q_i$$

Where: Q_i is the average daily dry matter intake and Q_r is the average quantity of undigested dry matter voided daily and D is the feed's apparent digestibility. The major weakness of this assumption is that not all the faeces are actually undigested feed residues. Faeces contain metabolic products including enzymes, cellular materials abraded from lining of the gut and other substances secreted into the gut and not reabsorbed (McDonald *et al.*, 1998), which leads to underestimation of the proportion of the feed actually absorbed by the animal. Besides, methane arising from the fermentation of carbohyrates is lost by eructation and not absorbed. This loss also leads to overestimation of the digestible carbohydrate.

The organic matter digestibility (OMD) was determined by the use of the following equation:

$$\text{OMD} = \frac{\text{(DMI – Ash) – (Faecal (DM) – Faecal Ash)}}{\text{DMI – Ash}}$$

The digestible organic matter in the dry matter (DOMD) was computed according to McDonald *et al.*, (1998) by multiplying the organic matter in the diet with the digestibility coefficient.

DOMD = Organic matter intake × Digestibility coefficient.

3.4.2 Energy

The metabolizable energy (ME MJ/kg DM) was calculated according to the equation given by MAFF (1975).

ME MJ/kg DM = 0.15 or 0.16 DOMD%

Where: **DOMD** (Dry organic matter digestibility) **= 0.98 DMD% - 4.8**

DMD% (g/kg DM) is the dry matter degradability at 48-hour degradability. The coefficients were varied according to the class of feed, 0.15 was used for hay and 0.16 for the supplements.

3.4.3 Collection of Urine for nitrogen determination

Urine was collected using special funnel-like device (Plate 11) fitted with a tube harnessed to the animal to avoid urine being contaminated with faeces (Plate 12). A 14 days adaptation period was used to get the animals accustomed to the devices before the actual collection period. Urine from each cow was collected directly into plastic bags (Plate 13) containing 500 ml of 10% sulphuric acid to lower the pH to 3 in order to prevent ammonia volatilisation. Daily total urine volume excreted by each cow was measured every morning at 0900 hours. A representative sample (200 ml) from each day's collection per cow was taken and stored at -20^0C. At the end of the experiment the urine samples were thawed, bulked by cow for each period, mixed thoroughly and sub-sampled and a representative sample (50 ml) taken for subsequent analysis for nitrogen contents.

3.4.4 Body weight measurements

The animals were weighed at the beginning of the experiment and subsequently at the end of each experimental period using a weighbridge. Weighing was carried out between 0700 and 0800h before morning feeding. The weight recorded at the end of each period was taken as the initial weight for the next period.

Plate 11. Urine collection device

Plate 12.Urine collection device fitted with a tube harnessed to the animal

Plate 13. Urine collection directly into plastic bags using a tube fitted to the urine collection device.

3.4.5 Chemical analysis

Chemical analyses for the faecal and urine samples were carried out as described in experiment one.

3.4.6 Statistical analysis

Analysis of variance was carried out to test the effect of dietary treatments on feed DM and OM digestibility, body weight changes and nitrogen utilization using the General Linear Models (GLM) procedure of SAS (2000) for a balanced 4 × 4 Latin square design.

3.4.6.1 DM and OM digestibility

Data collected were analysed using the following model:

$$\mathbf{Yijk} = \mu + \rho_i + \alpha_j + \lambda_k + (\alpha\lambda)_{jk} + \Sigma_{ijk}$$

Where:

Y_{ijk} = the k-th observation of the j-th animal assigned to the i-th treatment,

μ = Overall mean response,

ρ_i = Animal effect (as random effect),

α_j = Period effect,

λ_k = Treatment effect

$(\alpha\lambda)_{jk}$ = The interaction effect between j-th treatment and k-th period.

Σ_{ijk} = Error term.

For the treatment means, which showed significant difference they were compared using LSD at $P < 0.05$.

3.4.6.2 Body weight measurements

Data collected for live weight gain were analysed using the GLM procedure of the SAS Statistical package (SAS, 2000). Covariance analyses to remove the effect of initial body weights were used as described by Snedecor and Cochran (1989). The model used was as follows: $\mathbf{Yij} = \mu + T_i + P_j + b\ (x_{ij} - x) + \Sigma_{ijk}$

Whereby:

Y_{ij} = General response in terms of live weight changes (kg/day) of the j^{th} animal in i^{th} dietary treatment.

μ = Overall mean

T_i = Effect of i^{th} dietary treatment

P_j = Effect of j^{th} period

x_{ij} = Initial body weight of an individual cow

x = Overall mean of initial body weight

b = Regression of live weight changes on initial body weight.

$b\ (x_{ij} - x)$ = Covariate factor for adjustments of live weight change from initial body weight of animal

Σ_{ijk} = Error term peculiar to an individual animal.

The differences between treatment means were compared using probability of difference based on Least Significant Differences (LSD) at $P < 0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Experiment 1: Effect of cutting management on fodder production and quality

4.1.1 Fodder yields

The foliage DM yields per cutting of *A. angustissima* and *L. pallida* in the wet season is presented in Table 8. In both species, cutting regimes did not significantly ($P > 0.05$) affect young leaf DM yields, but there was significant difference ($P < 0.05$) between cutting regimes in old leaves and whole edible DM yields. The coppice regrowths of *A. angustissima* harvested at 3-months intervals had more old leaves and whole edible fractions yield per cutting than those from the other cuttings, which did not differ significantly ($P > 0.05$). The coppice regrowths of *L. pallida* harvested at 2-months interval had more old leaves DM yields per cutting than cuttings made at 1-month interval and from the control plots. On average, 3-months cutting interval produced the highest DM of old leaves and whole edible fractions. *Acacia angustissima* consistently produced relatively more leaf biomass per cutting than *L. pallida*.

Total wet and dry season fodder DM yields data are presented in Table 9. In the wet season, *L. pallida* DM yield of the young leaves was higher ($P < 0.05$) at 1-month cutting and lower at 3-months cutting, but did not differ significantly ($P > 0.05$) between 2-months and the control plot cuttings. The 3-months cuttings of *L. pallida* produced higher ($P < 0.05$) DM yields of old leaves than other cutting regimes in the

wet season. However, the whole edible fraction did not differ ($P > 0.05$) between cutting regimes.

Trends in fodder DM yields of *A. angustissima* in the wet season followed a similar pattern to that of *L. pallida*. DM yields from *Acacia angustissima* young leaves was lowest at 3-months cuttings and did not differ ($P > 0.05$) between 1-month and 2-months cuttings. The 3-month cuttings produced ($P < 0.05$) higher DM yields of old leaves and whole edible fraction than the other cuttings, which did not differ significantly. *Acacia angustissima* consistently produced relatively more leaf biomass yield than *L. pallida* at all cuttings in the wet season.

Fodder DM yields did not differ ($P > 0.05$) between cutting regimes in the dry season. Both species produced relatively higher quantities of fodder during the wet season than they did in the dry season. Fodder yields were 3 to 8 times higher in the wet season than in the dry season.

Table 8. Mean fodder DM yield (t/ha) for the wet season per cutting of *A. angustissima* and *L. pallida* at different cutting regimes

Plant Fraction	Cutting Regime				SEM	Pr > F	SIG.
	1-Month	2-Month	3-Month	Control			
Young leaves							
A. angustissima	0.15	0.24	0.25	0.19	0.04	0.3042	NS
L. pallida	0.13	0.17	0.17	0.13	0.03	0.6426	NS
Old leaves							
A. angustissima	0.61^{a}	1.36^{a}	3.63^{b}	1.08^{a}	0.33	0.0023	*
L. pallida	0.49^{a}	1.17^{b}	2.03^{c}	0.73^{ab}	0.13	0.0007	*
Whole edible							
A. angustissima	0.75^{a}	1.52^{a}	3.95^{b}	1.27^{a}	0.36	0.0030	*
L. pallida	0.63^{a}	1.34^{b}	2.21^{c}	0.87^{ab}	0.16	0.0018	*

Figures with different letter in the same row are significant difference at 5% level.
NS = Not significant. * = Significant at $P < 0.05$.
Fodder yield values are mean of 3 wet seasons.

Table 9. Total wet and dry seasons fodder DM yields (t/ha) of *L. pallida* and *A. angustissima* fodder banks at different cutting regimes

Season	Plant Fraction	Cutting Regime (Month) 1	2	3	Control	SEM	Pr > F	SIG.
Wet	**Young leaves**							
	A. angustissima	0.66[a]	0.67[a]	0.39[b]	0.54[ab]	0.07	0.0492	*
	L. pallida	0.67[a]	0.37[ab]	0.30[b]	0.38[ab]	0.09	0.0478	*
Dry	*A. angustissima*	0.11	0.15	0.15	0.22	0.05	0.4847	NS
	L. pallida	0.19	0.11	0.20	0.21	0.05	0.5108	NS
	Old leaves							
Wet	*A. angustissima*	2.73[a]	3.28[a]	5.02[b]	3.03[a]	0.42	0.0311	*
	L. pallida	2.10[a]	2.85[ab]	3.15[b]	1.99[a]	0.28	0.0488	*
Dry	*A. angustissima*	0.45	0.38	0.84	0.56	0.16	0.3019	NS
	L. pallida	0.56	0.39	0.70	0.62	0.22	0.7789	NS
	Whole edible							
Wet	*A. angustissima*	3.40[a]	3.95[a]	5.41[b]	3.57[a]	0.41	0.0484	*
	L. pallida	2.77	3.22	3.44	2.37	0.36	0.2603	NS
Dry	*A. angustissima*	0.64	0.49	1.03	0.77	0.19	0.3042	NS
	L. pallida	0.68	0.53	0.85	0.84	0.23	0.7560	NS

Figures with different letter in the same row are significant difference at 5% level.
NS = Not significant. * = Significant at $P < 0.05$.
Fodder yield values are mean of 3 seasons, each for wet and dry.

The increase in the foliage and stem DM yield from the trees at intervals of 1-month to 3-months are as reported elsewhere in literature. Guevara *et al.* (1978), for example observed total biomass DM yields (foliage and stem) of 11.9, 16.9 and 20.8 tons/ha for the Leucaena hedgerows harvested at 2, 3, and 4 months, respectively. Duguma *et al.* (1988) found that biomass yield increased with increasing pruning height and less frequent cutting, (1.6t/ha at 25 cm height) at lower cutting rates (1-month interval) while infrequent cutting (6-months interval) produced significantly higher biomass (13.3 tDM/ha at 150 cm height). Assefa (1998) reported annual increased biomass production of tagasaste (*Chamaecytisus palmensis*), when the harvesting interval was prolonged from two to six months. Similar observation was made by Krishnamurthy *et al.* (1986) working with *L. leucocephala.*

The possible explanations is due to the fact that under extended harvesting, trees accumulate adequate carbohydrate reserves to support more foliage regrowth, whereas frequent cutting depletes reserved carbohydrate and reduces residual leaf area required for regrowth, thus leading to low fodder yields. According to McKell (1980) replenishment of carbohydrate reserves must be considered in determining intensity and time of cutting. Strategic cutting frequencies of browse plants should therefore be applied for improved biomass production.

The increased biomass yield by trees with extended interval between harvests can also be attributed largely to the increase in the proportion of stem as reported by Guevarra *et al.* (1978). In general longer intervals between cuttings increases total DM yields, but the proportion of wood materials also increases, leading to decline in

forage quality (Ivory, 1990; Shelton and Brewbaker, 1994). In the present study, it was observed that additional yields beyond 2-months cutting interval consisted more of wood materials than frequent cuttings (Figure 4), which resulted into decline in foliage quality. Fodder harvested at 3-months had relatively higher fibre (NDF) contents and low in DM digestibility compared to those cut at 1-month and 2-months intervals (Table 16 and 22). The ideal cutting stage to optimise fodder yields and quality is therefore at 2-months. At this period the edible forage DM yields were 64% and 76% out of the total biomass produced for *L. pallida* and *A. angustissima*, respectively.

Differences observed between species in fodder yields was due to differences in growth forms and physiological characteristics associated with acquisitions of light, moisture and nutrients for biomass production (Larbi *et al.*, 1996). The rate of coppice regrowth after defoliation depends on the available regrowth buds, carbohydrate reserves and residual leaf area (Stur *et al.*, 1994). All these factors are quite variable between species and depend more on plant growth forms and defoliation intensity or cutting height.

Edible forage production appeared to be relatively higher in the wet than in the dry season. This was partly due to reduction in or lack of moisture and the accompanying reduction in uptake of nutrients from the soil during the dry season, resulting in slower growth rates. Cobbina *et al.* (1990) reported 82% and 35% reduction in coppice productivity rates for *L. leucocephala* and *G. sepium* respectively during the dry season in South-eastern Nigeria. It was also due to physical loss of fodder due to

leaf senescence and shedding. Extensive leaf shedding in Leucaena trees under extended cutting intervals has been reported by Guevara *et al.* (1978). The amount of leaf litter produced was not measured in the present study. The difference observed between the species could be due to response to drought stress. According to Salako and Tian (2001) the amount of litter produced depends on a number of factors including species and age of trees, climate, soil fertility and management.

Annual mean fodder DM yields varied from 3.21 to 4.29 t/ha and 4.03 to 6.44 t/ha for *L. pallida* and *A. angustissima* respectively (Table 10). In all the three years, the coppice regrowths under 3-month cuttings produced highest ($P < 0.05$) fodder while those under 1-month cuttings produced the lowest fodder. Annual fodder DM yields from 2-months and from the control cuttings did not differ ($P > 0.05$). Both species produced relatively higher quantities of edible forage during the second year of cutting than they did in the first and third year of cuttings.

Fodder: inedible wood ratios were generally higher in the wet season than in the dry season (Figure 5 and 6). There were no ($P > 0.05$) differences recorded between species and cutting regimes in inedible wood yields in both seasons. The highest biomass production in favour of fodder was achieved when the coppice regrowths were harvested at 1-months intervals, only 12% of the total DM consisted of inedible wood and 88% edible fodder. The 2-months cutting regime resulted into 76% and 24% edible fodder and inedible wood yields, respectively. The 3-month cutting regime produced 64% of the total DM yields as edible fodder and 36% as inedible

wood in the wet season (Figure 5). In the dry season, increase in wood yields relative to fodder yields (Figure 6) contributed to the low fodder to inedible wood ratios.

Table 10. Cumulative annual total fodder DM yield (t/ha) of *L. pallida* and *A. angustissima* fodder banks at different cutting regimes.

Cutting regime	Browse spp	Fodder yield (t/ha) Year 1	Year 2	Year 3	Mean
1-Month	*L. pallida*	2.85^{b} (5)	3.82 (7)	3.34^{b} (5)	3.34^{c}
	A. angustissima	3.88^{b} (5)	4.93 (7)	3.29^{b} (5)	4.03^{c}
2-Months	*L. pallida*	2.99^{b}(3)	4.81 (4)	3.46^{a} (3)	3.75^{bc}
	A. angustissima	4.33^{b}(3)	4.99 (4)	4.07^{a} (3)	4.44^{b}
3-Months	*L. pallida*	3.68^{b} (3)	5.51 (3)	3.69^{a} (2)	4.29^{b}
	A. angustissima	7.23^{a} (3)	6.71(2)	5.38^{a} (2)	6.44^{a}
Control	*L. pallida*	3.03^{b} (4)	3.90(4)	2.69^{b} (3)	3.21^{c}
	A. angustissima	4.44^{b}(4)	4.89 (4)	3.69^{a} (3)	4.34^{b}
SEM		0.67	0.01	0.70	0.27

Figure followed by different letter in the same column are significant difference at 5%. ( ) Number of cutting for each respective year.

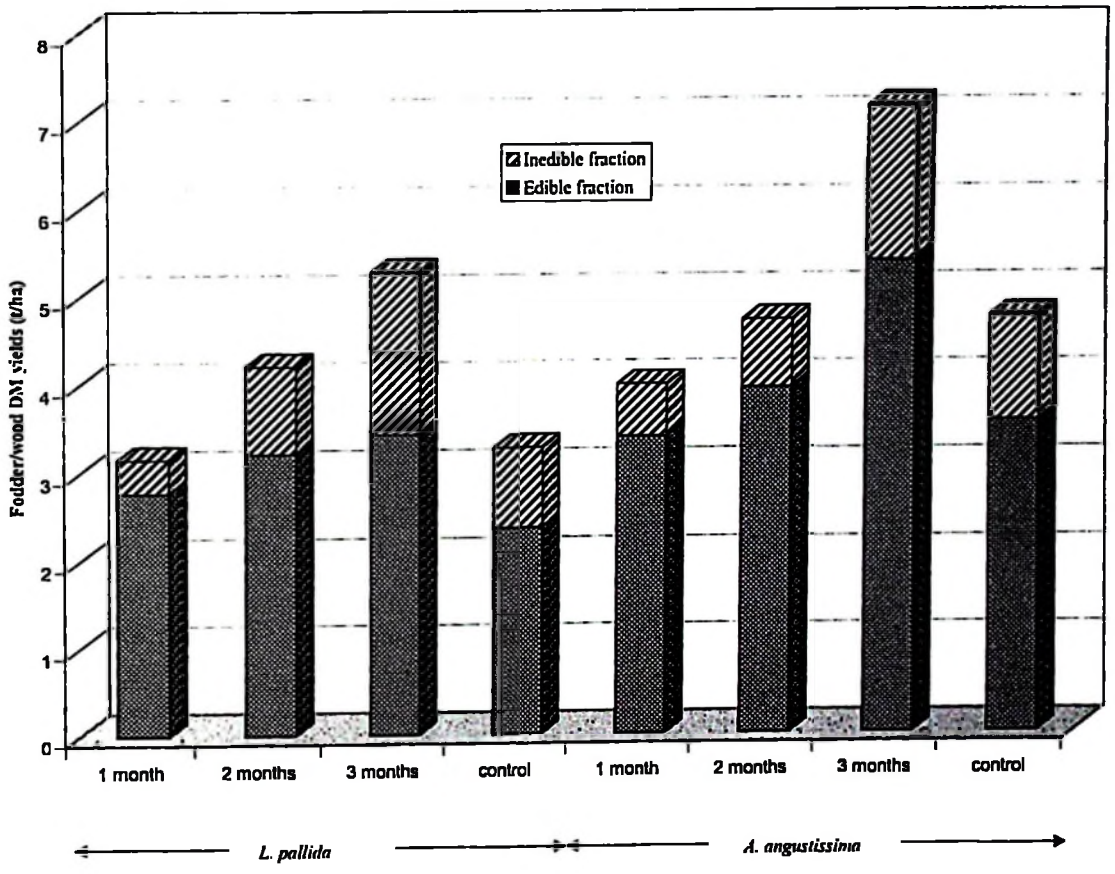

Figure 5. Effect of cutting regimes on fodder and inedible wood DM yields (t/ha) of *L. pallida* and *A. angustissima* fodder banks in wet season

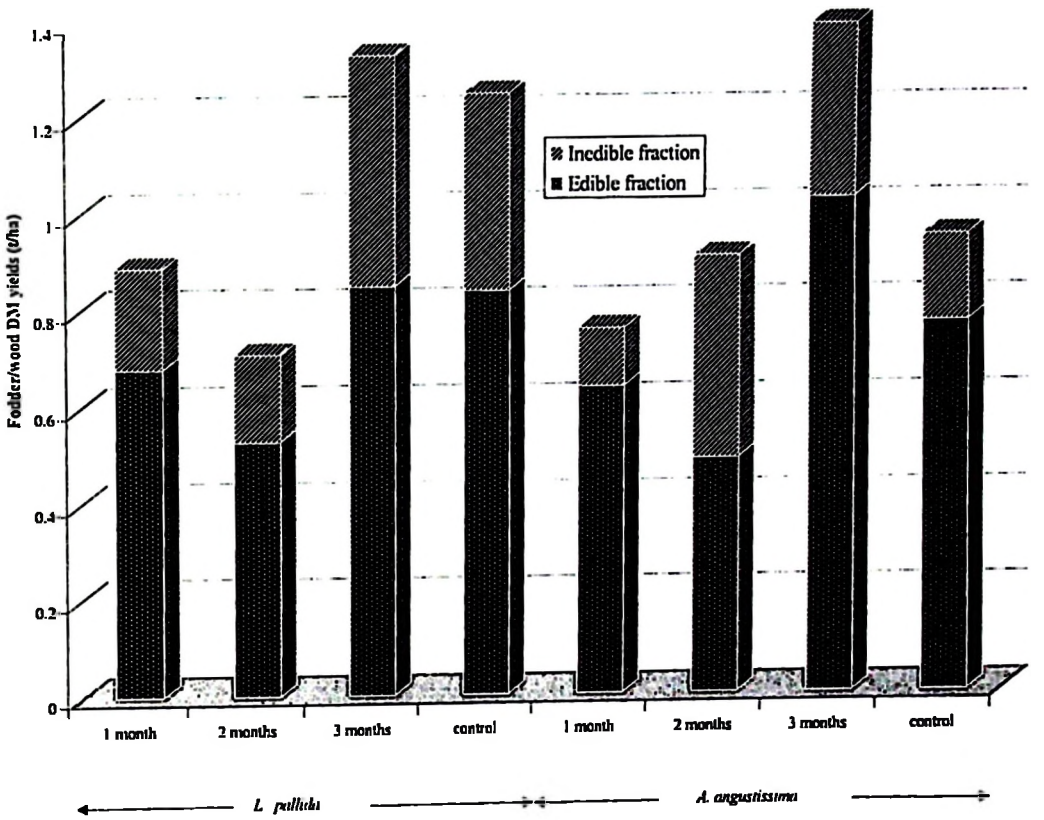

Figure 6. Effect of cutting regimes on fodder and inedible wood DM yields (t/ha) of *L. pallida* and *A. angustissima* fodder banks in dry season

Total annual fodder yield data reported in the present study compare fairly well with the results from studies done elsewhere. Fodder yield values reported for *Acacia angustissima* are in agreement with the findings of Dzowella *et al.* (1997) who reported fodder yield values of 3.5 to 5.2 tons/ha from Makoholi and Domoshawa in Zimbabwe. Evaluation of *A. angustissima,* under fodder banks technology in Shinyanga, Tanzania gave fodder yield of up to 5.41tons/ha per year (Otsyina *et al,* 1998), which is consistent to the reported value in the present study. However, fodder yield values for *A. angustissima* in the present study were much lower compared to those given by Brook *et al.* (1992), and to that reported by Bino (1997) and Isac *et al.* (1994). The latter authors reported biomass production ranging from 10.3 to 11.4 t DM/ha and 11.5 to 12.4 t DM/ha for *A. angustissima* planted at 2-m and 3-m spacing, respectively. These figures were however based on yearly cutting taken during and/or at the end of the wet season. Fodder yields for *L. pallida* falls within the range of 2.25 to 4.23 t DM/ha reported by Mawenya (1995) from Arusha and Kusekwa *et al.* (1997) from Mpwapwa, Tanzania.

The relatively low fodder yields recorded in 2001 and 2002 might be due to low rainfall received and poor distribution in those two years (Figure 3), which subjected trees to prolonged moisture stress and hence resulted into low fodder yields. Rainfall received in 2001 amounted to 1204.4 mm, which was 93% and 29% higher and better distributed than in the year 2000 and 2002, respectively.

4.1.2 Management implications

Tree foliage makes great contribution to livestock feed and crude protein production in the dry season than the wet season. However, both species showed poor performance in terms of fodder yields in the dry season when fodder is most needed. Results from the present study clearly indicate that these new fodder materials cannot be used effectively for dry season feeding without proper management and utilization strategies such as harvesting and drying extra leaf biomass produced in the wet season for dry season feeding as leaf meals, mulch application to conserve soil moisture and harvesting tree fodder one or two months earlier before the onset of the dry season so as to enhance tree survival and recovery at the end of the dry season.

Basing on fodder yield data reported in the present study, a farmer with one hectare of *L. pallida* could produce enough fodder (as leaf meal) to supplement 7 to 10 dairy cows per day in 5 – 6 months in the wet season and only 1 to 2 dairy cows in 6 – 7 months in the dry season, assuming an average daily intake of 2.5kg/cow/day of the leaf meal. Similarly, a farmer with one hectare of *A. angustissima* could produced enough fodder to supplement 9 to 18 dairy cows per day in the wet season and 1 to 3 cows in the dry season. Because most farmers in the study area keep 1 to 2 dairy cows, the extra leaf biomass produced during the wet season could be harvested, dried and used as leaf meals in the dry season to compliment the little fodder produced in the dry season.

4.1.3 Nitrogen contents

Concentration of nitrogen in the edible fraction of *A. angustissima* and *L. pallida* in the wet season is shown in Table 11. The young leaves of *A. angustissima* from1-month and the control plot cuttings had ($P < 0.05$) higher nitrogen content than those for the 2 and 3-months cuttings. There was no significant ($P > 0.05$) variation between cutting regimes in nitrogen content in old leaves and whole edible fraction. For *L. pallida*, the young leaves from 1-month, 2-month and the control plots cuttings did not differ significantly ($P > 0.05$) in nitrogen content, but had higher nitrogen content than that from the 3-months cuttings. The old leaves from 1, 2, and 3-months cuttings did not differ significantly ($P > 0.05$) in nitrogen content, but had lower nitrogen content than that from the control plots cuttings. The whole edible fraction from 3-month cuttings had the lowest nitrogen content while the control plot cuttings had the highest.

Nitrogen content of the edible fractions of *A. angustissima* and *L. pallida* during the dry season is presented in Table 12. There was no significant ($P > 0.05$) variation between cutting regimes in nitrogen content in the edible fractions of *A. angustissima.* The content of nitrogen in young and old leaves of *L. pallida* did not differ significantly ($P > 0.05$) between cutting regimes. The whole edible fractions of *L. pallida* from 3-months cuttings had the highest nitrogen content than the other cutting regimes.

The young leaves of both species had higher ($P < 0.05$) nitrogen content than old leaves and whole edible fractions (Table 13). Samples from the control plots had

significantly ($P < 0.05$) higher nitrogen content in the wet than in the dry season (Table 14). The nitrogen content from 1, 2, and 3-months cuttings did not differ significantly ($P > 0.05$) between seasons. For *L. pallida*, cuttings at 1-month in the wet season had more nitrogen content than dry season cuttings (Table 14). However, the 2-months, 3-months and the control plot cuttings had similar ($P > 0.05$) nitrogen content in both seasons.

Table 11. Nitrogen contents (g/kg DM) in edible fractions of *A. angustissima* and *L. pallida* at different cutting regimes in the wet season

	Cutting regime (Month)						
	1	2	3	Control	SEM	Pr >F	SIG
Young leaves							
A. angustissima	46.7^{a}	38.7^{b}	41.1^{b}	47.3^{a}	0.82	0.0008	*
L. pallida	43.0^{a}	43.3^{a}	37.2^{b}	47.8^{a}	1.47	0.0128	*
Old leaves							
A. angustissima	36.3	37.4	35.1	37.0	1.35	0.6652	NS
L. pallida	31.8^{b}	28.4^{b}	28.4^{b}	36.9^{a}	1.47	0.0199	*
Whole edible							
A. angustissima	37.4	34.3	37.2	38.0	1.36	0.3020	NS
L. pallida	33.9^{ab}	29.9^{bc}	28.7^{c}	34.9^{a}	1.35	0.0435	*

Figures with different subscripts in the same row are significant difference at 5% level. * = Significant at $P < 0.05$. NS = Not significant

Table 12. Nitrogen contents (g/kg DM) in edible fractions of *A. angustissima* and *L. pallida* at different cutting regimes in the dry season

	Cutting regime (Month)				SEM	Pr>F	SIG
	1	2	3	Control			
Young leaves							
A. angustissima	43.5	38.8	39.3	40.5	1.19	0.1111	NS
L. pallida	37.1	32.9	38.0	34.5	1.67	0.2233	NS
Old leaves							
A. angustissima	36.3	36.6	35.3	35.9	1.07	0.8510	NS
L. pallida	33.1	27.1	39.5	32.0	2.04	0.2576	NS
Whole ediblle							
A. angustissima	35.4	34.3	35.3	36.1	0.43	0.1245	NS
L. pallida	28.9^{b}	27.4^{b}	32.4^{a}	29.7^{ab}	0.92	0.0396	*

Figures with different subscripts in the same row are significant difference at 5% level. * = Significant at $P < 0.05$. NS = Not significant

Table 13. Differences in nitrogen contents (g/kg DM) in the edible fractions of *A. angustissima* and *L. pallida* at each cutting regime

	Plant Fraction					
	Young leaves	Old leaves	Whole edible	SEM	Pr > F	SIG.
A. angustissima						
1-Month	45.1^{a}	36.3^{b}	36.4^{b}	0.98	0.0001	*
2-Months	38.8^{a}	37.0^{a}	34.3^{b}	0.77	0.0050	*
3-Months	40.2^{a}	35.2^{b}	36.3^{b}	0.63	0.0003	*
Control	43.9^{a}	36.4^{b}	37.1^{b}	0.87	0.0073	*
L. pallida						
1-Month	40.1^{a}	32.5^{b}	31.4^{b}	1.06	0.0002	*
2-Months	35.1^{a}	27.8^{b}	28.0^{b}	0.92	0.0001	*
3-Months	40.7^{a}	28.9^{b}	31.1^{b}	1.53	0.0004	*
Control	41.1^{a}	34.4^{b}	32.3^{b}	1.26	0.0008	*

Figures with the same subscripts in the same row have no significant difference at 5% level. * = Significant at $P < 0.05$.

Table 14. Seasonal effects on the level of nitrogen (g/kg DM) in *A. angustissima* and *L. pallida* edible fractions

	Season				
	Wet	Dry	SEM	Pr > F	SIG.
A. angustissima					
1-Month	40.1	38.4	0.79	0.1558	NS
2-Months	36.8	36.6	0.63	0.8349	NS
3-Months	37.8	36.7	0.52	0.1439	NS
Control	40.8^{a}	37.5^{b}	0.71	0.0073	*
L. pallida					
1-Month	36.2^{a}	33.1^{b}	0.86	0.0233	*
2-Months	31.4	29.1	0.75	0.0526	NS
3-Months	33.9	33.3	1.25	0.7500	NS
Control	39.8^{a}	32^{b}	1.02	0.0002	*

Figures with different subscripts in the same row are significant difference at 5% level. * = Significant at $P < 0.05$. NS = Not significant

Variation in N content observed between cutting regimes in young leaves was probably due to differences in ratio of leaf to twigs in the analysed samples as these components were sampled together. Differences in nitrogen contents in old leaves and whole edible fractions between cutting regimes relate to differences in proportion of mature leaves in the sample and stage of maturity of the leaves. As the plant mature, protein concentration declines as its hydrolysed and translocated to the other plant parts (Van Soest, 1994).

Nitrogen content of the two browse species were higher than in young tropical grasses, which seldom exceed 15% CP and far above that of mature tropical grasses, which is usually less than 5% CP (Leng, 1991). The nitrogen contents of *A. angustissima* in this study are comparable to those reported by Dzowela *et al.* (1997) and Odenyo *et al.* (2003) for the same plant species (33.2 – 40.8g/kg DM), and were

within the range of 31.0 – 47.2g/kg DM reported by Shayo and Uden (1998) for *A. tortilis* and *A. manginum* from Central Tanzania. However, Sandoval Castrol *et al.* (2001) reported a lower value (29.1g/kg DM) for *A. angustissima* foliage. Similarly, Abdulrazak *et al.* (2000) in Kenya reported slightly lower values (31.04 – 34.1g/kg DM) in leaves and petioles of six species of Acacia (*A. brevispica, nubica, tortilis, seyal, nilotica* and *millifera*) harvested at the end of rainy season. At a range of 34-38gN/kg DM, *A. angustissima* compares favourably well with the values of 35.2-38.5 and 38.9 – 43.5gN/kg DM reported by Palmer *et al.* (1994) for *Calliandra callothyrsus* and Simons and Sterwart (1994) for *Gliricidia sepium*, respectively.

The values of nitrogen in the edible fractions of *L. pallida* reported in the current study are comparable to the 27.2 – 36.5g/kg DM reported by Austin *et al.* (1992) and Castillo (1993), cited by Norton (1994). Ngo-Tien *et al.* (2003) however reported lower values for the same plant species. When compared to other Leucaena species, these values are lower than that of 41.3 – 48g/kg DM reported by Torvan and Suhendi (1991) for *L. diversifolia* and 37.6 – 50.4g/kg DM for *L. leucocephala* reported by various workers (Kimbi, 1997; Ndemanisho *et al.*, 1998; El hassan *et al.*, 2000).

Considering the minimum protein requirement of 10 to 12 % proposed by NRC (2001) for the lactating dairy cow producing at least 10 litres/day, the CP level in the edible fractions in both species are satisfactory for lactating dairy cows and are far above the threshold of 7 – 8 % required for the optimum microbial activity in the rumen (Van Soest, 1994; Norton, 2003). However, high concentrations of condensed

tannins found in the forage, particularly in *L. pallida* may decrease protein availability and utilization by the ruminant animals (Mupungwa *et al.*, 2000; Ammar *et al.*, 2003).

It is known that animals require a continuous supply of protein if they are to maintain a constant level of production throughout the year. Given that *A. angustissima* and *L. pallida* are able to maintain their crude protein contents at higher levels (17 –27 %) than in grasses (3 –5 %) in the dry season, makes them particularly useful as protein supplements to the poor quality pastures and crop residues during the dry season.

4.1.4 Mineral concentrations

The contents of ash and minerals in the edible fractions of *A. angustissima* are given in Table 15 and Appendix 2.1. There were no significant ($P > 0.05$) variations between cutting regimes in ash, calcium and sodium contents. However, significant differences ($P < 0.05$) between cutting regimes were recorded for phosphorus and potassium contents. The P content was higher ($P < 0.05$) in the edible fractions from 1-month and the control plots cuttings than from 2 and 3-months cuttings. The edible fractions harvested from the control plots cuttings had higher ($P < 0.05$) K content than that harvested from 2 and 3-month cuttings. No significant ($P > 0.05$) variation was found between 2 and 3 months cuttings in K content.

The concentrations of minerals in the edible fractions of *L. pallida* followed a similar pattern to that of *A. angustissima* (Table 15 and Appendix 2.2). There were no significant ($P > 0.05$) variations between cutting regimes with respect to ash, calcium

and sodium contents. The young leaves of *L. pallida* from the control plot cuttings had the highest P contents in all cutting regimes, while that from 2-months cuttings had the lowest P content. The whole edible fractions from 1, 2 and 3-months cuttings did not differ ($P > 0.05$) in K content, but had lower K content than the control plots cuttings.

The whole edible fraction of *A. angustissima* from 1-month cuttings had the lowest Ca: P ratio (1.8:1), while 3-months cuttings had the highest ratio of 3:1. The 2-months and the control plots cuttings had intermediate Ca: P ratio of 2:1. With respect to *L. pallida,* the 3-months cuttings had the highest Ca: P ratio (3.8:1) while control plot cuttings had the lowest ratio of 2.1:1. The content of ash, Ca, Na and K were consistently higher in *A. angustissima* than in *L. pallida* at each cutting.

Table 15. Mineral concentration (g/kg DM) in whole edible fractions of *A. angustissima* and *L. pallida* at different cutting regimes.

Mineral	Cutting Regime (Month)						
	1	2	3	Control	SEM	Pr > F	SIG
Ash							
A. angustissima	50.9	46.5	52.1	53.0	2.12	0.2476	NS
L. pallida	60.7	57.2	55.5	60.8	2.34	0.4723	NS
Calcium (Ca)							
A. angustissima	4.97	3.30	5.13	5.57	0.91	0.4108	NS
L. pallida	5.60	4.93	7.17	5.47	0.61	0.1713	NS
Phosphorus (P)							
A. angustissima	2.77[a]	1.60[b]	1.70[b]	2.50[a]	0.11	0.0007	*
L. pallida	1.90	1.40	1.87	2.57	0.23	0.0595	NS
Sodium (Na)							
A. angustissima	9.76	8.37	10.2	10.4	1.23	0.6336	NS
L. pallida	11.7	12.2	14.1	11.7	1.26	0.5420	NS
Potassium (K)							
A. angustissima	14.3[ab]	11.6[b]	12.6[b]	16.4[a]	0.84	0.0205	*
L. pallida	17.5	16.7	17.2	22.4	1.36	0.0754	NS

Figures followed by different letter in the same row are significant difference at 5% level. * Significant at $P < 0.05$. NS = Not significant

Information on mineral contents in browse species is limited. However, the values obtained in the present study are comparable to those reported by Norton (1994b) for some tropical forage tree legumes. Low value of phosphorus in the edible fractions of *A. angustissima* are similar to that of *A.* aunera (1.3g/kg DM) reported by Ahn *et al.* (1990) and consistent to the values of 0.9 – 1.6g/kg DM reported by Abdulzarak *et al.* (2000) for six species of Acacia from Kenya. Topps (1992) also reported low value of phosphorus for most of the tree legume forage.

The concentration of calcium in *A. angustissima* was lower compared to the values of 6.4 – 11.3g/kg DM reported for *Acacia species* (Abdulrazak *et al.*, 2000; Sandoval *et al.*, 2001). The calcium content in *L. pallida* was comparable to the values of 6 – 16g/kg DM reported by Karachi and Shirima (1996) and Mutayoba *et al.* (2003) for *L. leucocephala.* In the present study, young leaves were lower in calcium than old leaves at each cutting. This was in agreement with the work of Karachi (1998). The high concentration of P and K observed at shorter cutting intervals relate to the high proportion of young leaves in the samples (Underwood and Suttle, 1999).

The Ca: P ratios obtained in the present study were higher than the recommended ratio of 2:1 (NRC, 2001). Topps (1992) also reported a much higher Ca: P ratio of 21.3:1 and indicated that the tree and shrubs were unlikely to be a well balance source of calcium and phosphorus. Several studies (Miller, 1983; ARC, 1996; McDowell, 1992), however, have shown that Ca: P ratios of between 1:1 and 7:1 results in nearly equal performance provided the animal phosphorus intake meets its requirements. Factors such as soil, climate, stage of maturity and season contribute to variation in the concentration of minerals in forages (Topps, 1992; Spears, 1994).

The calcium and potassium contents in both browse species were therefore adequate for maintenance and moderate production requirements of dairy animals. However, phosphorus and sodium were below the levels recommended for lactating dairy cows (NRC, 2001), which suggest that animals would require additional source of P and Na to avoid deficiencies in these elements (Lukhele and Van Ryssen, 2003).

4.1.4. Fiber contents

The fiber contents in edible fractions of *A. angustissima* and *L. pallida* in the wet season are shown in Table 16. The ADF, ADL and cellulose contents in both species did not differ ($P > 0.05$) between cutting regimes. The NDF and hemicellulose contents of *A. angustissima* differed significantly ($P < 0.05$) between cutting regimes. The NDF content in the edible fractions from 1-month, 2-months and control plot cuttings did not differ significantly ($P > 0.05$), but was lower than that from the 3-months cuttings. Hemicellulose content was highest from 3-months cuttings and lowest in edible fractions from 2-months cuttings. With respect to *L. pallida*, there were no significant ($P > 0.05$) variations between cutting regimes in terms of fibre contents.

There were significant ($P < 0.05$) variations between browse species and cutting regimes in fibre contents in the dry season (Table 17). In both species, the whole edible fractions from control plot and 1-month cuttings had higher NDF content than that from 2 and 3-month cuttings. The NDF content of *L. pallida* from 2 and 3-months cuttings did not differ ($P > 0.05$) in the dry season. However, the NDF content of *A. angustissima* from 3-months cuttings was lower than that of 2-months cuttings.

The control plot cuttings in both browse species had higher ADF content than other cuttings while 3-months cuttings of *A. angustissima* and 2-months cuttings of *L. pallida* had lower ADF content. The 2-months cuttings of *A. angustissima* and the control plot cuttings of *L. pallida* had higher ADL content than other cutting regimes.

The hemicellulose content in both species was ($P < 0.05$) lower from 3-months cuttings and higher from 1-month cuttings. In both seasons, *Leucaena pallida* consistently had ($P < 0.05$) higher NDF, ADF and ADL contents than *A. angustissima* at each cutting. The fibre contents did not differ significantly ($P > 0.05$) between seasons.

Table 16. Fibre contents (g/kg DM) of whole edible fractions of *A. angustissima* and *L. pallida* at different cutting regimes in the wet season

Fibre Fraction	Cutting Regime (Month)				SEM	Pr > F	SIG
	1	2	3	Control			.
NDF							
A. angustissima	437[b]	462[b]	477[a]	425[b]	10.8	0.0017	*
L. pallida	452	502	531	427	26.7	0.3158	NS
ADF							
A. angustissima	292	305	265	267	7.70	0.0624	NS
L. pallida	364	304	289	293	25.5	0.1439	NS
ADL							
A. angustissima	164	171	127	167	12.6	0.1466	NS
L. pallida	182	203	140	151	19.5	0.1894	NS
Hemicellulose							
A. angustissima	170[b]	137[c]	212[a]	158[cb]	7.10	0.0002	*
L. pallida	138	147	242	134	18.7	0.0757	NS
Cellulose							
A. angustissima	128	134	138	100	12.4	0.0652	NS
L. pallida	129	102	149	142	17.0	0.4551	NS

Figures followed by different letter in the same row are significant difference at 5% level. * Significant at $P < 0.05$. NS = Not significant

Table 17. Fibre contents (g/kg DM) of whole edible fractions of *A. angustissima* and *L. pallida* at different cutting regimes in the dry season

Cutting Regime	Browse species	Fibre contents (g/kg DM)				
		NDF	ADF	ADL	Hemi-cellulose	Cellulose
1-Month	*A. angustissima*	494^{b}	277^{c}	174^{d}	228^{a}	104^{c}
	L. pallida	505^{ab}	325^{b}	209^{b}	169^{b}	116^{bc}
2-Months	*A. angustissima*	413^{d}	270^{cd}	183^{c}	194^{b}	87.1^{cd}
	L. pallida	464^{c}	275^{c}	212^{b}	138^{c}	67.7^{d}
3-Months	*A. angustissima*	351^{e}	249^{d}	159^{f}	102^{d}	89^{cd}
	L. pallida	469^{c}	346^{ab}	166^{e}	123^{cd}	180^{a}
Control	*A. angustissima*	483^{bc}	312^{b}	178^{cd}	171^{b}	133^{b}
	L. pallida	523^{a}	353^{a}	221^{a}	170^{b}	132^{b}
SEM		0.82	0.81	0.18	0.93	0.73
Pr > F		0.0001	0.0001	0.0001	0.0243	0.0001

Figures followed by different letter in the same column have no significant difference at 5% level.

The NDF and ADF contents values reported in the present study are within the range of 220 – 694g/kg DM and 148 – 523g/kg DM, reported by Kaitho *et al.* (1997), Oji and Isilebo (2000) and Okoli *et al.* (2003), respectively for some tropical browse species. The NDF and ADF contents of *A. angustissima* edible fractions compare favourably well with those reported by Bologun *et al.* (1998) and Sandoval Castro *et al.* (2000) and to those reported by Dzowella *et al.* (1997) and Hove *et al.* (2001) from Zimbabwe. These authors reported values ranging from 259 – 532 and 191-394g/kg DM for the NDF and ADF, respectively. Similar NDF values of 498-511g/kg DM were reported by Shayo and Uden (1998) in young and old leaves of *A. tortilis* and *A manginum* from central Tanzania. Goodchild (1990) cited by Notron (1994) reported similar values for the *A. aunera*. The NDF and ADF values reported in the present study were however higher than the values of 154 – 312g/kg DM and

114- 251g/kg DM, respectively reported by Abdulrazak *et al.* (2000) for the leaves and petiole of six species of Acacia from Kenya.

The NDF and ADF contents of *L. pallida* were similar to the values of 368 – 565g/kg DM and 204 – 232g/kg DM for NDF and ADF, respectively reported by Austin *et al.* (1992) and Castillo (1993) cited by Norton (1994), and to that of *L. esculenta* (437 and 307 g/kg DM) and *L. diversifolia* (398 and 355g/kg DM) for the NDF and ADF respectively reported by Lowry *et al.* (1992). However, the values for *L. pallida* reported in the present study are much higher when compared to those of *L. leucocephala* (312 – 336g and 175 – 191 g/kg DM) for NDF and ADF, respectively reported by Kimbi, (1997), Ndemanisho *et al.* (1998) and El Hassan *et al.* (2000). The ADF fraction was a large proportion of the NDF in both species, which indicate high contents of cellulose and lignin and low levels of hemicellulose. The higher NDF and hemicellulose contents observed at 3-month cuttings were probably due to high proportion of mature leaves in the whole edible fractions. This is not unexpected because with advancing maturity the proportion of structural carbohydrates in plant increases (Van Soest, 1994). Differences in fibre contents between cutting regimes in the dry season was not due to differences in time of cuttings, but rather due to proportion of twigs, young and old leaves in the samples. This is because all plots were harvested in November after 6-months of dry season.

4.1.5. Anti-nutritive factors (secondary compounds)

4.1.5.1 Total extractable phenolics (TEPH)

The TEPH content in *A. angustissima* and *L. pallida* edible fractions at different cutting regimes in the wet and dry season are presented in Table 18. The concentration in the edible fractions of *A. angustissima* did not differ significantly ($P > 0.05$) between cutting regimes in the wet season, except for the young leaves and whole edible fraction from 3-month cuttings. However, the TEPH content in the whole edible fractions in *L. pallida* did not differ significantly ($P > 0.05$) between cutting regimes in the wet season. In both species, the TEPH content did not differ between cutting regimes in the dry season, except for *L. pallida* whole edible fractions from the control plots cuttings, which had higher content.

The young leaves in both species had relatively higher TEPH content than old leaves and whole edible fraction at each cutting, except for *A. angustissima* 1-month cuttings. In both species, the TEPH content was relatively higher in the wet season than in the dry season at each cutting, except for the 1-month cuttings and the control plot cuttings for *L. pallida.*

Table 18. Total extractable phenolics (TEPH) contents (mg/g DM) in *A. angustissima* and *L. pallida* edible fractions at different cutting regimes in the wet and dry seasons

	Cutting Regime					
Season	1-Month	2-Months	3-Months	Control	SEM	Pr > F
Wet:						
Young leaves						
A. *angustissima*	117[a]	126[a]	147[b]	128[a]	4.56	0.0183
L. pallida	161[a]	181[ab]	200[b]	172[ab]	9.80	0.0282
Old leaves						
A. *angustissima*	121	114	134	118	8.39	0.4114
L. pallida	122[a]	137[ab]	163[b]	160[ab]	10.6	0.0443
Whole edible						
A. *angustissima*	127[a]	119[a]	174[b]	127[a]	5.44	0.0014
L. pallida	152	170	161	140	14.1	0.5063
Dry:						
Young leaves						
A. *angustissima*	105	120	125	126	8.48	0.3781
L. pallida	182	162	168	196	14.1	0.3988
Old leaves						
A. *angustissima*	105	109	122	94.5	13.8	0.5888
L. pallida	125	109	124	142	14.6	0.5224
Whole edible						
A. *angustissima*	139	129	129	111	13.7	0.5873
L. pallida	143[a]	131[a]	151[a]	182[b]	7.48	0.0143

Means with different superscripts along the same row are significantly ($P < 0.05$) different. Concentration of total phenolics is expressed as leucocyanidin equivalent.

Information on total soluble phenolics in *L. pallida* and *A. angustissima* is limited. The TPH content in whole edible fractions of *A. angustissima* and *L. pallida* (119-174 mg/g DM and 131 – 182 mg/g DM, respectively) reported in the present study were slightly lower than the range of 156.8 – 308 mg/g DM reported by Nherera *et al.* (1998) and Abdulrazak *et al.* (2000) for different tropical browse species. The TPH contents of *A. angustissima,* however, falls within the 56 – 512 mg/g DM range reported by Rubanza *et al.* (2003) for other Acacia species. Shayo and Uden (1998)

however reported lower values (77 - 116 mg/g DM) in young and mature leaves of *A. tortilis* and *A. manginum* from Central Tanzania. The TPH values reported for *L. pallida* in the present study were similar to the 156.8 mg/g DM reported by Nherera *et al.* (1998), but were lower than the 178.1 and 181.8 mg/g DM reported by these authors for other psyllid tolerant Leucaena species, *L. esculenta* and *L. diversifolia*, respectively.

The wide variation in total phenolics reported in the present study and that in the literature could be attributed mainly to the differences in browse species. The variation could also be related to the method of analysis. Quantification of phenolic compounds in browse species is carried out using an array of analytical methods (Makkar, 2000). Variation is expected because the chemical properties that are involved in the reactivity of polyphenolics determined by the different method are widely different (Ammar *et al.*, 2003).

4.1.5.2 Total extractable tannins

Total extractable tannins (TET) content in *A. angustissima* and *L. pallida* edible fractions at different cutting regimes in the wet and dry season are presented in Table 19. The concentration in old leaves and whole edible fractions of *A. angustissima* did not differ significantly ($P > 0.05$) between cutting regimes in the wet season. However, young leaves from 2-month cuttings had lower content than those from the other cuttings.

The TET content in young leaves of *L. pallida* from 1, 2 and the control plot cuttings also did not differ significantly ($P > 0.05$) between cuttings. However, old leaves from the 3-month cuttings had higher content than other cutting regimes, while content in the whole edible fraction did not differ significantly ($P > 0.05$) between cutting regimes. The content in the edible fractions did not differ significantly ($P > 0.05$) between the cuttings regimes in both species in the dry season.

The young leaves in both species had relatively higher total extractable tannins than old leaves and whole edible fraction at each cutting. In both species, the 3-months cuttings had higher total tannin in the wet season than in the dry season, while the control plot cuttings had higher total tannin in the dry season than in the wet season.

Table 19. Total extractable tannin content (mg/g DM) in *A. angustissima* and *L. pallida* edible fractions at different cutting regimes in the wet and dry seasons

Season	Cutting Regime (Months)						
	1	2	3	Control	SEM	Pr > F	SIG.
Wet:							
Young leaves							
A. angustissima	82.4^{b}	63.7^{c}	96.1^{a}	71.1^{ab}	3.32	0.0021	*
L. pallida	95.9^{b}	109^{b}	135^{a}	102^{b}	5.19	0.0075	*
Old leaves							
A. angustissima	70.1	54.0	78.2	62.2	10.8	0.4852	NS
L. pallida	55.2^{b}	72.2^{ab}	109^{a}	73.4^{ab}	11.4	0.0446	*
Whole edible							
A. angustissima	79.5	75.5	98.1	71.2	7.60	0.1643	NS
L. pallida	79.4	92.0	102	85.1	7.06	0.2369	NS
Dry:							
Young leaves							
A. angustissima	58.3	73.3	85.1	84.0	8.87	0.2196	NS
L. pallida	118	99.5	115	136	12.6	0.3346	NS
Old leaves							
A. angustissima	54.0	57.3	78.3	55.1	10.9	0.4122	NS
L. pallida	75.3	61.0	73.9	86.6	15.1	0.7067	NS
Whole edible							
A. angustissima	54.3	66.3	73.4	77.2	10.9	0.5192	NS
L. pallida	83.4	85.7	106	126	10.3	0.0840	NS

Means with different superscripts along the same row are significantly ($P < 0.05$) different. * = Significant at $P < 0.05$. NS = Not significant.
Concentration of total phenolics is expressed as leucocyanidin equivalent.

The total extractable tannin content (71 – 98 mg/g DM) in *A. angustissima* edible fractions obtained in the present study was considerably low compared to the 117-227 mg/g DM reported by Odenyo *et al* (1997) for the same plant forage. Rubanza *et al.* (2003) also reported higher values (95 – 236 mg/g DM) in *A. polycantha*, *A. tortilis* and *A. nilotica* forages from Northwestern Tanzania. Norton (1994), however, reported lower values of 66 and 44 mg/g DM in *A. angustissima* and *A. aunera*

forages, respectively. Total tannins content in edible fractions of *L. pallida* (55-136mg/g DM) reported in the present study was within the range of 63 – 108 mg/g DM reported by Austin *et al.* (1992) in different accessions of *L. pallida*. These values also falls within the range of 99 – 141 and 90 – 124mg/g DM reported by Gupta *et al.* (1991) and Castillo (1993), cited by Norton (1994) for different accessions of *L. diversifolia* and *L. pallida* × *L. leucocephala* hybrids, respectively.

Differences between the total tannin values obtained by various authors and in the present study can be explained by the different assay used, the differences in plant species, plant part, stage of plant maturity and type of tannin present in browse species (Makkar, 2000; Ammar *et al.*, 2003). Organic solvents (methanol, ethanol and acetone) used for the extraction of tannin are known to influence the recovery of tannin in different forage species (Muetzel *et al.*, 2003). For example, Capetillo *et al.* (2003) reported total extractable tannin in twenty-two samples of forage tree leaves from central Mexico ranged from 0.0 to 32.6 (g/100 DM) with different solvents used as extracting agents. These authors found that ethanol 80% gave consitently the lowest estimated and acetone 70% the highest total extractable tannins. These results confirm that different assays used in the quantification of tannin are not very specific and/or quantify only a fraction of the tannins present in the sample and hence the wide variation found in the results. The lack of significant differences between cutting regimes for the whole edible fractions in both species suggest that cutting regimes had a similar influence in total tannin content.

4.1.5.3 Condensed tannins (CT)

The results for the concentration of condensed tannins (CT) in *A. angustissima* and *L. pallida* edible fractions in the wet and dry season are presented in Table 20. The young and old leaves of *A. angustissima* from the control plot cuttings had higher CT content than those of the other cuttings in the wet season. However, the CT content did not differ significantly ($P < 0.05$) between cutting regimes in other fractions. The whole edible fractions of *A. angustissima* from the control plot cuttings had highest CT content while the 2-month cuttings had the lowest CT content.

The young leaves of *L. pallida* from 1-month and the control plot cuttings had higher CT content than that from other cuttings (Table 20). The old leaves of *L. pallida* from 1-month cuttings had the lowest content and that from 2-month cuttings had the highest content. The whole edible fraction of *L. pallida* from the 3-months cuttings had the lowest CT content. Comparison between cutting regimes in the dry season revealed non-significant ($P > 0.05$) variation in CT content for *A. angustissima*. The 2-month cuttings of *L. pallida* in the dry season had higher CT content than other cutting regimes, which did not differ significantly ($P > 0.05$).

The young leaves of *L. pallida* and *A. angustissima* had relatively higher CT content than old leaves and whole edible fraction at each cutting, except for the 2-months cuttings of *L. pallida* harvested in the wet season and 1-month cuttings of *A. angustissima* harvested in the dry season. The CT content in the edible fractions in both browse species was relatively higher in the dry season than in the wet season, except for the control plot cuttings.

Table 20. The concentrations (mg/g DM) of total extractable condensed tannins (CT) in *A. angustissima* and *L. pallida* edible fractions at different cutting regimes in the wet and dry seasons

	Cutting Regime						
Season	1	2	3	Control	SEM	Pr > F	SIG.
Wet:							
Young leaves							
A. *angustissima*	7.07^{b}	7.57^{b}	9.83^{b}	13.7^{a}	0.94	0.0086	*
L. pallida	33.2^{a}	21.7^{b}	28.6^{ab}	32.9^{a}	2.59	0.0407	*
Old leaves							
A. *angustissima*	10.2^{b}	8.00^{b}	8.57^{b}	16.2^{a}	0.67	0.0004	*
L. pallida	16.5^{b}	30.2^{a}	19.1^{ab}	28.9^{ab}	3.50	0.0392	*
Whole edible							
A. *angustissima*	9.87^{ab}	9.03^{b}	11.4^{ab}	14.9^{a}	1.46	0.0110	*
L. pallida	20.7^{ab}	14.0^{b}	9.47^{c}	28.0^{a}	3.06	0.0221	*
Dry:							
Young leaves							
A. *angustissima*	12.5	13.5	13.9	11.5	2.51	0.9024	NS
L. pallida	31.4^{b}	65.1^{a}	26.9^{b}	41.0^{b}	4.48	0.0037	*
Old leaves							
A. *angustissima*	16.5	13.4	12.1	10.2	2.09	0.2827	NS
L. pallida	21.1^{b}	60.5^{a}	26.5^{b}	21.1^{b}	4.81	0.0031	*
Whole edible							
A. *angustissima*	16.3	12.9	13.2	11.4	2.46	0.5778	NS
L. pallida	24.0^{b}	46.6^{a}	23.1^{b}	20.2^{b}	4.55	0.0208	*

Means with different superscripts along the same row are significantly ($P < 0.05$) different. * = Significant at $P < 0.05$. NS = Not significant

Variation in CT content between cutting regimes may be attributed to differences in the ratio of young leaves to twigs, age and stage of maturity of the leaves sampled (Paakaj *et al.*, 1995; Shelton, 2001). This observation may be partly due to differences in ambient temperature and soil moisture at time of sampling (Furstenburg and Van Hoven, 1994). The high concentrations of CT in immature fractions (young leaves and twigs) than in old leaves reported in the present study support other research findings (Ernst *et al.*, 1991; Makkar *et al.*, 1991; Paakaj *et al.*,

1995). These results also support the hypothesis that browse species tend to invest more phenolic compounds in actively growing shoots to prevent herbivores from browsing these important plant parts (Malechek and Provenza, 1983; and Robbins *et al.*, 1987). However reasons for the higher CT content in old leaves than in young leaves for 2-months cuttings of *L. pallida* harvested in the wet season and that of *A. angustissima* from 1-month cuttings in the dry season could not be established.

Seasonal variation in temperature and soil moisture contents may be partly responsible for the relatively higher CT in the dry season than in the wet season. Environmental stress such as drought has been reported to affect concentration of phenolic compounds (Lees *et al.* 1994). For example, Barry and Forsus (1983) observed a substantial increase in CT concentration from 2 to 10% of DM when *Lotus pendiculatus* was grown in low-fertility acid soils under cold conditions as opposed to when it was grown in more fertile soil under warm condition. In the present study, condensed tannin in *A. angustissima* and *L. pallida* was 30 – 75% and 8.6 - 150 %, respectively higher in the dry season than in the wet season.

The CT levels of 9.03 – 16 mg/g DM in edible fractions of *A. angustissima* reported in the present study were within the range of 0.3 – 28 mg/g DM reported by Abdulrazak *et al.* (2000) for six species of Acacia from Kenya. However, these values were lower than the 28.8 mg/g DM reported by Sandoval *et al.* (2001) for the same plant forage in Mexico and to that of 23.0 – 26.8 mg/g DM reported by Odenyo *et al.* (1997) in various accessions of *A. angustissima* in Kenya. Rubanza *et al.* (2003) in Northwestern Tanzania reported much higher values (46 –51 mg/g DM) in

A. polycantha, *A. tortilis* and *A. nilotica* from North Western Tanzania. The CT content in *L. pallida* obtained in the present study was higher than the 3.8 – 6.1 mg/g DM reported by Athanasladon *et al.* (2000) in different accession of *L. pallida*, but lower than the 54 – 120 mg/g DM reported by Wheeler *et al.* (1994) in other psyllid resistant *Leucaena species*.

A threshold concentration of tannin of 5% has been reported beyond which there may be adverse nutritional implications in digestibility and protein utilization (Muetzel *et al.*, 2003). At lower level tannins can be an advantage in preventing bloat and reducing rumen degradation of protein (Jones *et al.*, 2000; Reed *et al.*, 2000). However at higher levels, tannins may reduce feed intake, dry matter digestibility and protein availability and utilization by ruminant animals (Miller, 1994; McMahon *et al.*, 1999). The CT content reported in the present study was however higher than the upper beneficial limit for animal nutrition, thus tannins in these browse fodder may have anti-nutritional effects upon feeding.

The high variation in tannin contents obtained between the present study and other reported values could possibly be due to differences in plant species, plant parts, stage of plant development, environmental conditions, solvent and methods used in the tannin analysis. Studies have shown that extraction of tannin with different solvents varies between tannins depending on chemical nature of tannins and how tightly the tannin is bound to protein and/or fibre components and this variation is considerable between and within forage species (Makkar, 2000; Capetillo, 2003). Further, most laboratory methods used in tannin analysis are not specific and/or

quantify only a fraction of the tannins or polyphenolic compounds present in the forage samples (Muetzel *et al.*, 2003; Ammar *et al.*, 2003), thus leading into wide variations in results. Therefore, understanding the chemical nature of tannins, together with the development of a standard method that relates chemical structures to biological activity of different tannins is particularly important.

4.1.5.4. Mimosine

The concentration of mimosine in the edible fractions of *L. pallida* in the wet and dry seasons is presented in Table 21. Mimosine concentrations in the young and old leaves did not differ significantly ($P > 0.05$) between cuttings in both seasons. However, the whole edible fraction from 1-month cutting regime had the lowest mimosine concentration in the dry season. The young leaves had relatively higher mimosine content than old leaves and whole edible fraction at each cutting. The concentration of mimosine was higher in the dry season than in the wet season, except for the 2-months cuttings.

Table 21. Mimosine concentrations (mg/g DM) in *L. pallida* edible fractions at different cutting regimes in wet and dry seasons

	Cutting Regime (Month)						
	I	2	3	Control	SEM	Pr > F	SIG.
Wet season							
Young leaves	49.5	52.5	52.8	63	4.21	0.1860	NS
Old leaves	30.3	40.0	20.5	29.5	5.78	0.4647	NS
Whole edible	40.9	37.0	28.6	41.7	5.65	0.4123	NS
Dry season							
Young leaves	59.8	50.9	50	58.9	4.53	0.3563	NS
Old leaves	37	26.8	39.8	30.9	3.79	0.1663	NS
Whole edible	33.3^{c}	29.9^{bc}	41.4^{ab}	50.3^{a}	3.17	0.0148	*

Means with different superscripts along the same row are significantly ($P < 0.05$) different. * = Significant at $P < 0.05$. NS = Not significant

Differences in mimosine content between cutting regimes in the whole edible fractions may be associated with differences in the ratio of young leaves to old leaves in the analysed samples. Concentration of mimosine is moderate to high in active growing plant parts and moderate to low in mature fractions (Norton *et al.* 1994). Water stress during the dry season may be partly responsible for the relatively higher mimosine content than in the wet season. Environmental stress such as drought is one of the non-genetical factors that increase mimosine concentration in plants (Bray, 1995).

The values of mimosine in the present study are slightly lower when compared to those reported elsewhere (25 –170mg/g DM) for most *Leucaena species* (Norton *et al.*, 1994; Bray, 1995; Hughes, 1998). However, compare favourably well to the 34-41mg/g DM reported by Gupta *et al.* (1991) for *L. diversifolia* and *L. esculenta,* which are tolerant to Leucaena psyllid (*Heteropsylla cubana*). This variation in

mimosine contents between the current findings and those in literature could be due to stage of plant development, part of the plant sampled (twigs, young leaves and old leaves), *Leucaena species* and time or season of sampling (Bray, 1995).

4.1.6. *In sacco* DM degradation

Dry matter degradability and DM loss data for the browse samples at different cutting regimes and seasons are presented in Table 22 and Figure 7 to 10. The DM degradability for the whole edible fractions at 48 hours of incubation was highly variable ($P < 0.05$) between cutting regimes and species. The 1-month cuttings of *A. angustissima* in the wet season had the highest ($P < 0.05$) DM degradability of 591g/kg DM, whilst the 2-months cuttings had the lowest degradability of 500g/kg DM. The control plots and 3-months cuttings had intermediate degradability values of 560 and 509g/kg DM, respectively.

There were no significant ($P > 0.05$) variations between the control plots and 2-months cuttings in the wet season, nor were there differences between 1-month and 3-month cuttings in DM degradability in *L. pallida* whole edible fraction. The DM degradability of the whole edible fractions of *L. pallida* from 1-month and 3-months cuttings did not differ in the dry season, but was lower than that of the control plots and 2-month cuttings.

Dry matter losses (g/kg DM) from the nylon bags incubated in the rumen of three cows for *A. angustissima* and *L. pallida* fodder (whole edible fractions) harvested at different cutting regimes in the wet and dry season are presented in Figure 7 to 10.

The great portion of DM disappeared from the bags between 12 and 48 hours of incubation for the fodder materials harvested in the wet season (Figure 7 and 8). For the fodder materials harvested in the dry season, the great portion of DM disappeared between 24 and 72 hours of incubation (Figure 9 and 10). Thereafter, DM losses increased slightly with increasing time of incubation and complete degradation curve was not attained even at 96 hours of incubation.

Table 22. *In-sacco* dry matter degradability (g/kg DM) for *A. angustissima* and *L. pallida* whole edible fractions harvested at different cutting regimes in the wet and dry seasons

Cutting Regime	Season	Browse species	Incubation 48 hours
1-Month	Wet	*A. angustissima*	500^{e}
		L. pallida	491^{ef}
	Dry	*A. angustissima*	466^{g}
		L. pallida	448^{h}
2-Month	Wet	*A. angustissima*	591^{a}
		L. pallida	535^{c}
	Dry	*A. angustissima*	467^{g}
		L. pallida	466^{g}
3-Month	Wet	*A. angustissima*	509^{dc}
		L. pallida	482^{f}
	Dry	*A. angustissima*	445^{h}
		L. pallida	442^{h}
Control	Wet	*A. angustissima*	560^{b}
		L. pallida	532^{c}
	Dry	*A. angustissima*	512^{d}
		L. pallida	492^{ef}
SEM			3.53
Pr > F			0.0001

Means with different superscripts along the same column are significantly ($P < 0.05$) different.

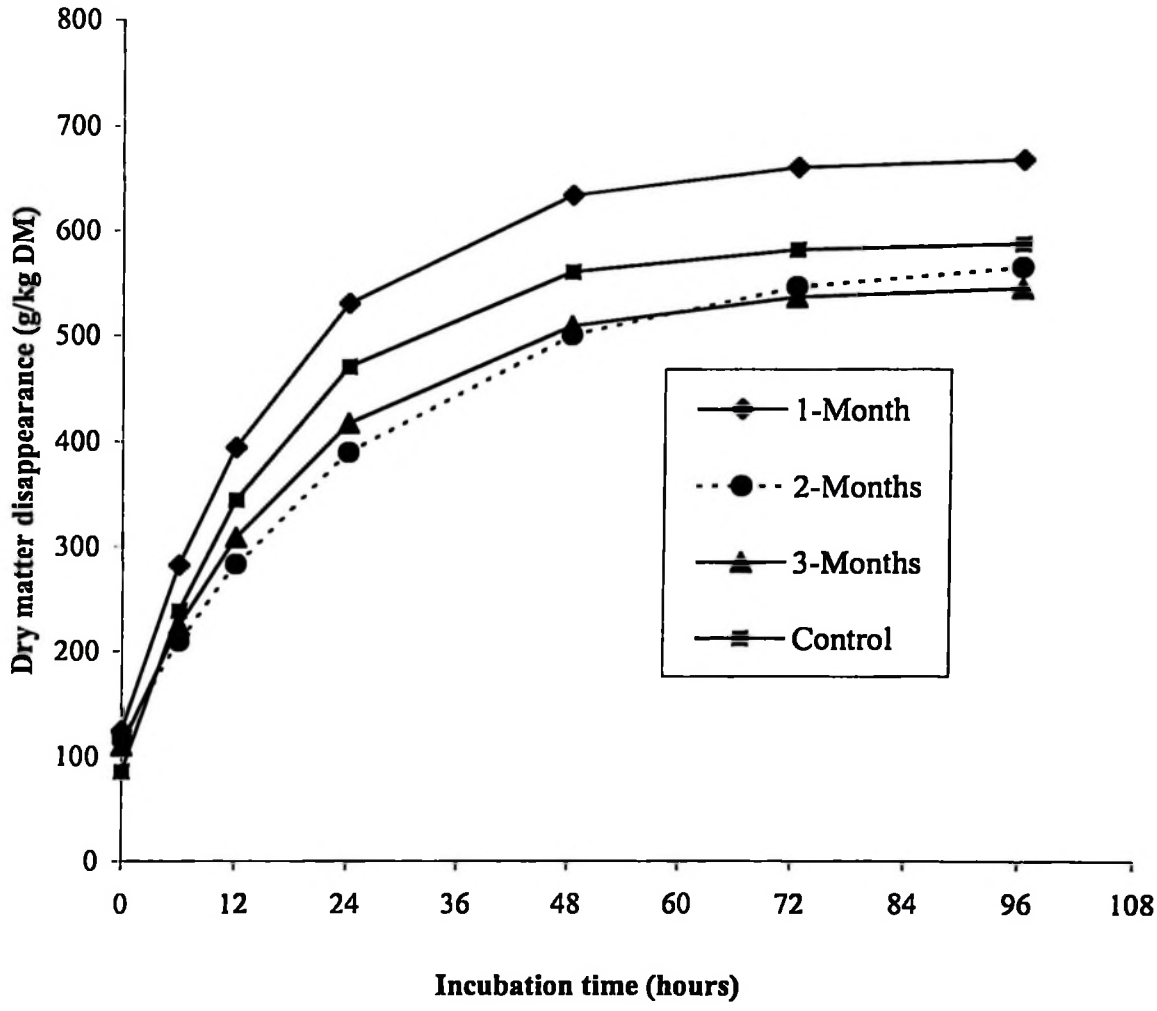

Figure 7. Dry matter losses (g/kg DM) from nylon bags incubated in the rumen of three cows for *A. angustissima* fodder (whole edible fractions) harvested at different cutting regimes during the wet season.

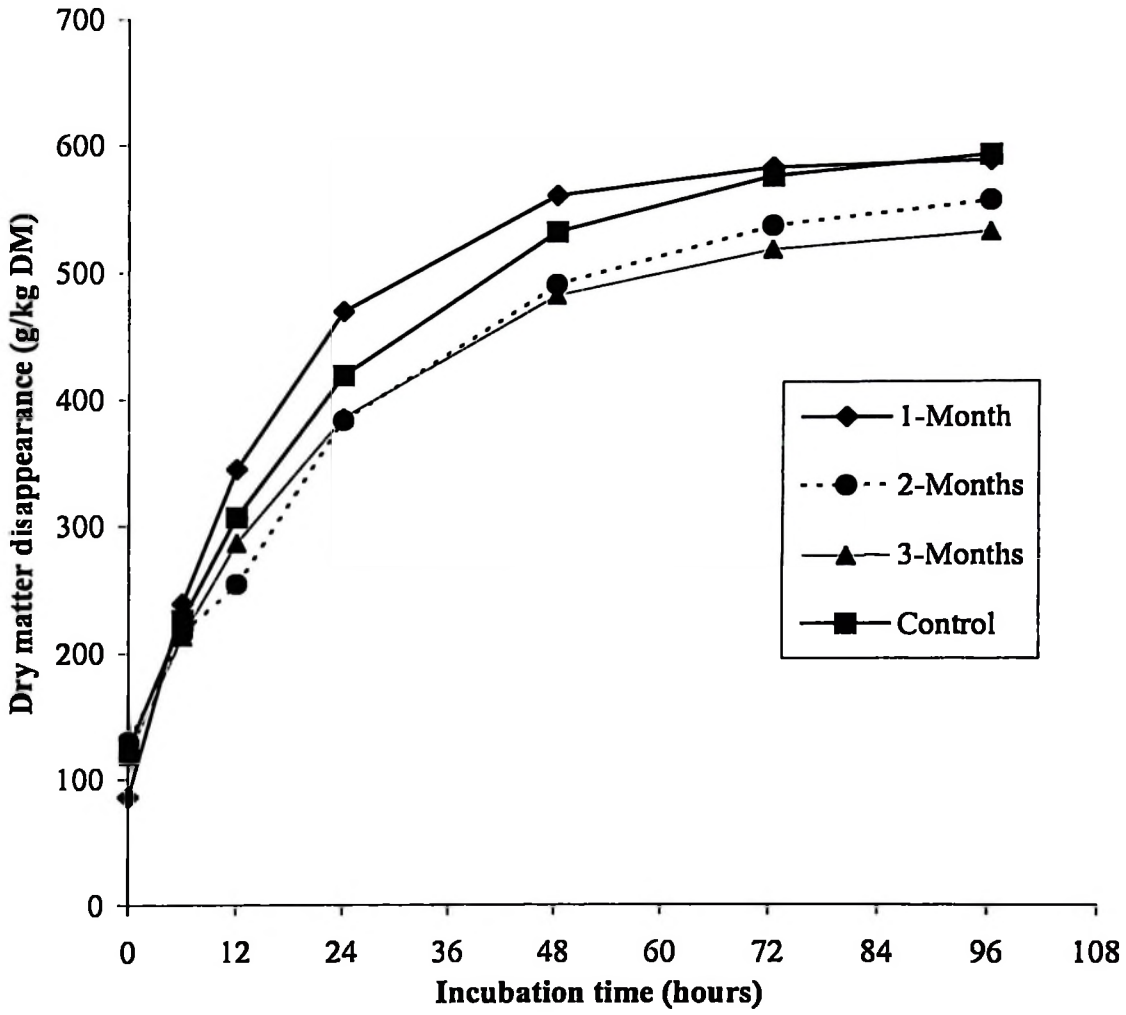

Figure 8. Dry matter losses (g/kg DM) from nylon bags incubated in the rumen of three cows for *L. pallida* fodder (whole edible fractions) harvested at different cutting regimes during the wet season.

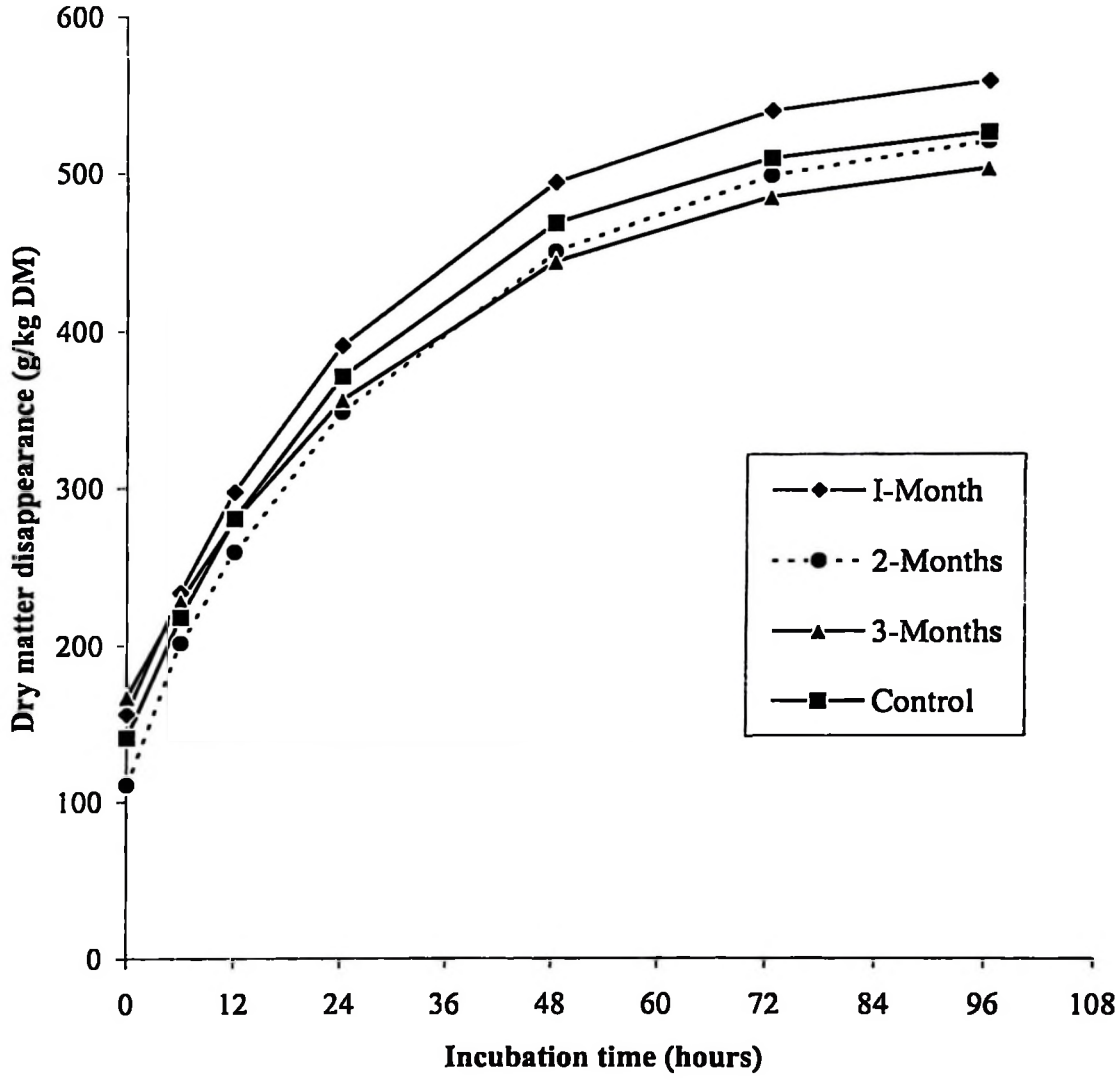

Figure 9. Dry matter losses (g/kg DM) from nylon bags incubated in the rumen of three cows for *A. angustissima* fodder (whole edible fractions) harvested at different cutting regimes during the dry season.

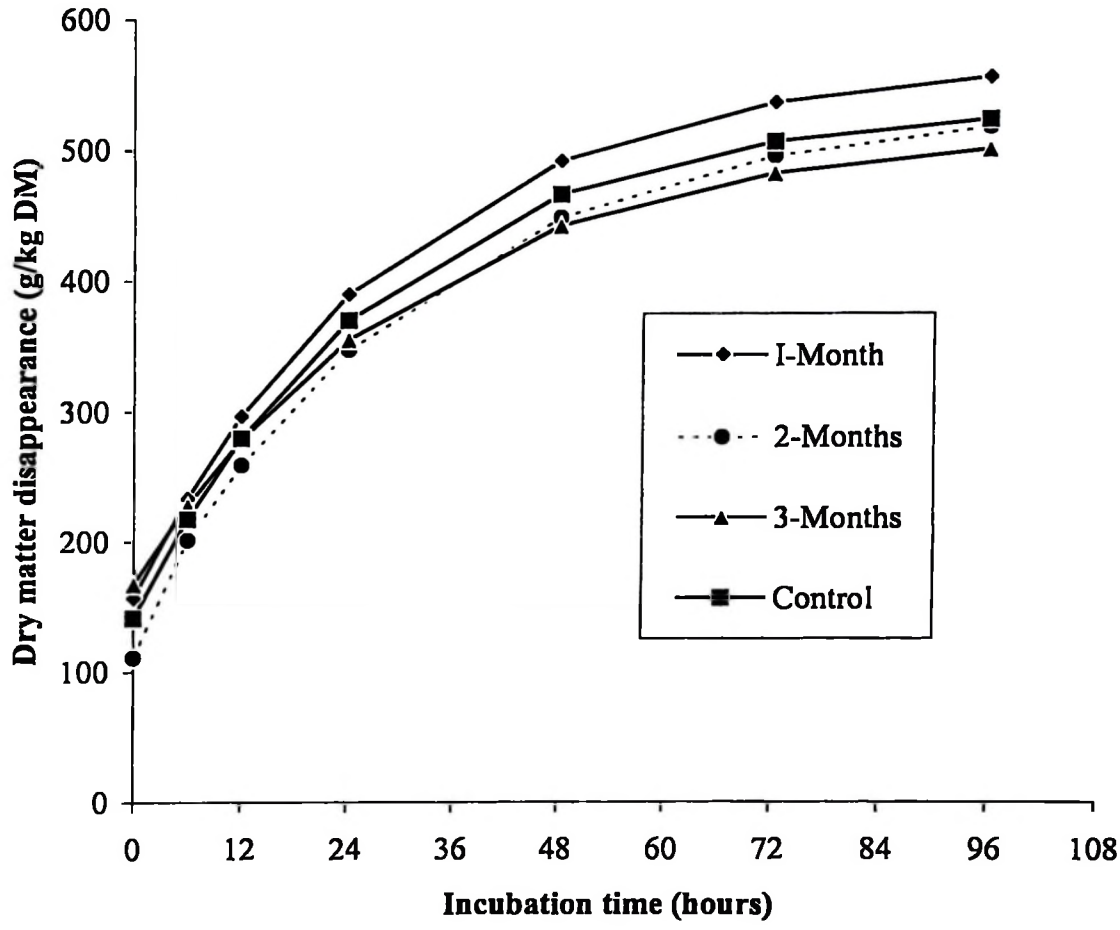

Figure 10. Dry matter losses (g/kg DM) from nylon bags incubated in the rumen of three cows for *L. pallida* fodder (whole edible fractions) harvested at different cutting regimes during the dry season.

Dry matter degradation characteristics of *A. angustissima* and *L. pallida* edible fractions are shown in Table 23 and Appendix 4. The degradability characteristics **(a)**, **(b)**, potential degradability **(a + b)** as well as the degradation rate **c** (h^{-1}) differed significantly ($P < 0.05$) between species, cutting regimes and edible fractions in the dry season. The **(a)** value of *A. angustissima* young leaves was significantly ($P < 0.05$) higher than in other fractions at each cutting, except at 1-month cutting. The **(b)** value of old leaves and whole edible fraction did not differ ($P > 0.05$) at each cutting. The **(a +b)** value of *A. angustissima* was highest in young leaves and lowest in old leaves at each cutting regime. The degradation rate constant **c** (h^{-1}) of *A. angustissima* edible fraction was highest for the young leaves at each cutting. The old leaves and whole edible fraction of *A. angustissima* from 1-month, 3-months and the control plot cuttings were degraded at the same rate ($P > 0.05$).

The young leaves of *L. pallida* harvested at 1, 2, and 3-months interval had ($P < 0.05$) higher **(a)** value than other fractions while old leaves had the lowest **(a)** value. The **(b)** value of young leaves and whole edible fraction of *L. pallida* at 1-month and 2-months cuttings did not differ significantly ($P > 0.05$) but was lower than that of the old leaves. The young leaves of *L. pallida* from 2-months, 3-months and the control plot cuttings had ($P < 0.05$) higher **(a + b)** value than other fractions, but the **(a + b)** value did not differ ($P > 0.05$) at 1-month cutting. The old leaves and whole edible fractions of *L. pallida* from 1-month, 2-months and the control plot cuttings were degraded at the same rate ($P > 0.05$). Dry matter degradation characteristics did not differ significantly ($P > 0.05$) between browse species, cutting regimes and edible plant fraction in the wet season.

Table 23. DM washing losses (a), insoluble but potentially degrable fraction (b), potential degradability (a +b) and degradation rate constant c (h^{-1}) of the edible fraction of *A. angustissima* and *L. pallida* incubated in nylon bags in the rumen of three cows.

Cutting Regime	DMD characteristic (g/kg DM)			C (h^{-1})
	a	b	a+b	
1 Month				
A. angustissima				
Young leaves	121^{ef}	439^{b}	560^{cd}	0.044^{a}
Old leaves	120^{ef}	415^{bc}	535^{de}	0.035^{cd}
Whole edible fraction	118^{f}	431^{bc}	548^{cd}	0.035^{cd}
L. pallida				
Young leaves	165^{bc}	390^{c}	555^{cd}	0.032^{d}
Old leaves	105^{g}	427^{bc}	532^{cd}	0.032^{d}
Whole edible fraction	131^{e}	406^{c}	536^{cd}	0.031^{d}
2 Month				
A. angustissima				
Young leaves	171^{b}	426^{bc}	597^{bc}	0.044^{a}
Old leaves	125^{ef}	404^{c}	529^{de}	0.037^{c}
Whole edible fraction	141^{de}	394^{c}	535^{de}	0.036^{cd}
L. pallida				
Young leaves	150^{cd}	395^{c}	545^{cd}	0.041^{ab}
Old leaves	117^{f}	411^{bc}	535^{de}	0.035^{cd}
Whole edible fraction	143^{d}	396^{c}	538^{d}	0.035^{cd}
3 Month				
A. angustissima				
Young leaves	181^{a}	393^{c}	574^{c}	0.038^{b}
Old leaves	147^{cd}	344^{de}	491^{e}	0.035^{cd}
Whole edible fraction	167^{bc}	342^{de}	515^{de}	0.036^{cd}
L. pallida				
Young leaves	195^{a}	345^{de}	538^{d}	0.036^{cd}
Old leaves	147^{cd}	359^{c}	506^{e}	0.044^{a}
Whole edible fraction	158^{e}	325^{e}	484^{e}	0.015^{cd}
Control				
A. angustissima				
Young leaves	172^{b}	462^{ab}	633^{a}	0.034^{cd}
Old leaves	138^{de}	479^{a}	617^{b}	0.031^{d}
Whole edible fraction	139^{de}	488^{a}	627^{ab}	0.030^{d}
L. pallida				
Young leaves	155^{c}	477^{a}	633^{a}	0.033^{d}
Old leaves	142^{d}	308^{e}	450^{f}	0.031^{d}
Whole edible fraction	156^{c}	414^{bc}	571^{c}	0.030^{d}
SEM	0.40	1.14	1.09	0.001
Pr > F	0.0001	0.0001	0.0001	0.0002

Means with different superscripts along the same column are significantly ($P < 0.05$) different.

The DM degradability values obtained in the present study are in agreement with findings of Topps *et al.*, (1990), Onwuka *et al.* (1996), Osagie (1998) and Siaw *et al.* (1993) for various tropical browse species. In the present study, *in-sacco* DM degradability of *L. pallida* varied from 450 to 570g/kg DM. These values are consistent to the values of 450 to 500g/kg DM reported by Austin *et al.* (1992) and Wheeler *et al.* (1994) for psyllid resistant Leucaena species. The values also related closely to 453 to 527g/kg DM reported by Palmer and Jones (2000) for *L. divesifolia* and *Calliandria calothrsus*, browse species with high tannin content. However, *L. pallida* had lower DM degradability when compared to the value of 650 – 870g/kg DM reported for different accessions of *L. leucocephala* (Austin *et al.*, 1992; El hassan *et a*l., 2000; Kimoro, 2003), This variation could be attributed to high tannins content present in the edible fractions of *L. pallida* (Wheeler *et al.*, 1994). With respect to *A. angustissima*, there were no comparable values, however the values reported in the present study relate closely to that of 334 to 747g/kg DM reported by Abdulrazak *et al.* (2000) for A. *tortilis, A. seyal* and *A. nilotica* from Kenya.

Relatively higher DM degradability values of *A. angustissima* when compared to that of *L. pallida* may relate to the higher nitrogen contents in *A. angustissima* edible fractions than in *L. pallida*. *Acacia angustissima* consistently had higher nitrogen contents than *L. pallida* at each cutting. Variation in tannin content is likely to explain in part the differences recorded in DM degradability between the two species. The presences of higher level of condensed tannins in *L. pallida* foliage possibly reduced or partially shield the protein from microbial attack (Leng, 1997). Tannins and other related polyphenols compounds are often implicated in low

degradability values in most browse species (Stvunt *et al.*, 1998; Mupungwa *et al.*, 2000). The relatively lower DM degradability in *L. pallida* may also be due to its high NDF and ADL contents. These constituents are negatively related to DM digestibility in browse species as has been reported by several workers. Solorio-Sanchez *et al.*, (2000) demonstrated the inverse relationship between the level of NDF in the feed and its digestibility such that an increase in the level of NDF results in low digestibility and vice versa. Ramirez *et al.* (2000) studied the effect of cell wall and its derivatives (Lignin and condensed tannins) upon degradability of 15 browse plants from North eastern Mexico, and reported that lignin content negatively influence the effective degradability of cell wall as also reported by Maya-Rodriguez *et al.* (2002) from the same area. Bamualin *et al.* (1980) reported that *in sacco* DM degradability of 23 tropical browse species during the dry season was negatively correlated to ADL (r = - 0.85) and NDF (r = - 0.62). Khazaal *et al.* (1993) also reported that NDF was negatively correlated (r = - 0.80) with potential DM degradability in browse species from Greece.

4.1.7 *In-sacco* N degradation

The 48 hours nitrogen degradability data (g/kg DM) and N degradability characteristics **a**, **b**, potential degradability (**a** + **b**) and degradation rate constant **c** (h^{-1}) of *A. angustissima* and *L. pallida* edible fractions are given in Table 24 and Appendix 5. The degradability of N at 48 hrs in the edible fractions of *A. angustissima* was highest ($P < 0.05$) in young leaves and lowest in old leaves at each cutting regime, except for the control plot cuttings. Nitrogen in the whole edible fraction of *L. pallida* was degraded more ($P < 0.05$) than in young and old leaves at

each cutting, except for the 3-months cuttings when N in young leaves was degraded more than in old leaves and whole edible fractions. The degradability of N in *L. pallida* edible fractions did not differ ($P > 0.05$) between fractions when the regrowths were harvested at 1-month interval. In both species, nitrogen was degraded at faster rate in young leaves than in the other fractions, except for the regrowths harvested at 1-month intervals. The (**b**) fraction and potential degradability (**a + b**) of *A. angustissima* edible fractions were higher ($P < 0.05$) than that of *L. pallida* at each cutting regime, except for the 2-months cuttings.

Figure 11 and 12 represent nitrogen losses (g/kg DM) from the nylon bags incubated in the rumen of three cows. At 48 hours of incubation, more than 50% of nitrogen in the whole edible fractions disappeared from the nylon bags for both species. As for the DM degradability, the great portion of N disappeared from the bags between 12 and 48 hours of incubation, thereafter nitrogen loss increased but with decreasing rate. In both species, nitrogen degradability was highest in the whole edible fractions from the 2-months cuttings compared to those of the other cuttings. The young leaves of *A. angustissima* consistently had the highest ($P < 0.05$) nitrogen degradability than other edible fractions at each cutting while edible fractions of *L. pallida* was highly variable ($P < 0.05$) within and between cutting regimes (Appendix 5).

Table 24. Washing losses (a), potentially soluble fraction (b), potential nitrogen degradability (a + b) (g/kg DM), rate constants (c) (h^{-1}) and 48 hrs N degradation (g/kg DM) of edible fractions of *A. angustissima* and *L. pallida* incubated in nylon bags in the rumen of three cows.

	N degradability characteristics (g/kg DM)				
Cutting regime	a	b	a+b	c^{-1}	48 hrs
1 Month					
A angustissima					
Young leaves	130^{c}	603^{a}	733^{b}	0.034^{de}	600^{c}
Old leaves	132^{c}	441^{cf}	573^{g}	0.047^{cd}	472^{g}
Whole edible fraction	132^{c}	533^{bc}	665^{d}	0.055^{bc}	549^{e}
L. pallida					
Young leaves	97^{d}	509^{cd}	606^{f}	0.030^{e}	507^{fg}
Old leaves	149^{bc}	3916^{g}	539^{h}	0.031^{e}	497^{fg}
Whole edible fraction	170^{bc}	371^{gh}	541^{h}	0.039^{de}	515^{fg}
2 Month					
A. angustissima					
Young leaves	152^{bc}	504^{cd}	657de	0.066^{ab}	635^{b}
Old leaves	174^{ab}	462^{e}	636^{e}	0.063^{b}	549^{e}
Whole edible fraction	144^{c}	460^{e}	660^{de}	0.072^{a}	618^{c}
L. pallida					
Young leaves	144^{c}	459^{e}	603^{ef}	0.065^{ab}	583^{d}
Old leaves	185^{ab}	358^{h}	543^{h}	0.053^{e}	519^{f}
Whole edible fraction	134^{c}	526^{c}	604^{f}	0.035^{de}	583^{d}
3 Month					
A angustissima					
Young leaves	159^{bc}	582^{ab}	741^{ab}	0.052^{c}	685^{a}
Old leaves	142^{bc}	472^{de}	634^{e}	0.041^{d}	584^{d}
Whole edible fraction	150^{bc}	603^{a}	753^{a}	0.027^{ef}	586^{d}
L. pallida					
Young leaves	172^{b}	450^{e}	623^{ef}	0.049^{cd}	584^{d}
Old leaves	168^{bc}	370^{gh}	535^{h}	0.044^{cd}	492^{g}
Whole edible fraction	187^{ab}	508^{cd}	696^{cd}	0.020^{f}	499^{fg}
Control					
A angustissima					
Young leaves	148^{bc}	513^{cd}	661^{de}	0.042^{d}	592^{d}
Old leaves	151^{bc}	558^{b}	703^{c}	0.037^{de}	617^{c}
Whole edible fraction	165^{bc}	419^{f}	584^{fg}	0.048^{cd}	503^{fg}
L. pallida					
Young leaves	201^{a}	441^{ef}	641^{e}	0.045^{cd}	590^{d}
Old leaves	162^{bc}	482^{de}	645^{de}	0.037^{de}	564^{e}
Whole edible fraction	152^{bc}	492^{d}	644^{de}	0.034^{de}	593^{cd}
SEM	9.60	9.60	0.50	0.003	0.81
Pr > F	0.0016	0.0001	0.0001	0.0001	0.0001

Means with different superscripts along the same column are significantly ($P < 0.05$) different.

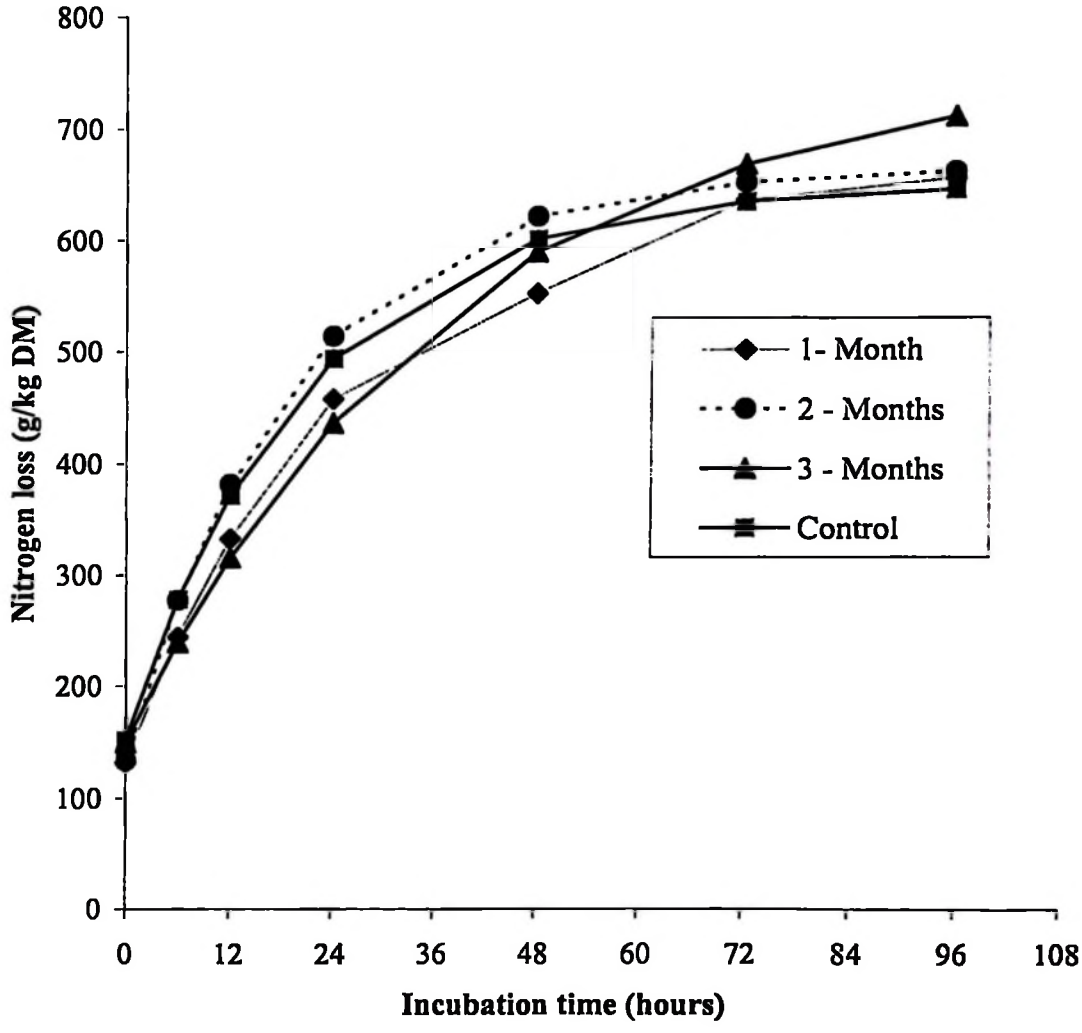

Figure 11. Nitrogen losses (g/kg DM) from nylon bags incubated in the rumen of three cows for *A. angustissima* whole edible fractions harvested at different cutting regimes.

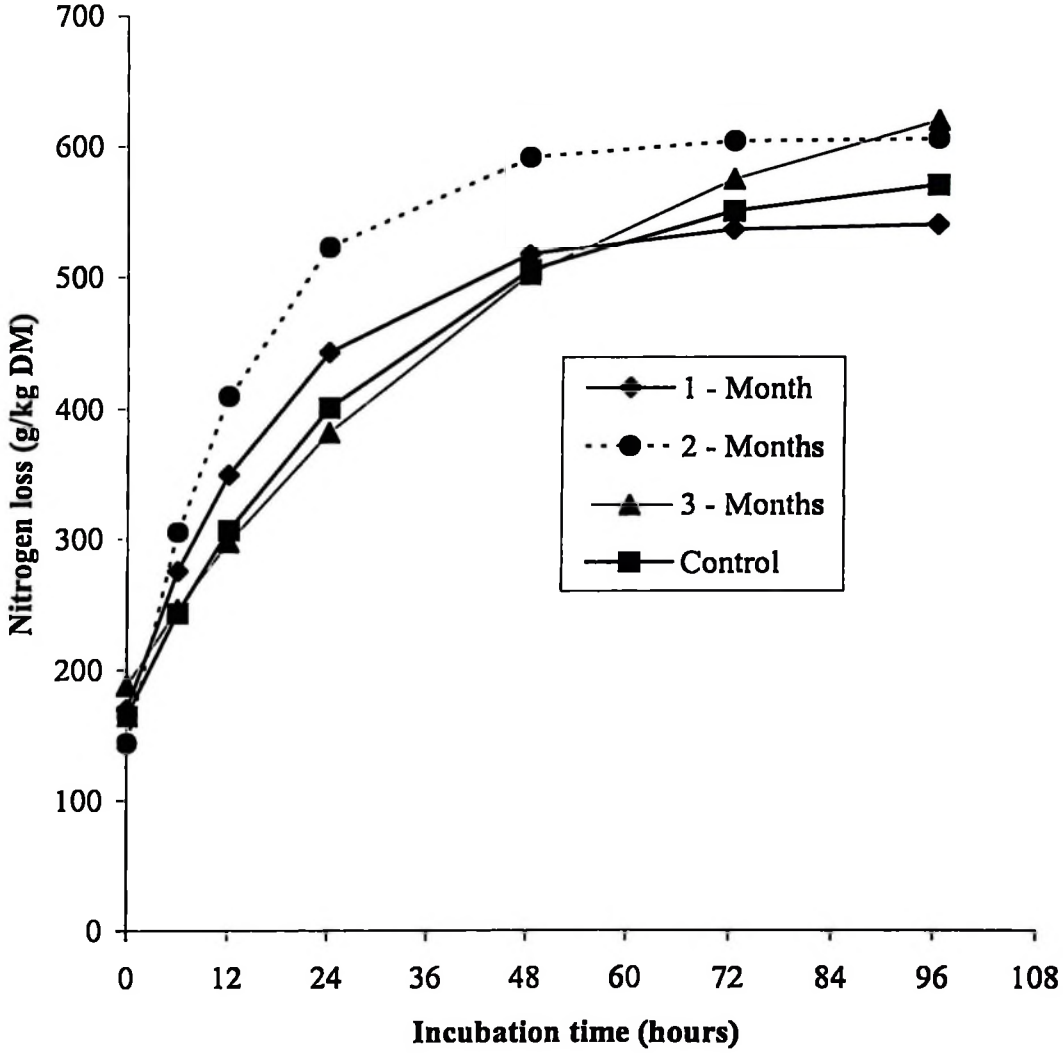

Figure 12. Nitrogen losses (g/kg DM) from nylon bags incubated in the rumen of three cows for *L. pallida* whole edible fractions harvested at different cutting regimes.

The nitrogen degradability values reported in the present study are within the range of 223 – 976g/kg DM reported by Kaitho *et al.* (1999) for 40 tropical browse species. The 48 hours degradability values for *L. pallida* are in agreement with results reported for other high tannin containing Leucaena species (Austin *et al.*, 1990; Gupta *et al.*, 1991; Castillo, 1993 cited by Norton, 1994). These authors reported values of 520 – 720 and 530 – 690g/kg DM for *L. diversifolia* and *L. esculenta*, respectively. These values also compare favourably well to 553g/kg DM reported by Kaitho *et al.* (1998b) for *Gliricidia sepium*, but lower than the 650 and 645g/kg DM reported by Abdulrazak *et al.* (1997) and Larbi *et al.* (1996) for *L. leucocephala* and Albizia species, respectively. El-hassan *et al.* (2000) however reported much higher value of 680g/kg DM for *L. leucocephala*. The 48 hours values (549 to 618g/kg DM) for *A. angustissima* whole edible fractions reported in the current study are higher compared to the 529g/kg DM reported by El-hassan (2000) for the same plant and to that of 280 and 320g/kg DM reported by Gatechew *et al.* (2000) for tannin containing Acacia species, *A. cyanophylla* and *A. albida*, respectively.

Relatively lower N degradability and rate constant of *L. pallida* compared to *A. angustissima* observed in the present study is tied to the low availability of its protein. *Leucaena pallida* was generally high in NDF and ADF values. Most of the nitrogen in *L. pallida* was probably bound to cell walls and thus unavailable to microbial enzymatic attack. This suggests that such nitrogen would be available to the rumen microbes with long periods of exposure of *L pallida* to microbial enzymes in the rumen. On the other hand, *A. angustissima* had higher 48 hours N degradability and rate constant because of its relatively low NDF and ADF values

and possibly most of the N was less bound to fibre components. The possible effect of condensed tannins on release of nitrogen in *L. pallida* is again manifested by the slightly lower value for 48 hours N degradability and the rate constant. The wide variations in N degradability between 2-months and other cuttings for the whole edible fraction of *L. pallida* (Figure 12) could also be due to differences in CT contents. The whole edible fraction of *L. pallida* from 2-month cuttings had lower CT content than those from 1-month and the control plot cuttings (Table 20).

Despite having high tannin contents, young leaves had higher dry matter and nitrogen degradability than old leaves. This was expected because with advancing maturity the proportions of structural carbohydrates in plant increases, while nutrient contents and digestibility decreases (Van Soest, 1994). It is known that tannins produced by different species or by the same species in different parts or at different times exhibits different affinities for different proteins. The extent of that variation is considerable and depends on many factors such as level of tannins and its molecular weight, rumen environment and time available for complex formation (Hegerman *et al.*, 1992; Makkar, 2000). In this regard, the specificity by which phenolics interact with protein cannot be judged from the levels of tannins present in the forage materials.

Norton (1994) for example, found that all forage species that did not contain tannins had high degradability (> 78%), while most tannin containing species were of low degradability (< 39%). Contrarily, *Codoriocalyx gyroides*, gliricidia and Leucaena showed moderate degradability (64-84%) yet contained 3-7% tannins. The high

degradability values in these three species suggest that tannins did not reduce or interfered with degradability. The work of McNeill *et al.* (1998) highlighted the complexity role of condensed tannins in animal nutrition by demonstrating that their tendency to bind protein varies between species, with condensed tannins in *L. pallida* having a higher binding ability than in *L. leucocephala.* Thus, interpretation of the nutritional value of protein in tree forage requires some knowledge of the nature and reactivity of tannins.

4.2 Experiment 2: Effect of different post-harvesting treatment methods on the levels of anti-nutritive factors in the two browse species.

4.2.1 Effect of post harvesting treatment methods on mimosine content

The effects of sun drying, drying under shade, wilting and soaking in still water on mimosine removal in the edible fractions of *L. pallida* are presented in Table 25. There were high variations between treatment methods in mimosine removal. The treatment effects on mimosine removal was such that soaking in water for 48 hrs > soaking in water for 24 hrs > drying in the sun > wilting to 50% moisture content > wilting to 75% moiture content > drying under shade. The concentration of mimosine in the treated fodder material shows that young leaves had more mimosine content than old leaves and whole edible fractions in each treatment method, and the old leaves had the lowest mimosine content.

There was progressive increase in mimosine removal over period of wilting or soaking in still water. Mimosine loss was greater ($P < 0.05$) for the fodder materials wilted to 50% moisture contents (20 to 40% mimosine loss) compared to that wilted

to 75% moisture contents (23 to 26% mimosine loss). Similarly, soaking the fodder materials in still water for 48 hours resulted into significantly ($P < 0.05$) lower content of mimosine (81 to 90% mimosine loss) than soaking for 24 hours (74 to 79% mimosine loss). Sun drying reduced the mimosine content in the edible fractions by as much as 41 to 55%. The fodder materials dried under shade had the highest content of mimosine (12 to 17% mimosine loss) compared to the other treatment methods.

Reduction in mimosine content (41 to 55 %) in the treated fodder materials are in agreement with the findings of Onwuka (1997) who reported that mimosine contents in *Leucaena leucocephala* foliage decreased approximately by 50% (33.5 to 16.1 mg/g DM) after drying. According to El-Ashyry *et al.* (1993) mimosine content was 19.2, 16.1 and 6.4 mg/g DM in fresh, semi-dried and dried Leucaena leaves, respectively, indicating a reduction of 67% and 16% in the dried and semi-dried (wilted) leaves, respectively. Mukhopadhyay and Ray (1997), and Maitra and Ray (2003) reported similar values when using dried Leucaena leaves to feed *Labeo rohita* fingerlings.

Detoxification of mimosine by soaking the leaves in fresh water and then drying has been reported by various researchers. Penoflorida *et al.* (1995) reported that 90% of mimosine was extracted by soaking Leucaena leaves in water for 30 – 48 hours. Hassan *et al.* (1994) reported reduction of mimosine concentration from 2.4% to 0.40%, and Mondal and Ray (1998) reported the reduction from 2.5% to 0.08% on dry matter basis in 48h soaked Leucaena leaf meal. These observations are also in

agreement with findings of Vogt *et al.* (1986) and Avtar-Singh (1993) who observed significant reduction in mimosine contents by 70–97% by soaking Leucaena leaves in water for 24 hours. However, the values reported in the present study are slightly lower when compared to those reported by Soedargo and Barthakur (1996) who found that soaking in water for 24 hours eliminated up to 97% of mimosine from young leaves, pods and split seeds of Leucaena. Wee and Wang (1987) however detected no mimosine in 48 h soaked Leucaena leaves. These variations in mimosine contents in the soaked fodder materials could be due to differences in the proportion of foliage sampled (young vs mature leaves) and stage of growth of the foliage.

Table 25. The effects of post-harvesting treatment methods on the level of mimosine (g/kg DM) in *L. pallida* edible fractions

Treatment method	Conc. of mimosine (mg/g DM)			% mimosine loss		
	Young leaves	Old leaves	Whole edible	Young leaves	Old leaves	Whole edible
PT1	3.50^{d}	2.29^{c}	2.39^{e}	41.1^{b}	49.7^{c}	55.1^{c}
PT2	5.11^{b}	4.03^{b}	4.41^{b}	13.9^{d}	11.9^{f}	17.3^{f}
PT3	4.75^{bc}	3.04^{d}	3.22^{d}	20.2^{cd}	33.4^{d}	39.6^{d}
PT4	4.42^{c}	3.53^{c}	4.08^{c}	25.5^{c}	22.6^{e}	23.4^{e}
PT5	1.52^{e}	0.96^{f}	1.18^{f}	74.4^{a}	79.1^{b}	77.8^{b}
PT6	1.12^{e}	0.42^{g}	0.56^{g}	81.1^{a}	90.8^{a}	89.4^{a}
Control	5.94^{a}	4.57^{a}	5.33^{a}	-	-	-
SEM	0.18	0.07	0.09	2.99	1.55	1.42
Pr > F	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Means with different superscripts along the same column are significantly ($P < 0.05$) different. PT1 = drying in the sun, PT2 = drying under shade, PT3 = wilting to 50% moisture content, PT4 = wilting to 75% moisture content, PT5 = soaking in water for 24 hours and PT6 = soaking in water for 48 hours.

4.2.2 Effect of drying, wilting and soaking on condensed tannins contents

The concentration of total extractable condensed tannins (CT) in the treated *L. pallida* fodder materials differed ($P < 0.05$) between fractions and treatment methods (Table 26). Drying under shade resulted into lower reduction of condensed tannins in young leaves than in old leaves and whole edible fractions. There were no differences ($P > 0.05$) in CT content between old leaves and whole edible fractions in fodder materials wilted to 50% and 75% moisture levels nor were there any differences between fodder materials dried in the sun or soaked in still water for 24 or 48 hours.

Extractable condensed tannins in edible fraction soaked in still water for 24 or 48 hrs were lower than in those wilted or dried under shade. Soaking for 24 and 48 hours resulted into 41- 43% and 47- 48% loss in CT contents, respectively and drying in the sun by 37- 40%. Less than 10% of CT was eliminated when the material was dried under shade.

The concentrations of CT in dried, wilted and soaked *A. angustissima* fodder material showed that young leaves had higher CT content than old leaves and whole edible fractions, except for the materials dried under shade (Table 27). Drying under shade had little effect on CT reduction in the edible fractions (7 to 10% loss). Sun dried fodder had significantly higher ($P < 0.05$) CT content than those soaked in still water for 24 or 48 hrs (Table 27). There were no significant ($P > 0.05$) differences in CT content between materials dried under shade and wilted to 75% moisture

contents. Generally, soaked fodder had lower ($P < 0.05$) CT content compared to the other treatment methods.

Table 26. The effects of post-harvesting treatment methods on the level of condensed tannins (mg/g DM) in the edible fractions of *L. pallida*

	Conc. of CT (mg/g DM)			% CT loss		
Treatment method	Young leaves	Old leaves	Whole edible	Young leaves	Old leaves	Whole edible
PT1	3.92^{d}	3.40^{c}	3.50^{c}	36.9^{b}	40.2^{a}	37.5^{a}
PT2	5.66^{b}	5.16^{ab}	5.12^{ab}	9.00^{f}	9.31^{b}	8.57^{b}
PT3	5.08^{c}	4.81^{b}	4.69^{b}	18.3^{d}	15.5^{b}	16.3^{b}
PT4	5.43^{b}	5.03^{b}	4.77^{b}	12.7^{c}	11.6^{b}	14.8^{b}
PT5	3.70^{d}	3.24^{c}	3.28^{c}	40.5^{c}	43.1^{a}	41.4^{a}
PT6	3.30^{e}	2.98^{c}	2.97^{c}	46.9^{a}	47.6^{a}	46.9^{a}
Control	6.22^{a}	5.69^{a}	5.60^{a}	-	-	-
SEM	0.10	0.19	0.18	0.73	2.99	3.09
Pr > F	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Means with different superscripts along the same column are significantly ($P < 0.05$) different. PT1 = drying in the sun, PT2 = drying under shade, PT3 = wilting to 50% moisture content, PT4 = wilting to 75% moisture content, PT5 = soaking in water for 24 hours and PT6 = soaking in water for 48 hours.

Table 27. Effects of post-harvesting treatment methods on the level of condensed tannins (mg/g DM) in the edible fractions of *A. angustissima*

Treatment method	Conc. of CT (mg/g DM)			% CT loss		
	Young leaves	Old leaves	Whole edible	Young leaves	Old leaves	Whole edible
PT1	1.41^{d}	1.22^{d}	1.52^{d}	35.6^{c}	22.3^{c}	26.9^{c}
PT2	2.01^{b}	1.46^{b}	1.88^{b}	8.22^{f}	7.01^{e}	9.62^{f}
PT3	1.84^{c}	1.32^{c}	1.69^{c}	16.0^{d}	15.9^{d}	18.8^{d}
PT4	$1.92b^{c}$	1.36^{c}	1.83^{b}	12.36^{e}	13.4^{d}	12.0^{e}
PT5	1.29^{e}	0.99^{e}	1.21^{e}	41.1^{b}	36.9^{b}	41.8^{b}
PT6	1.18^{f}	0.83^{f}	1.06^{f}	46.1^{a}	47.4^{a}	48.9^{a}
Control	2.19^{a}	-	2.08^{a}	-	-	-
SEM	0.03	0.03	0.03	0.57	1.31	0.33
Pr > F	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Means with different superscripts along the same column are significantly ($P < 0.05$) different. PT1 = drying in the sun, PT2 = drying under shade, PT3 = wilting to 50% moisture content, PT4 = wilting to 75% moisture content, PT5 = soaking in water for 24 hours and PT6 = soaking in water for 48 hours.

Reduction in CT content is reported to be dependent on many factors including treatment methods, temperature, drying methods and plant species (Norton and Ahn, 1997). The latter author reported that sun drying decreased CT contents in *Calliandra calothyrsus* from 37.7 to 21.2 g/kg DM (39%) and from 20 to 0 g/kg DM in *Gliricidia sepium*. Terrill and Windham (1989) also observed that field drying of high-tannin *Sericea Lespedeza* decreased its assayable tannin concentration, resulting in improved intake and increased N and fibre digestibility. However, in other plant species drying treatment is less effective in reducing tannin contents. For example, Azaryan (1985) reported that drying treatment reduced tannin content in fresh

herbage of *H. perforatum* by 5 - 6.6%. According to Ahn *et al.* (1990) oven drying at 50^0 C reduced tannin content of *A. aneura, A. angustissima, A. chinensis* and *Calliandra calothyrsus,* thus improving N utilization in the rumen of sheep. However, wilting or drying of oak leaves had no effect on removal or inactivation of tannins.

Conflicting reports on drying and its inactivation of tannin may be due to differences in initial moisture levels in the leaves and the different chemical nature of tannins (Makkar, 2000; Ammar *et al.*, 2003)). Genetic variations in the chemical nature and structure of tannin and the way in which soluble phenolics are complexed with fibre and protein may account for the differences observed between the two browse species as also observed by Capetillo (2003). The above factors and others influence the easiness of tannins extraction or elimination from the tree foliage.

When sun-dried and wilted fractions were compared, the amount of tannins eliminated from the fresh fodder increased with prolonged time of drying, indicating that the concentration of tannins decreased with increasing time of drying. Similar findings were reported by Dzowela *et al.* (1997) when comparing two methods (sun-drying for 3 days at 25^oC vs oven-drying at 65^oC for 48 hours) using *Cajanus cajan, Calliandra calothyrsus, Gliricidia sepium, Leucaena leucocephala, Sesbania macrantha, Sesbania sesban* var nubica, *Flemingia macrophyla* and *A. angustissima.* The latter authors observed that oven drying resulted in an overall decrease in tannins concentration compared to sun drying and freeze-drying. Hove *et al.* (2003) found that extractable proanthocyanidins from the leaves of shrub legumes (*A.*

angustissima, *Calliandra calothyrsus* and *Leucaena leucocephala*) and their capacity to precipitate protein were affected by drying methods. Extracts from shade-dried leaves were 10% and 20% more reactive than extracts from sun- and oven-dried leaves, respectively. It is evident from these results that the effect of drying on the level of tannins depends on the methods used and on drying temperature.

In view of the above results, sun drying preferably during the mid day when the temperatures are high could be a cheap and effective way of reducing mimosine and tannin contents to acceptable levels under practical feeding condition using ruminant. If drying methods were to be ranked, they would be ranked in the following order: sun drying > wilting to 50% of the original moisture content > wilting to 75% of the original moisture content.

The effect of soaking treatment on the levels of tannins in tree foliage is not well documented in the literature. However, available data indicate that soaking in water could reduce tannin contents by 35 to 50%, which is in agreement with the values obtained in this study. According to Mulchopadhyay and Ray (1986), tannins could be reduced from 34 to 7g/kg DM (70%) by soaking in water for 16 hours at room temperature. Soaking in water was also found to reduce 50% of tannins in *Carica papaya* and *Ipomea batatas* (Peneflorida, 1995).

4.2.3 Management implications

Soaking of browse foliage for 48 hours or more in still water followed by drying in the sun could probably be the best method that could be used under practical feeding

conditions. Prolonged soaking in water followed by drying could virtually eliminate all the mimosine in Leucaena leaves. Basing on results from the present study, small-scale farmers in the rural areas could use one or combine these methods to reduce assayable tannins and mimosine concentration in the foliage before they are fed to animals. In the wet season, the extra leaf biomass produced could be harvested, soaked in water, dried in the sun and stored for use as leaf meals in the dry season. To avoid spoilage, this can be done in small quantities at a time and the treated fodder materials should be dried in closed shade when it is raining. However, this will only be possible in those areas where water and labour are not limiting. The major constraint that could be faced by the farmers is lack of labour for cutting, soaking and drying, especially with large amount of browse fodder. Water supply is difficult especially during the dry season. Alternatively, toxicity problems associated with secondary compounds could be countered by feeding tree/shrub fodder at or below 30% of the total diet offered to ruminant livestock (Chen *et al.*, 1992) or feeding mixture of browse fodder to reduce toxins below the threshold level (Bosman *et al.*, 1995; Rosale, 1996).

4.3 Experiment 3: The performance of lactating dairy cows fed on low quality grass hay supplemented with *L. pallida* and *A. angustissima* foliage

4.3.1 Chemical composition of the rations

The chemical composition of the ration components is shown in Table 28. Both *Acacia angustissima* and *L. pallida* leaf meals had lower CP content (233 and 221 g/kg DM) than cotton seed cake (315 g/kg DM). However, CSC had relatively higher fibre contents than the browse leaf meals.

In this study the levels of the supplements used were not varied. Diets were formulated in a similar manner and contained same amounts of protein and energy. The diets were also balanced to meet requirements for maintenance, growth and production of a minimum of 8 litres of milk per cow per day (Appendix. 1). A protein supplement (cotton seed cake) was used as a positive control.

The crude protein content (4.2%) of the hay used in the present study as the basal feed was below the critical threshold level of 7–8% (Van Soest, 1994; Norton, 2003). Its NDF was high and comparable to the values reported by several workers (Mero and Uden, 1990; Kimambo *et al.*, 1994; Shem *et al.*, 1995). Calcium and phosphorus contents were also low and not adequate for maintenance and production requirements of lactating dairy cows (NRC, 2001).

The level of CP in the browse leaf meals and cottonseed cake were high and well above the level of 13–16% required for normal growth and moderate lactation (NRC,

1989). *Leucaena pallida* leaf meal had CP contents (22%), which was within the range of 17 to 29% reported for most *Leucaena species* (Austin *et al.*, 1992; Kimbi, 1997; Ndemanisho *et al.*, 1998). With respect to *A. angustissima* leaf meal, the CP value of 23% was comparable to the values reported by Dzowella *et al.* (1997) and Hove *et al.* (2001) for the same species.

The NDF and ADF contents of the two browse leaf meals were within the range reported elsewhere (Austin *et al.*, 1992; Sandoval Catro *et al.*, 2001). The mineral contents (Ca and P) were adequate for normal metabolic body function and comparable to most findings reported in the literature (Guttridge, 1994; Karachi, 1998). The CP content of the cotton seed cake fell within the range of 300 – 330g/kg DM reported by Hove *et al.* (2001) and Kimoro (2003), but slightly lower when compared to those of 340 –370g/kg DM reported by Sarwatt *et al.* (2001), Murro (2002) and Shem *et al.* (2003).

These variations in CP contents of cotton seed cakes may be due to differences in processing prior to and after oil extraction and seed variety (Kaitho *et al.*, 1998a, Wood *et al.*, 1998). The hominy meal used in the present study had CP value close to the values of 120 – 139g/kg DM reported by Katakweba (2002), Murro (2002) and Kimoro (2003). The slight differences in the chemical composition may be attributed to the maize variety and processing of this feed during and after milling.

The high CP content (22 – 23%) in browse leaf meals in the present study underline their potentials as protein supplements in ruminant nutrition, especially in systems

where nitrogen is considered as constraint to production. On the other hand, the low CP content (4.2%) and high fibre contents of grass hay is an indication of its low quality and limitation as dairy feed.

Table 28. Chemical composition of grass hay (GH), cotton seed cake (CSC), dried leaf meals of *L. pallida* (LP) and *A. angustissima* (AA), and homily meal (HM) used in the experiment

	Chemical Composition (g/kg DM)				
Constituent	GH	CSC	LP	AA	HM
Dry matter	925.3	928.9	934	932.5	898.2
Organic matter	842	874.8	874.4	873	856.7
NDF	800.3	485.2	391.4	412.2	*
ADF	513.7	283.0	219.3	227.4	*
Crude protein	41.9	315	221.1	233	118.5
Phosphorus	4.0	14.1	8.3	6.4	7.6
Calcium	2.8	1.9	6.6	6.4	4.0
Energy (MJ/kg DM)	6.99	10.22	7.74	8.39	12.56
Condensed tannins	*	*	14.56	9.62	*

* Not determined NDF = Neutral detergent fiber, ADF = Acid detergent fiber

4.3.2 Intake of the rations

Dry matter intake (DMI) and organic matter intake (OMI) differed significantly ($P > 0.05$) between the rations fed (Table 29). However, DMI and OMI for ration 1, 2, and 3 did not differ significantly ($P > 0.05$). Protein intake was similar ($P > 0.05$) among the rations fed, but calcium and phosphorus intakes were highest for cows fed ration 1, lowest for cows fed ration 4 and intermediate for cows fed ration 2 and 3. However there were no differences ($P > 0.05$) in Ca and P intakes between ration 2

and 3. Estimated energy intake was highest ($P < 0.05$) for the animals fed ration 4 and lowest for animals fed rations 1 and 2.

The notable feature about the responses to supplementation was higher DM and organic matter intake in cows supplemented with cotton seed cake (ration 4) than in those receiving rations 1, 2 and 3. A possible reason for higher DM intake observed in ration 4 when compared to the other rations could be that it supplied more nitrogen to rumen microbes thus facilitating the breakdown of digesta as a result of increased in crude protein digestibility (Table 33). Digestibility of the forage is closely related to dry matter intake and foods that are digested rapidly promote high intakes. The faster the rate of digestion, the faster the outflow rates and hence higher intake (McDonald *et al.*, 1995; Mgheni, 2000). On the other hand, the low digestibility of ration 1 and 2 was possibly due to high content of condensed tannins and mimosine in browse leaf meals (Table 20 and 21).

The presence of DHP (3-hydroxy-4 (1H)-pyridone) a byproduct of mimosine breakdown is known to depress cellulolytic activity and cause rumen stasis when Leucaena is fed (Adejumo and Ademosum, 1991). Furthermore, it may be possible that tannins which are present in large amount in these browse materials could have reacted with leaf protein and formed protein: tannins complexes, which reduced protein availability to the rumen microbes (Paterson *et al.*, 1998). This would result in depressed microbial metabolism and consequently reduced dry matter intake and digestibility (Reed, 1995). Hove *et al.* (2001) reported reduced intake in goats when high level of *A. angustissima* was included in native pasture based diet. Minson *et al.*

(1993) found a decrease in DM intake from 50 to 40% due to condensed tannins. Condensed tannins also diminish the activity of certain fiber-degrading enzymes by binding bacterial enzymes and/or forming indigestible complexes with cell wall carbohydrate (Mupungwa *et al.*, 2000), consequently, increase the amount of time feed stays in the rumen and thus decrease DM intake (Faverdin *et al.*, 1999, Mgheni, 2000).

Information from literature on the use of *A. angustissima* and *L. pallida* as supplements to poor quality roughages is limited. However, improved DM intake in different species of ruminant fed poor quality basal roughages and supplemented with tree and shrubs foliage, particularly that from *Leucaena leucocephala* and *Gliricidia sepium* has been reported by various workers (Karachi and Zengo 1997; Abdulrazak *et al.*, 1997; Kaitho *et al* 1998a; Sterwart *et al.*, 1998, Kakengi *et al.*, 2001). For example, Bonsi and Osuji (1997) reported increased DM intake from 53.8 to 89.1g/kg $W^{0.75}$ in sheep feed a basal diet of rice straw supplemented with Leucaena. Bosman *et al.* (1995) and Stewart *et al.* (1998) noted increases in total DM intake of between 46 and 72.1g/kg $W^{0.75}$ in goats fed poor quality roughage and supplemented with *Gliricidia sepium*. Kaitho *et al.* (1997) reported similar results when supplementing steers fed maize stover with *G. sepium* and *L. leucocephala.* Differences observed in Ca, P and energy intake by the animals relate to chemical composition and proportion of different components used in the rations.

Table 29. Voluntary DM, OM, nitrogen, Calcium (Ca), phosphorus (P), and estimated energy (MJ) intake and milk yield by dairy cow fed grass hay supplemented with cotton seed cake and dried leaf meals from *L. pallida* and *A. angustissima*.

Ration	DM (kg/day)	OM (kg/day)	N (g/day)	Ca (g/day)	P (g/day)	Energy (MJ/day)	Milk yield (kg/day)
1	10.4^{b}	9.06^{b}	167^{a}	41.8^{a}	81.6^{a}	88.2^{bc}	7.78^{c}
2	10.1^{b}	8.85^{b}	163^{a}	40.1^{b}	76.4^{b}	89.3^{b}	8.17^{b}
3	10.3^{b}	9.09^{b}	164^{a}	39.8^{b}	76.9^{b}	85.9^{c}	8.25^{b}
4	11.1^{a}	9.79^{a}	165^{a}	32.2^{c}	71.4^{c}	95.5^{a}	9.94^{a}
SEM	0.16	0.14	1.07	0.450	0.64	1.11	0.09
Pr > F	0.0002	0.0001	0.4772	0.0001	0.0001	0.0001	0.0001

Means in the same column with the same letters (a-c) do not differ (i.e. P > 0.05).
Ration: 1 = basal feed + *L. pallida* leaf meal, 2 = basal feed + *A. angustissima* leaf meal, 3 = basal feed + 50% *L. pallida* and 50% *A. angustissima* and 4 = basal feed + cotton seed meal.

4.3.3 Milk yields

Milk yields differed significantly (P < 0.05) between rations and was highest for cows fed ration 4 (9.94 kg/day), lowest for cows fed ration 1 (7.78 kg/day) and intermediate for cows fed ration 2 and 3 with average milk yield of 8.17 and 8.25 kg/day, respectively (Table 29). Cows fed on ration 3 (a mixture of 50% *A. angustissima* and 50% *L. pallida* leaf meals) produced more milk than those on rations 1 (*L. pallida*).

Utilization of low quality forages is often constrained by their low nitrogen content, which limits microbial activity in the rumen (Van Soest, 1994; Norton, 2003). The

consequence of this is manifested in slow ruminal digestion, low passage rate and DM intake and ultimately low animal productivity (Romney and Gill 2000). Feeding leguminous fodder to dairy cows have been reported to improve rumen fermentation parameters, leading to increased digestibility, and intake of low quality roughages and hence improve milk production (Camero and Franco, 2001, Shem *et al.*, 2003).

The higher milk yield observed when the cows were fed on ration 4 (cotton seed cake supplement) compared to the other rations could be attributed to the higher potential of cotton seed cake to supply more energy and nitrogen to the microbial population in the rumen and total amino acids digested and absorbed in the small intestine (Mgheni *et al.*, 1996). According to Bath *et al.* (1995) the rate at which the available nutrients are drawn from the blood determines the level of milk production. This, however, depends on whether or not the blood reaching the mammary gland is enriched with elements necessary for milk synthesis (Mephan, 1976).

The increase in milk yield reported in the current study are in agreement with the findings of Shem (1996), Kakengi *et al.* (2001) and Tudsi *et al.* (2001) using tropical browse. Relatively low milk yield by cows on ration 1 (*L. pallida* supplement) could have been caused by binding of protein by insoluble proanthocyanidins (condensed tannins) resulting in reduced protein availability and utilization by the dairy cows. Babadilla *et al.* (2003) observed that the use of tree foliage as a supplement in Holstein × zebu cross has an impact on milk yield and on DM intake of the supplements, but the effect of browse supplementation decreased when the animals were offered tree foliage with a high concentration of condensed tannins, as reflected

in the current study when a high tannin containing browse species, L. *pallida* was used as a supplement.

Results from this study show an average milk yield of 7.78, 8.17 and 8.25 kg per day for the cows supplemented with ration 1, 2 and 3, respectively. These amount of milk produced were about 60% higher than 4 to 5 litres of milk produced under traditional management system during the dry season. These values relate closely to that of Kakengi *et al.* (2001) who reported a net increase in milk yields of 46%, 77% and 83.4% in grazing dairy cows supplemented with 1.2, 2.0 and 2.6kg DM of Leucaena leaf meal in semi-arid Western Tanzania. Even though grass in the wet season may contain more crude protein than the critical minimum (7-8%) below, which forage intake is depressed (Norton, 2003), the efficiency with which grass nitrogen is utilized is low (Van Eys *et al.*, 1986) and thus would necessitate supplementation of grass diets with legume foliage even in the wet season. For example, Shem (1996) reported milk yield increase of 20% by supplementing dairy cows on natural pasture with 2 kg of Leucaena leaf meal per cow per day in the wet season.

4.3.4 Milk composition

Protein, SNF, fat, lactose and ash components did not differ ($P > 0.05$) between ration fed (Table 30). The milk of cows fed ration 3 had higher ($P < 0.05$) total solids content than that of cows on other rations. Milk fat, which is the most variable component of milk (Bauman and Griinari, 2001), was also fairly stable between the rations. This was probably due to the fact that the amount of supplement (concentrates) offered was low, contributing less than 40% of the total daily dry

matter intake. According to Clark and Davis (1980) changes or depression of milk fat is seen when the proportion of concentrate is increased to above 60% of the total dry matter intake. In other words, high concentrate diets which increases the proportions of propionic acid and decreases that of acetic and butyric acids leads into decreased in milk fat (Rook, 1976). A similar finding was reported by Kakengi *et al.*, (2001) who reported that Leucaena leaf meal had no significant influence on milk crude protein (CP), butter fat (BF), solid not fat (SNF) and ash contents when fed as a supplement to grazing dairy cows. Shem *et al.* (2003) made similar observation when using *Gliricidia sepium* to supplement lactating dairy cows as an alternative protein supplement to cotton seed cake.

Milk crude protein content (2.55 to 3.11 %) was relatively low compared to the values of 3.32 to 4 % reported by McDonald *et al.* (1998) and Jensen *et al.* (1991) for tropical dairy breeds. This was not related to the supplements offered to the cows, but rather was due to the stage of lactation. The cows used for this study were in their second months of lactation. Milk protein is known to fall gradually from 15 to 45 days postpartum, but later increase towards the end of lactation (McDonald *et al.*, 1998). Milk protein did not differ significantly ($P > 0.05$) between treatment diets. According to Oldham and Sutton (1979), variations in the protein content of diets within the normal accepted range have only a small effect on milk protein content. Lactose and ash contents were similar between rations fed and comparable to the values given by Jensen *et al.* (1991).

Table 30. Effect of supplementing local grass hay with cotton seed cake and dried leaf meals from *L. pallida* and A. *angustissima* on milk composition

Ration	Milk composition (%)					
	Total Solids	SNF*	Protein	Fat	Lactose	Ash
1	12.10[b]	7.98[a]	2.83[a]	4.13[a]	4.43[a]	0.73[a]
2	12.04[b]	8.34[a]	3.11[a]	3.70[a]	4.54[a]	0.70[a]
3	13.49[a]	9.21[a]	2.75[a]	4.28[a]	5.64[a]	0.71[a]
4	12.34[b]	8.39[a]	2.94[a]	4.08[a]	4.75[a]	0.69[a]
SEM	0.21	0.30	0.15	0.18	0.41	0.02

Means in the same column with the same letters (a-b) do not differ (i.e. $P > 0.05$).
* Solid Not Fat
Ration: 1 = Basal feed + *L. pallida* leaf meal, 2 = Basal feed + *A. angustissima* leaf meal, 3 = Basal feed + 50% *L. pallida* and 50% *A. angustissima* and 4 = Basal feed + cotton seed meal.

4.3.5 Simple economics of the experimental rations

Production costs of the experimental rations are presented in Table 31 and Appendix 6. Production costs was relatively lower for ration 2 followed closely by ration 3, whilst ration 4 had the highest cost of production. The total cost of producing *L. pallida* leaf meal was relatively higher than that of producing *A. angustissima* leaf meal. Realized profit (Tshs/litre) and net returns for each of the four rations used are reported in Table 32 and Appendix 6. The costs of production per litre of milk were 102.30, 95.80, 96.00 and 133.40 Tshs for ration 1, 2, 3 and 4 respectively. The net returns per litre of milk produced were 97.70, 104.00, 104.20, and 66.60 Tshs for ration 1, 2, 3 and 4, respectively. Ration 2 and 3 gave almost equal returns while

ration 4 recorded the lowest net returns. Ration 3 yielded relatively higher return over the control (ration 4) followed very closely by ration 2 and lastly ration 1 with net return over the control of 37.60, 37.40 and 31.10 Tshs, respectively.

Table 31. Estimated costs (Tshs/kg) of production of experimental rations

Ingredient fed	Price (Tshs) per kg DM	Amount offered/day (kg DM)			
		Ration 1	Ration 2	Ration 3	Ration 4
Maize bran	25	2.17	2.40	2.30	3.26
Cotton seed	150	0.0	0.0	0.0	1.21
L. pallida	28.67	2.28	0.0	1.09	0.0
A. angustissima	24.41	0.0	2.07	1.09	0.0
Mineral mixture	700	0.09	0.09	0.09	0.09
Costs of ingredients (Tshs/day)		182.59	173.57	178.36	326
Costs of ingredients (Tshs/kg)		40.20	38.00	39.00	71.50
Cost of production (Tshs/litre)		102.30	95.80	96.00	133.40

Ration: 1 = Basal feed and *L. pallida* leaf meal, 2 = Basal feed and *A. angustissima* leaf meal, 3 = Basal feed, 50% *L. pallida* and 50% *A. angustissima* and 4 = Basal feed and cotton seed cake.

Table 32. The realized financial returns (Tshs/litre) for dairy cows fed grass hay supplemented with browse leaf meals or cotton seed cake

Ration	Milk yield (Litres/day)	Tshs per litre			
		Price of milk	Cost of production	Net* return	Net return** over control
1	7.78	200	102.30	97.70	31.10
2	8.17	200	95.80	104.00	37.40
3	8.25	200	96.00	104.20	37.60
4	9.94	200	133.40	66.60	-

* Net return = Price of milk – cost of production per litre

** Net return over control = Net return of individual ration less net return of the control (i.e. ration 4).

In this particular study, the costs of production of browse leaf meals were estimated basing on the amount of edible fodder produced per unit area. Based on this, the cost of production of ration 1 (*L. pallida*) was higher than that for ration 2 because *A. angustissima* produced more edible biomass per unit area than *L. pallida* when harvested at the same stage of growth. The high net return of ration 2 resides from the fact that *A. angustissima* produced more edible biomass than *L. pallida* at the same costs of production. Despite giving the highest milk yield ration 4 had the lowest net returns because of the high price of cottonseed cake and other related charges such as transport. If these four rations are ranked according to their net income, ration 3 had the highest net income followed closely by ration 2, then ration 1 and lastly ration 4. These results suggest that browse supplementation is more economical for milk production than the commercial protein supplements.

5.3.6 Management implications

In the study area, most dairy cows are genetically capable of producing at least 15 litres of milk per day (about 4,000 litres per lactation) due to high proportion of either Friesian or Ayrshire bloodlines. However, only a few give more than 10 litres per day due to poor nutrition and sub-optimal management. Basing on results from the present study, in a typical lactation of 270 to 300 days, a small scale dairy farmer with one dairy cow will need about 1800 trees of *L. pallida* or 1400 trees of *A. angustissima* to produce the required amount of browse leaf meals (2 - 2.5kg DM per day) to supplement his or her cow per lactation, which would require an area of less than 0.2 of a hectare. If land and labour are non limiting factors, browse leaf meals, particularly that of *A. angustissima* could be of particular benefits to resource poor

farmers who cannot afford to buy commercial protein supplements due to lack of cash, transport and unreliable supply of the commercial supplements.

Wide adoption of fodder bank technology by small scale farmers in the study area has been limited by a number of factors including shortage of planting materials, insect pests which eat/cut the young seedlings and roaming livestock that damage established seedlings, especially during the dry season. To improve seed production and supply, farmers should be involved as contract seed producers. Application of insecticide will protect the young seedlings from insect damage and improve trees survival. The effect of roaming livestock could be reduced by introduction of live-fencing materials. Reinforcement of village by laws could also help to reduce some of the problems. Other social factors including land holding, land tenure, labour availability and frequent changes in government policy may however affect adoption of the technology.

Possession of land is necessary condition for adoption of agroforestry technologies. In areas with small farm sizes, agroforestry trees may compete with food crops and negatively affect adoption of the technology. In the study area, households close to the municipality had land holdings on the average less than 2 acres. Some farmers fail to allocate some of their land for non-food tree crops. Land tenure is another institutional factors influencing adoption of land management technologies. Land tenure affects the degree of risk and uncertainty in farming. Insecure system leads to a pre-mature depletion of resources. This is because farmers without security of tenure cannot capture the future gains that arise from long-term investment projects

(e.g. tree-based technologies) instead they tend to maximize on short-term production projects. Privatising land possibly could motivate farmers to adopt tree-based innovation technologies such as fodder banks.

In smallholder farming systems, labour is frequently the limiting resource during cropping seasons. Farmers in Tabora usually hire labour for crop production in addition to family labour on an annual basis. Dairy farming in urban and peri-urban areas is of a high labour costs because the system is labour intensive, scarcity of labour may therefore limit adoption of the fodder bank technology in the study area. Frequent changes in government policy affect development projects. While positive changes and reforms are desirable, some changes does not address the needs of the farmers or community problems, thus negatively affect adoption of some technologies.

4.4 Experiment 4: *In-vivo* digestibility and nitrogen balance experiment

4.4.1 In-vivo DM and N digestibility

Table 33 shows apparent dry matter, organic matter and nitrogen digestibility by dairy cows of the 4 rations used in the feeding trial. The DM, OM and nitrogen digestibility were highest ($P< 0.05$) for cows fed ration 4 and lowest for cows fed ration 1. The animal fed ration 3 (a mixture of 50% *A. angustissima* and 50% *L. pallida* leaf meals) had higher ($P < 0.05$) DM, OM and nitrogen digestibility than those fed rations 1 (*L. pallida*) and 2 (*A. angustissima*). There was a positive relationship ($r = 0.72$, $n = 16$) between dry matter digestibility (DMD) and nitrogen

digestibility. For each unit increase in nitrogen digestibility there was approximately a corresponding increase in DM digestibility.

The *in vivo* digestibility coefficients from the present study compare closely with results of studies conducted elsewhere with other browse species within the tropics. However, most studies evaluating the effect of browse plants on intake and digestibility in ruminants have put emphasis on utilization of *Grilicidia sepium* and *L. leucocephala* and little work has been done with other browse species, particularly with the lesser known Leucaena species such as *L. pallida*. On the other hand, *A. angustissima* is a relatively unknown browse plant whose potential as a ruminant feed has not been thoroughly investigated. Comparison data regarding these two browse species are not available in the literature. Abdulrazak *et al.* (1997) fed steers maize stover supplemented with graded levels of *Gliricidia sepium* and *L. leucocephala* and reported DM and OM digestibility values of 584 and 610g/kg DM in the case of the Gliricidia and 557 and 597g/kg DM for Leucaena based concentrates, respectively. Smith *et al.* (1995) recorded digestibility values of 618 – 665g/kg when *G. sepium* was used as supplement to maize stover.

The DM and OM digestibility coefficients of ration 4 were higher compared to browse leaf meal based supplements. This was possibly attributed to the superiority of cotton seed cake over browse leaf meals with regards to the supply of additional essential nutrients to the rumen microbes. The slightly lower fibre and tannins contents of *A. angustissima* leaf meal favoured slightly higher DM and OM digestibility of ration 2 than ration 1 (*L. pallida* supplemented ration). Forage with

low cell wall constituents have been reported to have high digestibility (Tolera and Sundstϕl, 2000).

The highly significant differences among the rations with regards to nitrogen digestibility coefficients indicated potential of the browse leaf meals and cotton seed cake as protein supplements. Cows on ration 3 had significantly higher nitrogen digestibility coefficient than those on ration 1 and 2, possibly due to dilution of toxins associated with *L. pallida* and *A. angustissima* below the threshold levels (positive associative effects, synergistic). Feeding mixtures of browse fodder have been reported to improve feeding values (dry matter intake and digestibility) of browse fodder than feeding single species alone (Phiri *et al.*, 1992; Bosman *et al.*, 1995; Rosale, 1996). The low nitrogen digestibility of ration 1 was possibly due to the presence of high level of condensed tannins (proanthocyanidins) which lowed protein digestibility (Paterson *et al.*, 1998; Makkar and Becker, 1998). This also explains the large variation in nitrogen digestibility observed between ration 4 (cotton seed cake based ration) and other rations. The high levels of nitrogen in the faeces of the cows fed ration 1 (*L. pallida*) compared to those on other rations further confirms the binding effects of tannin on the protein making it less available for digestion.

4.4.2 Nitrogen utilization

The results for nitrogen intake, excretion and retention are presented in Table 33. The cows fed ration 1 (*L. pallida* supplemented ration) had relatively higher N intake and the highest faecal-N losses. The cotton seed cake supplemented diet (ration 4) had

relatively lower ($P < 0.05$) N intake and the least ($P < 0.05$) faecal-N losses. There was negative relationship ($r = 0.98$, $n = 16$) between nitrogen digestibility and faecal-N excretion (Figure 13). Urinary nitrogen levels were generally low in all diets, with ration 3, a mixture of 50% *L. pallida* and 50% *A. angustissima* leaf meals, resulting in the lowest ($P < 0.05$) urinary N excretion. The amount of nitrogen excreted in the milk differed ($P < 0.05$) between the rations. The cows fed ration 4 excreted more ($P < 0.05$) nitrogen in the milk than those on the other rations. Feeding the cows with ration 1 resulted in less milk nitrogen excretion.

The cows receiving ration 4 had the highest N retention value while those on ration 1 and 2 retained similar ($P > 0.05$) amount of nitrogen. There was no statistically significant difference between the rations in live weight changes. Positive weight gain of 70g/day was recorded only in those animals receiving ration 3. Animals fed other diets lost weight at an average of 70, 130 and 60g/day for ration 1, 2 and 4, respectively.

Animals in all treatment diets manifested positive nitrogen balance (4.2 – 21.8 g/day) an indication that the amount of nitrogen supplied by the rations was adequate and met their maintenance needs and extra for milk production. The positive N retention reported in the current study are in agreement with the findings of Reed *et al.* (1990), Bonsi *et al.* (1994), Wiegand *et al.* (1995) and Ayers *et al.* (1996) using tropical browse supplementation in ruminant diets.

Milk nitrogen was relatively higher from animals fed ration 4 as compared to the rest of the rations. The amount of nitrogen excreted in the milk was positively correlated to the amount of milk produced. The relatively lower N excretion in the urine is an indication that the correct nutrient balance (protein: energy ratio) was achieved (Sibanda *et al.*, 1993). The animal fed ration 3 utilised nitrogen more efficiently when compared to those on ration 1 and 2. This was possibly due to their relatively high efficiency in protein digestibility, which also explains their relatively lower urinary N loss. The higher faecal N loss compared to urinary nitrogen was due to the fact that a larger portion of faecal N is of a non-dietary origin. According to McDonald *et al.* (1998) about 70-80% of nitrogen arises from endogenous sources such as microbial protein, enzymes and cell wall sloughing. However, judging from the proportion of N excreted in the faeces, it seems possible that browse leaf meals provide more escape protein than cottonseed meals as animals fed browse leaf meals had significantly more faecal N than those consuming cotton seed cake. Tannins found in browse species form complexes with plant proteins which decrease their rate of degradability in the rumen, thereby increasing the amount of plant protein by passing the rumen (Norton, 1994).

Comparing the two browse leaf meals, animals fed ration 1(L. *pallida* leaf meal) had significantly higher faecal nitrogen than those fed ration 2 (*A. angustissima*). It may be possible that *L. pallida* tannins are stronger or more efficient in binding protein than those of *A. angustissima*, probably due to the differences in tannin molecular structure (weight) and the reactivity of phenolic hydroxyl groups, which influence protein precipitation capacity of the tannins (Hagerman *et al.*, 1992; Min Zhu *et al.*,

1997). Results similar to the present study were reported by Hove *et al.* (2001) using goats fed dried leaves of the shrub legumes *Acacia angustissima*, *Calliandra calothyrsus* and *Leucaena leucocephala* as supplements to native pasture hay. In their study, animals fed *C. calothyrsus*, a species with high tannin content, had most of the N in the faeces and those offered cottonseed meal had the least. In another related study, Norton and Ahn (1997) observed consistent increases in faecal N content in sheep when *C. calothyrsus* was included in barley straw based diet.

Table 33. Apparent digestibility of DM, OM and crude protein, and nitrogen utilization and body weight changes by dairy cow fed cotton seed cake and dried leaf meals from *L. pallida* and *A. angustissima* as supplements to grass hay

Parameter	Ration 1	Ration 2	Ration 3	Ration 4	SEM	Pr > F
Digestibility (g/kg)						
DM	466^{d}	505^{c}	534^{b}	585^{a}	7.85	0.0001
OM	494^{d}	532^{c}	566^{b}	615^{a}	7.63	0.0001
N (g/kg DM)	60.3^{d}	66.4^{c}	70.4^{b}	93.1^{a}	1.54	0.0001
Nitrogen utilization:						
Nitrogen intake						
(g/day)	167.87^{a}	166.04^{ab}	164.24^{b}	161.89^{b}	1.07	0.0010
g/kg $BW^{0.75/day}$	3.60^{a}	3.59^{a}	3.58^{b}	3.57^{b}	0.01	0.0011
N-excretion (g/day)						
Milk	35.29^{c}	40.57^{b}	36.31^{c}	46.52^{a}	0.51	0.0001
Faecal	104.63^{a}	97.23^{b}	92.17^{b}	67.66^{c}	1.85	0.0001
Urine	21.80^{c}	24.01^{b}	18.43^{d}	25.95^{a}	0.66	0.0001
Total	161.71^{a}	161.80^{a}	146.90^{b}	140.13^{c}	1.94	0.0001
g/kgN intake (faecal)	622.81^{a}	585.07^{b}	560.02^{c}	418.00^{d}	9.49	0.0001
g/kgN intake (urine)	129.57^{c}	144.23^{b}	113.11^{d}	160.96^{a}	4.05	0.0001
g/kgN intake (milk)	210.27^{d}	244.60^{b}	222.94^{c}	288.89^{a}	3.58	0.0001
Nitrogen retained						
g/day	6.15^{b}	4.24^{b}	17.34^{ab}	21.76^{a}	1.62	0.0001
g/kgN intake	37.35^{c}	26.10^{c}	103.94^{b}	132.06^{a}	9.86	0.0001
Live weight changes						
(kg/day)	- 0.70^{a}	- 0.13^{a}	0.07^{a}	- 0.06^{a}	0.25	0.2345

Means in the same row with the same letters (a-d) do not differ (i.e. P > 0.05).
Ration: 1 = Basal feed + *L. pallida* leaf meal, 2 = Basal feed + *A. angustissima* leaf meal, 3 = Basal feed + 50% *L. pallida* and 50% *A. angustissima* and 4 = Basal feed + cotton seed cake

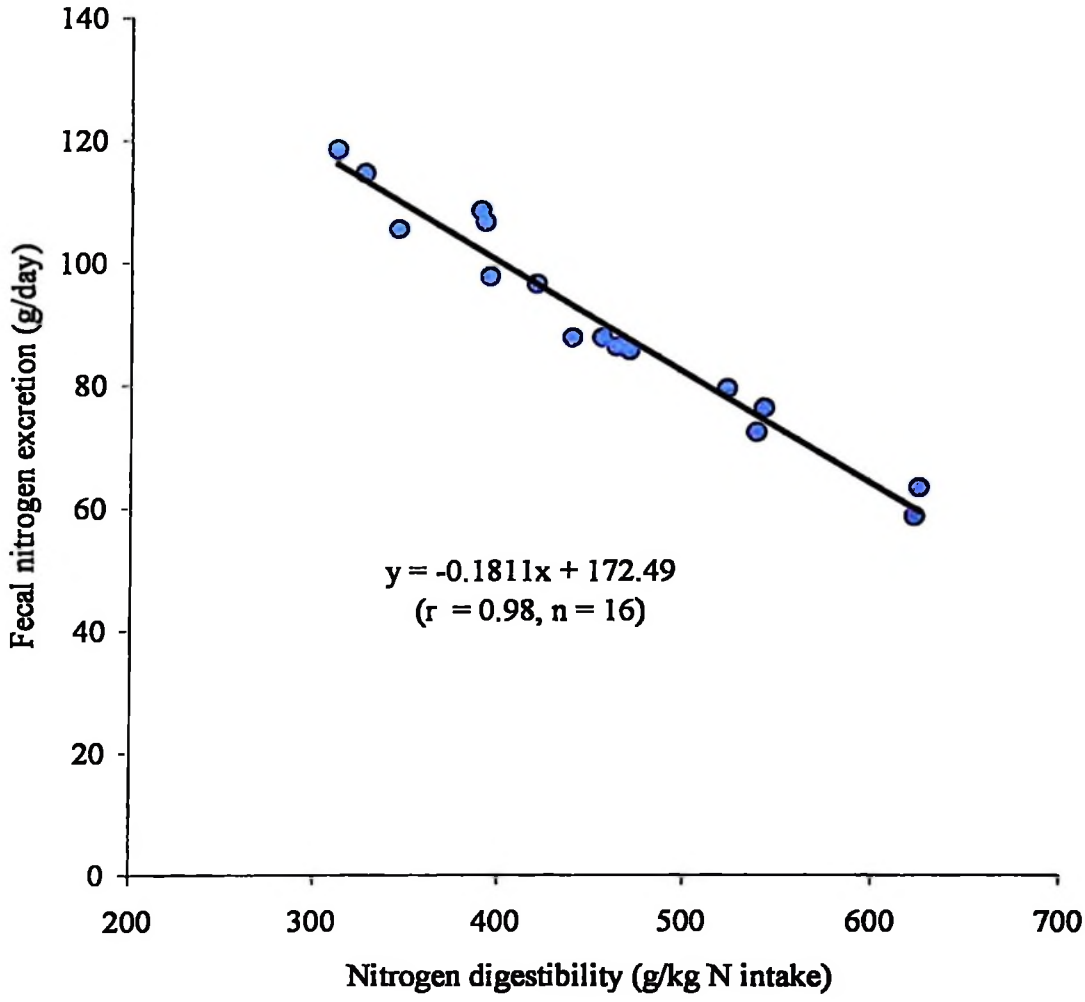

Figure 13. Relationship between faecal nitrogen excretion and nitrogen digestibility

4.5 General discussion

4.5.1 Introduced browse species in Western Tanzania

In recent years, there has been a great interest in introducing exotic browse species for use in different agro-ecological zones of the country. The interest has been based on their high nutritive value and biomass production, but perhaps most important is in an effort to search for an alternative tree species to *Leucaena leucocephala* following its attack by Leucaena psyllid (*Heteropsylla cubana*).

In Tabora Region of Western Tanzania *Leucaena pallida* and *A. angustissima* are some of the promising fodder species when considering fodder production, psyllid tolerance and survival (Otsyina *et al.*, 1998). However, there is limited information on the feeding value, secondary compounds and appropriate cutting management of these new fodder materials. This study was therefore carried out to seek answers to some of these questions. In the following sections, the main findings from the study are discussed and practical implication of the results and areas for further studies are suggested.

4.5.2 Cutting regimes, fodder yield and quality of *L. pallida* and *A. angustissima* fodder banks

Cutting management has a very important influence on the productivity and quality of browse species. In general longer intervals between cuttings increased total yield, however, the proportion of inedible wood also increased, leading to decline in foliage quality the fact that has also been noted by Ivory (1990) and Shelton and Brewbaker (1994). Fodder harvested at 3-months interval had relatively higher fibre (NDF)

content and low in DM digestibility compared to that from other cuttings. From this study, the ideal cutting stage to optimise fodder yield and quality in Tabora Region is therefore at 2-months. At this period the edible forage DM yield were 64% and 76% out of the total biomass produced for *L. pallida* and *A. angustissima*, respectively. The increase in the foliage DM yield from the trees at cutting interval of 1-month to 3-months are as reported elsewhere in the literature for other browse species (Guevara *et al.*, 1978; Duguma *et al.*, 1988; Assefa, 1998). This is due to the fact that under extended harvesting, the browse tree/shrubs accumulate adequate carbohydrate reserve to support more foliage regrowth whereas frequent cutting depletes reserved carbohydrate and reduces residual leaf area required for the regrowth, thus leading to low fodder yields (Stur *et al.*, 1994).

It was interesting to note that *L. pallida* and *A. angustissima* maintained high content of nitrogen (27.1 to 47.7g N/kg DM) even at the peak of the dry season. These results were consistent with the results reported by Dzowela *et al.* (1997) and Odenyo *et al.* (2001) for *A. angustissima.* However, Sandoval Castrol *et al.* (2001) reported lower value (29.1g N/kg DM) for *A. angustissima* foliage. The value for nitrogen for *L. pallida* compared fairly well with the value reported by Austin *et al.* (1992) for the same plant species, but lower than the values reported by Torvan and Suhendi (1991) for *L. diversifolia* and Kimbi, (1997), Ndemanisho *et al.* (1998), El-hassan *et al.* (2000) for *L. leucocephala.*

Variation in N content observed between cutting regimes in the young leaves was probably due to differences in ratio of leaf to twigs in the analysed samples as these

components were sampled together. Differences in nitrogen contents in old leaves and whole edible fractions between cutting regimes may relate to differences in proportion of mature leaves in the sample and stage of maturity of the leaves. As the plant mature, protein concentration declines as the protein is hydrolysed and translocated to the other plant parts (Van Soest, 1994). Cutting regimes had no effect on mineral contents, except for the phosphorus and potassium. The high concentration of P and K observed at shorter cutting intervals may relate to the high proportion of young leaves in the samples. Phosphorus and potassium are generally high in young leaves than in old leaves (Karachi, 1998).

Despite high CP contents in these new fodder materials, their feeding value will depend on whether the ingested materials can be digested and utilized by the animals. High tannin content, especially in *L. pallida* reduced *in-sacco* DM and nitrogen degradability and thus availability of N to the animals. However, tannins content in *A. angustissima* obtained in the present study was considerably low compared to that reported by Odenyo *et al.* (1997) for the same plant forage. Similarly, Rubanza *et al* (2003) in North-western Tanzania reported much higher values for local *Acacia species*. Contrarily, Norton (1994) reported lower value (66 and 44 mg/g DM) for *A. angustissima* and *A. aunera* forages, respectively. For *L. pallida,* the values reported in the present study were similar to that given by Austin *et al.* (1992) and Castillo (1993) in different accessions of *L. pallida.*

Variation in tannin and mimosine content between cutting regimes and reported values in the literature may be due to differences in ratio of leaf to twigs, proportion

of old leaves and stage of maturity of the leaves sampled. Amount of tannins in foliage vary with the age of the plant and foliage, generally being higher in young leaves and immature fractions and low in mature leaves (Makkar, 2000; Shelton, 2001).

Considerable variations in *in-sacco* DM and N degradation characteristics between cutting regimes and browse species were demonstrated in this study. *Acacia angustissima* had significantly higher degradability of DM and N than *L. pallida* at each cutting, which may relate to the significantly lower tannins and higher N contents of *A. angustissima* than *L. pallida* and relatively higher NDF and ADL contents of *L. pallida.* These constituents are negatively related to DM and N degradation in browses (Ramirez *et al.*, 2000; Maya-Rodriguez *et al.*, 2002). The degradability ranges for DM and N in this study are comparable to other values reported elsewhere for *L. pallida* (Austin *et al.*, 1992; Wheeler *et al* 1994). The value of N degradability reported in the current study for *A. angustissima* was higher than that reported by El-hassan (2000) for the same plant and Gatechew *et al.* (2000) for other tannin containing *Acacia species*.

4.5.3 Effect of post-harvesting treatment methods on secondary compounds

Results of experiment 2 showed that drying and soaking could reduce tannin and mimosine contents in browse fodder to an acceptable level before feeding to ruminant animals. Results similar to the present study were reported by Peneflorida *et al.* (1995) and Mandal and Ray (1998) for soaked Leucaena leaves in water for 30 – 48 hours. Similarly, Onwuka (1997) and Mukhopadhyyay and Ray (1997) reported

50 – 67% loss in mimosine in Leucaena leaves after sun drying. However, there was wide variation in results obtained in the present study and other reported values. In the present study, soaking in water resulted into 41 – 48% loss in CT contents and drying in the sun by 37 – 40%. According to Peneflorida *et al.* (1995) and Mukhopadhyyay and Ray (1986) soaking in water could reduce tannin content by 50 –70%. Norton and Ahn (1997) reported that sun drying resulted into 39% and 100% loss in CT contents in *Calliandra callothyrsus* and *Gliricidia*, respectively. On the other hand, only 5 – 6.6% of CT was reduced by drying fresh herbage of *H. perforatum* in the sun (Azaryan, 1985). These conflicting reports on soaking and drying and their inactivation of tannin may be due to differences in initial moisture levels in the leaves and the different chemical nature of tannins which varies considerably depending on plant species, plant parts, stage of development and environmental condition (Lees *et al.*, 1994; Makkar, 2000; Ammar *et al.*, 2003).

4.5.4 *Acacia angustissima* and *L. pallida* leaf meals as protein supplements to poor quality grass hay

The notable feature about the responses to supplementation was higher DM intake and digestibility and milk yield in cows supplemented with cotton seed cake than in those receiving browse leaf meals. A possible reason could be that cotton seed cake was able to supply more nitrogen for microbial action in the rumen breakdown of the digesta, as a result of increased in crude protein digestibility and thus provided more amino acids digested and absorbed in the small intestine (Mgheni *et al.*, 1996). The faster the rate of digestion, the faster the outflow rates and hence higher DM intake (McDonald *et al.*, 1998; Mgheni, 2000).

On the other hand, tannins which are present in large amount in these browse materials could have reacted with leaf protein and formed protein: tannins complexes, which reduced protein availability to the rumen microbes (Patterson *et al.*, 1998). This would result in depressed microbial metabolism and consequently reduced dry matter intake and digestibility (Reed, 1995; Mupungwa *et al.*, 2000; Hove *et al.* 2001), resulting in reduced protein availability and utilization by the dairy cows. Babadilla *et al.* (2003) observed that the effect of browse supplementation decreased when the animals were offered tree foliage with a high concentration of condensed tannins, as reflected in the current study when a high tannin containing browse species, *L. pallida* was used as a supplement.

The *in vivo* digestibility coefficients showed that the cows fed mixture of *A. angustissima* and *L. pallida* leaf meals had significantly higher nitrogen digestibility coefficient than those fed *L. pallida* and *A. angustissima* leaf meals, possibly due to dilution of inhibitors associated with *L. pallida* and *A. angustissima* below the threshold levels (Phiri *et al.*, 1992; Bosman *et al.*, 1995; Rosale, 1996).

Animals in all treatment diets manifested positive nitrogen balance an indication that the amount of nitrogen supplied by the rations was adequate and met their maintenance needs and extra for milk production. The positive N retention reported in the current study are in agreement with the findings of Reed *et al.* (1990), Bonsi *et al.* (1994), Wiegand *et al.* (1995) and Ayers *et al.* (1996) using tropical browse supplementation in ruminant diets.

CHAPTER FIVE

CONCULUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the present study the following conclusion can be drawn:

1. Longer intervals between cuttings increased total fodder yield, but the proportion of inedible wood also increased leading to decline in foliage quality.

2. *Acacia angustissima* produced significantly more edible forage than *L. pallida* in all seasons.

3. This study showed that optimum productivity of high quality fodder for ruminant feeding is obtained by harvesting the coppice regrowths at 2-months interval.

4. The edible fractions of both species were sufficiently high in CP and mineral contents for them to be used as supplements for low quality feedstuffs. However, animals may require additional source of phosphorus and sodium to avoid deficiencies in these elements.

5. The edible fractions of both browse species had high contents of tannins i.e. more than 5% of the DM considered as an upper beneficial level in ruminant feeding and nutrition. These were higher in *L. pallida* than in *A. angustissima* at each cutting.

6. Potential degradability of DM and N in the edible fractions of *A. angustissima* was higher than that of *L. pallida* and these were related to the effect of tannins on protein availability and utilization by the animals.

7. Post harvesting treatment methods showed that sun drying and soaking in water could reduce tannins and mimosine contents in the edible fractions to an acceptable level before feeding the browse foliage to ruminant animals.

8. *Acacia angustissima* and *L. pallida* are potential source of protein supplement for low quality fibrous feeds and more economical than cotton seed cake. Tree/shrub fodder, particularly that of *A. angustissima* could therefore be of particular benefit to resource poor farmer who cannot afford to buy costly protein feed supplements due to lack of cash, transport and unreliable supply.

5.2 Recommendations

1. The extra leaf biomass produced during the wet season could be dried, stored and used as leaf meals during the dry season to compliment the little fodder produced in the dry season.

2. Farmers should be encouraged to soak browse fodder in still water for at least 48 hours followed by drying in the sun before feeding their animals to reduce deleterious effects of the secondary compounds.

3. Optimal utilization of browse fodder in the rural areas could be achieved through feeding mixtures of browse species to dilute toxic effects of anti-nutritive compounds such as tannins below the threshold level.

5.3 Future research needs

The following areas for further studies are highlighted by results from the present study.

1. Studies to determine intake and optimal levels of supplementation with the two browse fodder for growth and milk production should be carried out.

2. Agronomic strategies to maximize fodder production during the dry season should be given attention. These will ensure availability of high quality fodder during the dry season when it is most needed.

3. The economics of post-harvesting processing techniques need to be evaluated, especially with large amount of browse fodder.

4. Studies to determine the effect of tannins and other related polyphenolic compounds on protein availability and utilization by ruminant animals should be carried out in order to improve the prediction of the nutritive value of potential browse species such as *A. angustissima.*

5.4 Limitations of the study

There were many limitations encountered during the study. These included lack of laboratory equipments and chemicals for sample analysis, inadequate research funds and number of animals in the research site in Tabora. There were few laboratory equipments which could not meet the needs for students under different programmes and others were in poor working conditions, as such some analysis had to be carried outside Sokoine University of Agriculture (SUA), Morogoro. Thanks to ICRAF Shinyanga, Tanzania as they allowed me to use their laboratory facilities to carry out some of the analysis. Some of the laboratory chemicals and reagents, especially for secondary compounds determination were not readily available at Morogoro, they had to be ordered from outside the country, which delayed the work.

Funds allocated for research work was inadequate to cover costs of materials, laboratory chemical analysis and field works due to the increase in prices and fall of the currency value. This necessitated the search for additional funds elsewhere. Fortunately, ICRAF provided additional funds to cover the deficiency and thus enabled me to carry out my research work according to the approved research proposal. There were no laboratory equipments and enough animals at Agricultural Research Institute (ARI), Tumbi, Tabora. Digestibility and feeding experiments were therefore carried out at SUA, Morogoro. This involved shipping of browse leaf meals from Tabora to Morogoro that delayed the commencement of experiment three and four.

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7.0 APPENDICES

Appendix 1. Ration formulation for the feeding trial

Four dairy cows in their second and third lactation and in their first to second month of lactation were used. This trial was conducted at Magadu dairy farm of the Sokoine University of Agriculture (SUA), Morogoro.

Appendix 1.1. Weight of Experimental Animals

Cow Number	Weight (kg)	Lactation Number
9825	321	2nd
9806	381	3rd
9814	321	2nd
9805	379	3rd

(a) Dry Matter intake

In this trial it was estimated that the cows would consume dry matter equivalent to 3% of their body weight. Based on the above assumption, it was therefore estimated that the cows weighing 380kg would consume 11.4kg of dry matter per day, whereas the 321kg cows would consume 9.63kg dry matter per day.

(b) Basal Diet

Grass hay, a mixture of *Brachria spp* and *Chloris gayana* were used as basal feed. The basal feed was offered *ad libitum* and was expected to contribute 60% of the

total dry matter intake per day. That is, 60% of 11.4kg and 9.63kg, which is equivalent to 6.84kg and 5.78kg of hay per day, respectively.

(c) Specification of the supplements

The two browse leaf meals were offered at not more than 30% of the total dry matter intake per day. *L. pallida*, *A. angustissima* and cotton seedcake were used as protein sources, whereas maize bran was used as energy source.

(d) Treatment Diets (Rations)

Four experimental diets were used as follows:

T1 = basal feed, *L. pallida* leaf meal and hominy meal

T2 = Basal feed, *A. angustissima* leaf meal and hominy meal

T3 = Basal feed, 50% *L. pallida* leaf meal, 50% *A. angustissima* leaf meal and hominy meal.

T4 = Basal feed, cotton seed cake and hominy meal

Appendix 1.2. Nutrient concentration of basal feeds, supplements and mineral mixture.

Item	Crude Protein (g/kg DM)	Energy* (ME MJ/kg DM)	Calcium (g/kg DM)	Phosphorus (g/kg DM))
Grass Hay	41.9	6.99	2.8	4.0
Cotton Seed Cake	315	10.22	1.9	141
L. pallida	222.1	7.74	6.6	8.3
A. *angustissima*	233	8.39	6.4	6.4
Hominy meal	118.5	12.56	4.0	7.6
Mineral mixture	-	-	185.1	150

* Metabolizable energy (ME MJ) was estimated using the formula:
ME (MJ/kg DM) = 2.76 + (0.107 × DMD% at 48 hrs)

Appendix 1.3. Calculation of nutrients provided by basal diet

Cow	DM Feed Intake (kg)	Energy (MJ)	Crude Protein (g/kg DM)	Calcium (g/kg DM)	Phosphorus (g/kg DM)
380kg	6.84	47.81	286.69	19.15	27.36
321kg	5.78	49.40	242.18	16.18	23.12

Appendix 1.4. Daily nutrient requirements to meet maintenance and milk production (For cow weighing 380kg and producing 8lts of milk per day)

Item	ME (MJ)	Crude Protein (g)	Calcium (g)	Phosphorus (g)
Maintenance, 380kg, Cow	50.44	381	16	11
Milk, 8kg/day (3.5%Fat)	38.98	672	21.8	14.64
Total	89.34	1053	37.8	25.64

Appendix 1.5. Daily nutrient requirements to meet maintenance, growth and milk production (for cow weighing 321kg and producing 8lts of milk per day)

Item	ME MJ	Crude Protein (g)	Calcium (g)	Phosphorus (g)
Maintenance, 321kg, Cow	42.42	323.02	13.42	9.84
Weight gain, (10% of maintenance)	4.24	32.3	1.34	0.98
Milk, 8kg/day (3.5%Fat)	38.98	656	20.8	14
Total	**85.64**	**1011.32**	**35.56**	**24.82**

(e) Ration formulation for 380 kg cows

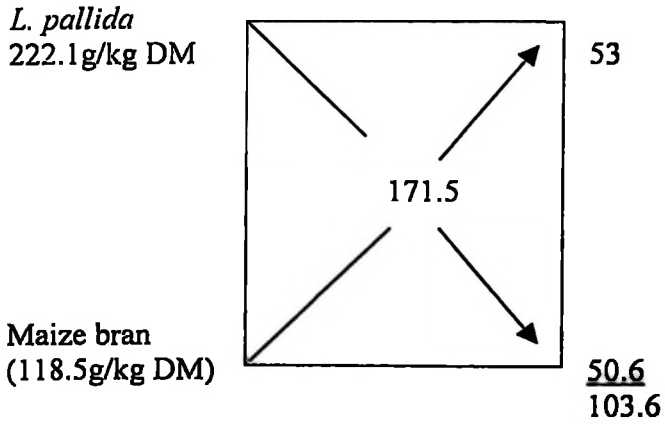
The basal feed (grass hay) provided 47.81MJ of metabolizable energy out of 89.34MJ required for maintenance and milk production (Table 3 & 4. For the protein, only 286.6g were provided by the basal feed and there was a deficit of 766.4g of protein, which was furnished by 4.56kg of the concentrate mixture. The most limiting nutrient in this case was protein.

Appendix 1.6. Nutrients required in the concentrate mixture

Item	Energy ME (MJ)	Crude Protein (g)	Calcium (g)	Phosphorus (g)
Requirement	89.34	1053	37.80	25.64
Provided by Basal feed	47.81	286.60	19.15	27.36
Def. needed in The conc. mixture	41.53	766.4	18.65	+ 1.72

If mineral mixture constituted 2% of the total supplement offered, then protein concentration required per kg DM of the concentrate mixture would be (766.4g)/4.56 (i.e. 168.07g/kg DM. Mineral mixture has no protein and energy. Therefore, protein concentration per kg dry matter, would be as follows: (168.07g/kg DM)/98) 100, which is equivalent to 171.5g/kg DM.

RATION 1.



a) Amount of *L. pallida* in the concentrate mixture = (53/103.6)(98/100) × 4.56kg

this is equal to 2.28 kg/day

b) Amount of maize bran in the concentrate mixture = (50.60/103.6)(98/100) × 4.56kg, this is equivalent to 2.17 kg/day.

c) Amount of mineral mixture in the concentrate mixture = (2/100) × 4.56kg, this is equal to 0.09 kg/day.

Appendix 1.7. Calculation of nutrients provided by ration 1

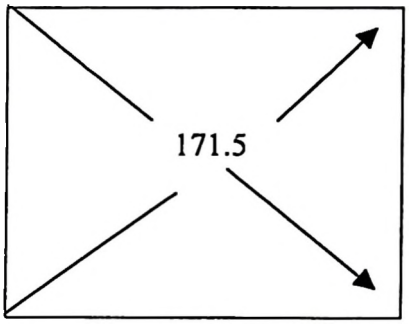
Item	Energy ME (MJ)	Crude Protein (g)	Calcium (g)	Phosphorus (g)
Basal Feed	47.81	286.60	19.15	27.36
L. pallida	**14.71**	**506.39**	**15.05**	**18.92**
Hoominy meal	33.41	257.15	8.68	16.49
Mineral mixture	-	-	16.66	13.50
Total	**95.93**	**1050.14**	**59.54**	**76.27**
Deficiency or surplus	+ 6.59	- 2.86	+ 21.74	+ 50.63

The resulting figures showed that 2.28 part of *L. pallida* with 2.17 of maize bran would provide a concentrate mixture containing 95.93 MJ per kg DM. The protein deficiency of 2.86g was then met by addition of 0.2kg of maize bran. Therefore the proportions of different ingredients in ration 1 were as follows:

Basal feed (6.84kg DM,), *L. pallida* (2.28kg DM), hominy meal (2.37kg DM) and mineral mixture (0.09kg DM).

RATION 2

A. angustissima (233g/kg DM



53.

Maize bran (118.5g/kg DM)

61.5
114.5

a) Amount of *A. angustissima* in the concentrate mixture

= (53/114.5)(98/100) x 4.56kg. this is equal to 2.07 kg/day

b) Amount of maize bran in the concentrate mixture

= (61.5/114.5)(98/100) x 4.56kg, this is equal to 2.40 kg/day

c) Amount of mineral mixture in the concentrate mixture

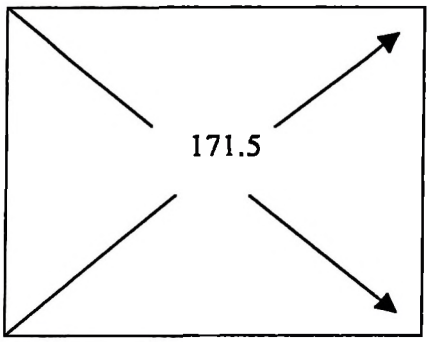
= (2/100) x 4.56kg, this is equal to 0.09 kg/day

Appendix 1.8. Calculation of nutrients provided by ration 2

Item	Crude Protein (g)	Energy ME MJ	Calcium (g)	Phosphorus (g)
Grass hay	286.6	47.81	19.15	27.36
A. angustissima	**482.30**	**17.37**	**13.25**	**12.25**
Maize bran	284.4	30.14	9.60	18.24
Mineral mixture	-	-	16.66	13.5
Total	**1053.3**	**95.32**	**58.66**	**54.11**
Deficiency or Surplus	+ 0.3	+ 5.98	+ 20.86	+ 28.47

RATION 3

AA & LP (227.5g/kg DM) 53



Maize bran (118.5g/kg DM) 56

109

a) Amount of A. angustissima and *L. pallida* in the concentrate mixture

= (53/109)(98/100) × 4.56kg, this is equal to 2.17 kg/day

b) Amount of maize bran in the concentrate mixture

= (56109)(98/100) × 4.56kg, this is equal to 2.30 kg/day

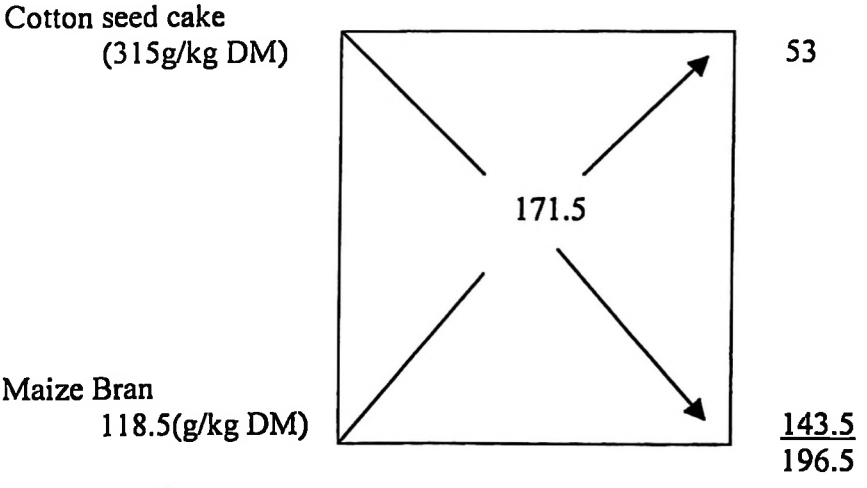
c) Amount of mineral mixture in the concentrate mixture

= (2/100) × 4.56kg, this is equal to 0.09 kg/day

Appendix 1.9. Calculation of nutrients provided by ration 3

Item	Energy (ME MJ)	Crude Protein (g)	Calcium (g)	Phosphorus (g)
Grass Hay	47.81	286.6	19.15	27.36
A. angustissima	**9.10**	**252.81**	**6.94**	**6.94**
L. pallida	**8.40**	**240.98**	**7.16**	**9.01**
Maize bran	28.89	272.55	9.20	17.48
Mineral mixture	-	-	16.66	12.50
Total	**94.20**	**1052.94**	**59.41**	**74.29**
Deficiency or Surplus	+ 11.79	- 0.06	+ 21.61	+ 48.69

RATION 4



a) Amount of cotton seed cake in the concentrate mixture

= (53/196.5)(98/100) × 4.56kg, this is equal to 1.21kg per day

b) Amount of maize bran in the concentrate mixture

= (143.5/196.5)(98/100) × 4.56 kg, this is equal to 3.20 kg/day

c) Amount of mineral mixture in the concentrate mixture

= (2/100) × 4.56kg, this is equal to 0.09 kg/day

Appendix 1.10. Calculation of nutrients provided by ration 4

Item	Crude Protein (g)	Energy (ME MJ)	Calcium (g)	Phosphorus (g)
Grass hay	286.6	47.81	19.15	27.36
Cotton Seed Cake	**381.15**	**12.37**	**2.30**	**1.71**
Maize bran	386.31	40.95	12.80	24.78
Mineral mixture	-	-	16.66	13.5
Total	**1054.06**	**101.13**	**50.91**	**67.35**
Deficiency or surplus	+ 1.06	+ 11.79	+ 12.3	+ 41.71

NOTE: These 4 rations also met requirements for maintenance, growth and milk production for the cows weighing 321kg.

Appendix 2. Mineral contents in edible fractions of *A. angustissima* and *L. pallida.*

Appendix 2.1. Mineral concentrations (g/kg DM) in edible fractions of *A. angustissima* harvested at different cutting regimes

	Cutting regimes						
	1-Month	2-Months	3-Months	Control	SEM	Pr >F	SIG.
Ash							
Young leaves	49.4[a]	48.8[a]	49.6[a]	49.9[a]	0.90	0.7655	NS
Old leaves	54.5[a]	50.1[a]	49.8[a]	52[a]	1.80	0.3343	NS
Whole edible	50.9[a]	46.5[a]	52.1[a]	53[a]	2.12	0.2476	NS
Calcium (Ca)							
Young leaves	5.46[a]	8.47[a]	6.63[a]	8.17[a]	0.62	0.7711	NS
Old leaves	3.17[a]	2.37[a]	2.37[a]	2.40[a]	1.00	0.2259	NS
Whole edible	4.97[a]	3.30[a]	5.13[a]	5.57[a]	0.61	0.1713	NS
Phosphorus (P)							
Young leaves	4.63[a]	2.87[b]	3.37[b]	4.90[a]	0.36	0.0182	*
Old leaves	2.23[a]	1.53[c]	1.80[b]	2.03[ab]	0.08	0.0031	*
Whole edible	2.77[a]	1.60[b]	1.70[b]	2.50[a]	0.11	0.0007	*
Sodium (Na)							
Young leaves	11.7[a]	12.9[a]	16.6[a]	12.1[a]	1.71	0.2658	NS
Old leaves	9.40[a]	10.3[a]	11.3[a]	10.2[a]	0.82	0.4865	NS
Whole edible	9.76[a]	8.37[a]	10.2[a]	10.4[a]	1.23	0.6336	NS
Potassium (K)							
Young leaves	17.8[b]	14.5[c]	16.1[cb]	20.8[a]	0.73	0.0048	*
Old leaves	13.3[b]	12.2[b]	13.5[b]	15.6[a]	0.41	0.0054	*
Whole edible	14.3[ab]	11.6[b]	12.6[b]	16.4a	0.84	0.0205	*

Figures followed by the same letter in the same row have no significant difference at 5% level

* Significant at $P < 0.05$. NS = Not significant

Appendix 2.2. Mineral concentrations (g/kg DM) in *L. pallida* edible fractions harvested at different cutting regimes

	Cutting regimes						
	1-Month	2-Months	3-Months	Control	SEM	Pr >F	SIG.
Ash							
Young leaves	60.9^{a}	59.4^{a}	56.3^{a}	63.2^{a}	1.42	0.6167	NS
Old leaves	5.61^{a}	5.81^{a}	53.8^{a}	57.1^{a}	2.10	0.5987	NS
Whole edible	6.07^{a}	57.2^{a}	55.5^{a}	60.8^{a}	2.34	0.4723	NS
Calcium (Ca)							
Young leaves	6.13^{a}	6.70^{a}	6.43^{a}	7.60^{a}	0.27	0.1359	NS
Old leaves	2.87^{b}	3.40^{ab}	3.93^{a}	3.20^{ab}	1.22	0.8470	NS
Whole edible	5.60^{a}	4.93^{a}	7.17^{a}	5.47^{a}	0.91	0.4108	NS
Phosphorus (P)							
Young leaves	3.77^{b}	2.60^{c}	3.80^{b}	4.73^{a}	0.25	0.0065	*
Old leaves	1.83^{a}	1.70^{a}	1.60^{a}	2.43^{a}	0.27	0.2192	NS
Whole edible	1.90^{ab}	1.40^{b}	1.87^{ab}	2.57^{a}	0.23	0.0595	NS
Sodium (Na)							
Young leaves	14.2^{a}	15.1^{a}	14.7^{a}	16.6^{a}	1.38	0.6739	NS
Old leaves	9.77^{a}	6.73^{a}	11.3^{a}	13.2^{a}	2.12	0.2713	NS
Whole edible	11.7^{a}	12.2^{a}	14.1^{a}	11.7^{a}	1.26	0.5420	NS
Potassium (K)							
Young leaves	21.2^{ab}	16.7^{c}	18.9^{bc}	23.1^{a}	0.89	0.0100	*
Old leaves	16.9^{ab}	14.8^{b}	17.7^{ab}	21.8^{a}	1.48	0.0748	NS
Whole edible	17.5^{b}	16.7^{b}	17.2^{b}	22.4^{a}	1.36	0.0754	NS

Figures followed by the same letter in the same row have no significant difference at 5% level

* Significant at $P < 0.05$. NS = Not significant

Appendix 3. Fibre contents in edible fractions of *A. angustissima* and *L. pallida*

Appendix 3.1. Fibre contents (g/kg DM) of edible fractions of *A. angustissima* at different cutting regimes in the wet and dry season

Cutting Regime	Season	Plant fraction	Fibre contents (g/kg DM)				
			NDF	ADF	ADL	Hemi-cellulose	Cellulose
1-Month	Wet	Young leaves	391^{d}	303^{b}	144^{c}	153^{c}	46.7^{d}
		Old leaves	407^{cd}	307^{b}	145^{c}	100^{d}	162^{ab}
		Whole edible	462^{bc}	292^{bc}	164^{bc}	170^{bc}	129^{bc}
	Dry	Young leaves	398^{d}	215^{c}	163^{bc}	183^{bc}	52.3^{d}
		Old leaves	494^{b}	280^{bc}	179^{ab}	214^{ab}	101^{bc}
		Whole edible	505^{ab}	277^{bc}	174^{b}	228^{ab}	103^{bc}
2-Month	Wet	Young leaves	417^{cd}	301^{bc}	181^{ab}	116^{cd}	95.4^{c}
		Old leaves	452^{bc}	281^{bc}	177^{ab}	171^{bc}	99.9^{bc}
		Whole edible	437^{cd}	305^{b}	171^{b}	137^{cd}	134^{bc}
	Dry	Young leaves	436^{cd}	298^{bc}	197^{a}	139^{c}	103^{bc}
		Old leaves	407^{cd}	263^{bc}	203^{a}	132^{cd}	67.4^{cd}
		Whole edible	464^{bc}	270^{bc}	183^{ab}	194^{b}	87.1^{cd}
3-Month	Wet	Young leaves	443^{cd}	249c	105^{d}	194^{b}	145^{ab}
		Old leaves	541^{a}	324^{ab}	159^{bc}	217^{ab}	165^{ab}
		Whole edible	531^{ab}	289^{bc}	127^{cd}	242^{a}	162^{ab}
	Dry	Young leaves	489^{bc}	354^{ab}	141^{c}	134^{cd}	139^{b}
		Old leaves	447^{c}	364^{a}	180^{ab}	82.7^{d}	157^{ab}
		Whole edible	469^{bc}	346^{ab}	166^{bc}	123^{cd}	179^{a}
Control	Wet	Young leaves	372^{d}	213^{c}	152^{bc}	159^{bc}	60.6^{cd}
		Old leaves	439^{cd}	254^{c}	177^{ab}	186^{bc}	77.8^{cd}
		Whole edible	425^{cd}	267^{bc}	167^{bc}	158^{bc}	100^{bc}
	Dry	Young leaves	459^{bc}	299^{bc}	159^{bc}	159^{bc}	140^{ab}
		Old leaves	523^{ab}	367^{a}	188^{ab}	156^{bc}	179^{a}
		Whole edible	523^{ab}	312^{b}	178^{ab}	181^{bc}	133^{bc}
SEM			16.2	17.2	8.60	13.3	14.3
Pr > F			0.0012	0.0420	0.0401	0.0013	0.0024
SIG.			*	*	*	*	*

Figures followed by the same letter in the same column have no significant difference at 5% level

* Significant at $P < 0.05$.

Appendix 3.2. Fibre contents (g/kg DM) of edible fractions of *L. pallida* at different cutting regimes in the wet and dry season

Cutting Regime	Season	Plant Fraction	Fibre contents (g/kg DM)				
			NDF	ADF	ADL	Hemi-cellulose	Cellulose
1-Month	Wet	Young leaves	438^{bc}	277^{bc}	165^{cd}	160^{b}	112^{ab}
		Old leaves	448^{bc}	334^{ab}	220^{b}	114^{bc}	114^{ab}
		Whole edible	502^{ab}	364^{a}	182^{cd}	138^{bc}	129^{ab}
	Dry	Young leaves	471^{bc}	278^{bc}	183^{cd}	143^{bc}	92^{b}
		Old leaves	539^{a}	320^{ab}	259^{a}	219^{a}	61^{bc}
		Whole edible	494^{ab}	325^{ab}	209^{bc}	169^{ab}	116^{ab}
2-Month	Wet	Young leaves	474^{bc}	274^{bc}	177^{cd}	199^{ab}	75^{bc}
		Old leaves	458^{bc}	290^{bc}	211^{bc}	168^{ab}	79^{bc}
		Whole edible	452^{bc}	304^{b}	203^{bc}	147^{bc}	102^{ab}
	Dry	Young leaves	449^{bc}	317^{ab}	190^{c}	132^{bc}	127^{ab}
		Old leaves	477^{bc}	293^{bc}	226^{b}	184^{ab}	66^{bc}
		Whole edible	413^{c}	275^{bc}	212^{bc}	138^{bc}	68^{bc}
3-Month	Wet	Young leaves	416^{c}	273^{bc}	146^{d}	143^{bc}	127^{ab}
		Old leaves	503^{ab}	285^{bc}	143^{d}	219^{a}	142^{a}
		Whole edible	477^{bc}	265^{bc}	139^{d}	212^{ab}	125^{ab}
	Dry	Young leaves	473^{bc}	362^{a}	152^{d}	110^{bc}	140^{a}
		Old leaves	495^{ab}	309^{b}	174^{cd}	186^{ab}	135^{ab}
		Whole edible	351^{d}	249^{c}	159^{d}	102^{c}	89^{bc}
Control	Wet	Young leaves	380^{cd}	227^{c}	169^{cd}	153^{bc}	58^{bc}
		Old leaves	438^{bc}	273^{bc}	225^{b}	166^{ab}	47^{c}
		Whole edible	427^{c}	293^{bc}	151^{d}	134^{bc}	142^{a}
	Dry	Young leaves	398^{cd}	286^{bc}	179^{cd}	112^{bc}	120^{ab}
		Old leaves	458^{bc}	304^{b}	240^{ab}	154^{bc}	64^{bc}
		Whole edible	483^{b}	353^{ab}	221^{b}	130^{bc}	132^{ab}
SEM			19.1	17.2	9.34	20.4	14.8
Pr > F			0.0001	0.0002	0.0020	0.0484	0.0001
SIG			*	*	*	*	*

Figures followed by the same letter in the same column have no significant difference at 5% level

* Significant at $P < 0.05$.

Appendix 4. Dry matter degradability for the edible fractions of *A. angustissima* and *L. pallida*

Appendix 4.1. Dry matter degradability (g/kg DM) for *A. angustissima* and *L. pallida* whole edible fractions harvested at different cutting regimes in the wet and dry seasons

Cutting regime	Season	Browse species	Incubation time (hours)						
			0	6	12	24	48	72	96
1-Month	Wet	*A. angustissima*	117.5^{d}	209.5^{e}	283.1^{e}	389.1^{e}	500.1^{e}	545.5^{d}	564^{de}
		L. pallida	130^{cd}	215.2^{de}	283.9^{e}	383.7^{ef}	490.7^{ef}	535.9^{d}	554.9^{e}
	Dry	*A. angustissima*	117.9^{d}	198.6^{f}	264.1^{f}	360.4^{g}	466^{g}	512.1^{ef}	532.4^{f}
		L. pallida	130.8^{c}	201.5^{ef}	259.4^{f}	347.6^{h}	448.3^{h}	495.3^{g}	517.3^{g}
2-Months	Wet	*A. angustissima*	97.4^{e}	253.9^{a}	363.8^{a}	495^{a}	591.4^{a}	614.9^{a}	620.6^{a}
		L. pallida	105.1^{e}	228.4^{c}	319.4^{c}	436.1^{c}	534.5^{c}	563.8^{c}	572.5^{d}
	Dry	*A. angustissima*	143.3^{b}	219.8^{d}	281.4^{e}	370.9^{fg}	467.2^{g}	508.1^{ef}	522.3^{fg}
		L. pallida	141.3^{bc}	218.5^{d}	280.6^{e}	370.6^{fg}	466.4^{g}	506.4^{f}	523.1^{fg}
3-Months	Wet	*A. angustissima*	110.4^{de}	224.3^{cd}	308.6^{cd}	417.0^{d}	508.6^{de}	536^{d}	543.8^{e}
		L. pallida	118.9^{cd}	213.2^{de}	286.1^{e}	386.1^{e}	482.2^{f}	517.2^{e}	530.4^{f}
	Dry	*A. angustissima*	158.6^{a}	235.1^{bc}	283.6^{e}	372.7^{f}	444.8^{h}	471.3^{i}	479.9^{i}
		L. pallida	167.2^{a}	228.9^{c}	279.7^{e}	355.8^{gh}	442.3^{h}	482^{h}	500.2^{h}
Control	Wet	*A. angustissima*	85.9^{f}	238.7^{b}	344.4^{b}	470.2^{b}	560.1^{b}	581.3^{b}	586.3^{c}
		L. pallida	123.4^{cd}	226.1^{cd}	306.7^{d}	419.5^{d}	531.8^{c}	574.5^{b}	590.8^{bc}
	Dry	*A. angustissima*	138.8^{bc}	219.7^{d}	287.2^{e}	390.4^{e}	512.4^{d}	571.6^{bc}	600.4^{b}
		L. pallida	156.4^{a}	234.1^{bc}	297.3^{de}	390.2^{e}	492^{ef}	536.3^{d}	555.5^{e}
SEM			4.20	2.81	4.23	4.12	3.53	3.54	4.10
Pr > F			0.0019	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
SIG			*	*	*	*	*	*	*

Values in same column followed by the same superscripts do not differ significantly at the 0.5% level.
* = Significant at $P < 0.05$.

Appendix 4.2. Dry matter losses (%) from nylon bags incubated in the rumen of cows of edible fractions of *A. angustissima* and *L. pallida* harvested at 1-month interval during the wet season

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	15.88^{a}	33.79^{a}	25.87^{a}	45.06^{a}	56.58^{a}	61.14^{a}	62.94^{a}
	Old leaves	10.41^{d}	26.17^{d}	19.16^{d}	36.29^{d}	45.12^{d}	51.43^{e}	53.45^{d}
	Whole	11.75^{c}	28.31^{c}	20.95^{c}	38.91^{c}	50.01^{c}	54.55^{c}	56.40^{c}
L. pallida	Young leaves	13.68^{b}	29.99^{b}	22.66^{b}	40.82^{b}	52.83^{b}	58.15^{b}	60.51^{b}
	Old leaves	11.73^{c}	25.84^{d}	19.47^{d}	35.38^{d}	46.19^{d}	51.14^{e}	53.41^{d}
	Whole	13.00^{b}	28.39^{c}	21.52^{c}	38.37^{c}	49.07^{c}	53.58^{d}	55.49^{c}
SEM		0.37	0.28	0.21	0.37	0.77	0.25	0.37

Means followed by different superscripts in the same column are significantly different ($P < 0.05$).

Appendix 4.3. Dry matter losses (%) from nylon bags incubated in the rumen of cows of edible fractions of *A. angustissima* and *L. pallida* harvested at 2-months interval during the wet season

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	12.45^{a}	28.22^{a}	39.41^{a}	53.02^{a}	63.36^{a}	65.99^{a}	66.67^{a}
	Old leaves	7.86^{d}	22.45^{c}	32.60^{c}	44.57^{d}	53.19^{d}	55.21^{d}	55.69^{d}
	Whole	9.74^{c}	25.39^{b}	36.38^{b}	49.50^{b}	59.14^{b}	61.49^{b}	62.06^{b}
L. pallida	Young leaves	12.80^{a}	26.34^{b}	35.87^{b}	47.30^{c}	55.78^{c}	57.86^{c}	58.38^{c}
	Old leaves	7.36^{d}	20.63^{d}	29.95^{d}	41.13^{e}	49.54^{e}	51.71^{e}	52.28^{e}
	Whole	10.51^{b}	22.84^{c}	31.94^{c}	43.61^{d}	53.45^{d}	56.38^{cd}	57.25^{cd}
SEM		0.22	0.38	0.51	0.48	0.42	0.53	0.61

Means followed by different superscripts in the same column are significantly different ($P < 0.05$).

Appendix 4.4. Dry matter losses (%) from nylon bags incubated in the rumen of cows of edible fractions of *A. angustissima* and *L. pallida* harvested at 3-months interval during the wet season

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	13.52^{a}	23.82^{a}	31.83^{a}	42.91^{a}	53.67^{a}	57.62^{a}	59.06^{a}
	Old leaves	10.59^{c}	21.89^{bc}	30.21^{b}	40.81^{b}	49.64^{d}	52.22^{c}	52.97^{bc}
	Whole	11.04^{bc}	22.43^{b}	30.86^{ab}	41.70^{b}	50.86^{c}	53.60^{b}	54.38^{b}
L. pallida	Young leaves	11.92^{b}	21.65^{bc}	29.41^{bc}	40.55^{b}	52.17^{b}	56.89^{a}	58.82^{a}
	Old leaves	10.09^{c}	20.82^{c}	28.83^{c}	39.31^{c}	48.49^{e}	51.47^{c}	52.25^{bc}
	Whole	11.89^{b}	21.32^{c}	28.61^{c}	38.61^{c}	48.22^{e}	51.72^{c}	53.04^{bc}
SEM		0.38	0.29	0.35	0.38	0.34	0.43	0.51

Means followed by different superscripts in the same column are significantly different ($P < 0.05$).

Appendix 4.5. Dry matter losses (%) from nylon bags incubated in the rumen of cows of edible fractions of *A. angustissima* and *L. pallida* harvested from the control plots during the wet season

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	10.96^{c}	25.24^{a}	35.44^{a}	47.94^{a}	57.51^{a}	60.08^{a}	60.74^{a}
	Old leaves	9.61^{cd}	22.29^{c}	31.66^{bc}	43.71^{b}	53.91^{cd}	56.96^{c}	57.87^{bc}
	Whole	8.59^{d}	23.87^{b}	34.44^{a}	47.02^{a}	56.01^{b}	58.13^{bc}	58.63^{bc}
L. pallida	Young leaves	14.58^{a}	24.49^{ab}	32.30^{b}	43.29^{b}	54.36^{c}	58.62^{b}	60.27^{ab}
	Old leaves	9.66^{cd}	20.46^{d}	28.85^{d}	40.44^{d}	51.69^{e}	55.81^{c}	57.33^{c}
	Whole	12.34^{b}	22.61^{c}	30.67^{c}	41.95^{c}	53.18^{d}	57.45^{bc}	59.08^{b}
SEM		0.43	0.31	0.34	0.36	0.35	0.42	0.49

Means followed by different superscripts in the same column are significantly different ($P < 0.05$).

Appendix 4.6. Dry matter losses (%) from nylon bags incubated in the rumen of cows of edible fractions of *A. angustissima* and *L. pallida* harvested at 1-month interval during the dry season

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	12.06^{bc}	22.29^{b}	30.14^{a}	40.78^{a}	50.72^{a}	54.16^{a}	55.35^{a}
	Old leaves	12.04^{bc}	19.79^{c}	26.08^{c}	35.35^{cd}	45.52^{c}	49.98^{c}	51.95^{c}
	Whole	11.79^{c}	19.86^{c}	26.41^{c}	36.04^{c}	46.60^{b}	51.21^{b}	53.24^{b}
L. pallida	Young leaves	16.47^{a}	23.44^{a}	29.17^{b}	37.76^{b}	47.49^{b}	51.82^{b}	53.97^{b}
	Old leaves	10.54^{d}	18.05^{d}	24.23^{d}	33.52^{e}	44.05^{d}	49.01^{d}	51.27^{c}
	Whole	13.08^{b}	20.15^{c}	25.98^{c}	34.76^{d}	44.83^{cd}	49.53^{cd}	51.73^{c}
SEM		0.38	0.29	0.29	0.32	0.29	0.29	0.40

Means followed by different superscripts in the same column are significantly different ($P < 0.05$).

Appendix 4.7. Dry matter losses (%) from nylon bags incubated in the rumen of cows of edible fractions of *A. angustissima* and *L. pallida* harvested at 2-months interval during the dry season

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	17.08^{a}	26.28^{a}	33.49^{a}	43.57^{a}	53.58^{a}	57.37^{a}	58.80^{a}
	Old leaves	11.72^{d}	20.29^{d}	27.10^{d}	36.83^{c}	46.86^{c}	50.84^{c}	52.48^{c}
	Whole	14.33^{b}	21.98^{c}	28.14^{c}	37.10^{c}	46.72^{c}	50.81^{c}	52.23^{c}
L. pallida	Young leaves	14.96^{b}	24.07^{b}	31.07^{b}	40.60^{b}	49.58^{b}	52.74^{b}	53.85^{b}
	Old leaves	12.59^{c}	20.68^{d}	27.16^{d}	36.47^{c}	46.23^{c}	50.22^{d}	51.85^{c}
	Whole	14.13^{b}	21.85^{c}	28.06^{c}	37.06^{c}	46.64^{c}	50.64^{c}	52.31^{c}
SEM		0.26	0.13	0.20	0.28	0.22	0.13	0.22

Means followed by different superscripts in the same column are significantly different ($P < 0.05$).

Appendix 4.8. Dry matter losses (%) from nylon bags incubated in the rumen of cows of edible fractions of *A. angustissima* and *L. pallida* harvested at 3-months interval during the dry season

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	18.13^{a}	25.77^{a}	31.91^{a}	40.86^{a}	50.44^{a}	54.48^{a}	56.18^{a}
	Old leaves	14.73^{c}	21.41^{c}	26.79^{bc}	34.62^{de}	42.99^{d}	46.54^{d}	48.03^{d}
	Whole	15.86^{bc}	23.51^{b}	28.36^{b}	37.27^{c}	44.48^{c}	47.13^{d}	47.99^{d}
L. pallida	Young leaves	19.24^{a}	25.84^{a}	31.16^{a}	38.94^{b}	47.34^{b}	50.95^{b}	52.52^{b}
	Old leaves	14.68^{c}	20.86^{c}	26.20^{c}	33.70^{e}	42.63^{d}	46.84^{d}	48.82^{d}
	Whole	16.72^{b}	22.89^{b}	21.97^{bc}	35.58^{d}	44.23c	48.20^{c}	50.02^{c}
SEM		0.43	0.34	0.67	0.41	0.36	0.30	0.32

Means followed by different superscripts in the same column are significantly different ($P < 0.05$).

Table 4.9. Dry matter losses (%) from nylon bags incubated in the rumen of cows of edible fractions of *A. angustissima* and *L. pallida* harvested from the control plots during the wet season

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	15.54^{ab}	24.26^{a}	31.38^{a}	41.94^{a}	53.71^{a}	58.98^{a}	61.35^{a}
	Old leaves	13.78^{b}	21.94^{b}	28.72^{b}	39.05^{b}	50.91^{b}	56.56^{b}	59.25^{b}
	Whole	13.88^{b}	21.97^{b}	28.72^{b}	39.04^{b}	51.24^{b}	57.16^{b}	60.04^{ab}
L. pallida	Young leaves	17.19^{a}	25.00^{a}	31.48^{a}	41.33^{a}	52.84^{a}	58.33^{ab}	60.94^{a}
	Old leaves	14.24^{b}	20.89^{b}	26.29^{c}	34.28^{c}	43.08^{d}	46.95^{d}	48.66^{d}
	Whole	15.64ab	23.41^{a}	29.73^{ab}	39.02^{b}	49.20^{c}	53.63^{c}	55.55^{c}
SEM		0.57	0.58	0.60	0.60	0.51	0.45	0.47

Means followed by different superscripts in the same column are significantly different ($P < 0.05$).

Appendix 5. Nitrogen degradability for the edible fractions of *A. angustissima* and *L. pallida*

Appendix 5.1. Nitrogen degradability (g/kg DM) for *A. angustissima* and *L. pallida* whole edible fraction harvested at different cutting regimes in the wet and dry seasons.

Cutting regime	Browse species	Incubation time (hours)						
		0	6	12	24	48	72	96
1-Month	*A. angustissima*	132^{c}	244^{c}	332^{e}	456^{c}	549^{b}	632^{c}	652^{bc}
	L. pallida	170^{ab}	275^{b}	349^{d}	442^{d}	515^{bc}	534^{g}	538^{g}
2-Months	*A. angustissima*	133^{c}	277^{b}	381^{b}	512^{a}	618^{a}	648^{b}	658^{b}
	L. pallida	144^{bc}	305^{a}	409^{a}	521^{a}	589^{a}	601^{d}	603^{e}
3-Months	*A. angustissima*	150^{bc}	239^{c}	315^{f}	435^{d}	586^{ab}	664^{a}	707^{a}
	L. pallida	188^{a}	246^{c}	297^{g}	381^{f}	500^{c}	572^{e}	617^{d}
Control	*A. angustissima*	152^{bc}	277^{b}	371^{c}	492^{b}	598^{a}	631^{c}	642^{c}
	L. pallida	165^{b}	243^{c}	306^{f}	400^{e}	503^{c}	548^{f}	568^{f}
SEM		7.04	3.47	3.06	4.23	12.9	2.89	3.82
Pr > F		0.0021	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
SIG.		*	*	*	*	*	*	*

Values in same column followed by the same superscripts do not differ significantly at the 0.5% level.
* = Significant at $P < 0.05$.

Appendix 5.2. Nitrogen losses (%) from nylon bags incubated in the rumen of cows for the edible fractions of *A. angustissima* and *L. pallida* harvested at 1-month interval.

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	13.24^{b}	20.63^{c}	26.77^{d}	36.15^{c}	47.15^{c}	52.44^{d}	54.28^{d}
	Old leaves	13.03^{b}	23.41^{b}	31.99^{c}	44.99^{ab}	60.02^{a}	67.09^{a}	70.41^{a}
	Whole	13.23^{b}	24.36^{b}	33.15^{b}	45.58^{a}	54.88^{b}	63.21^{b}	65.19^{b}
L. pallida	Young leaves	14.87^{b}	24.39^{b}	31.51^{c}	41.09^{c}	49.66^{c}	52.49^{d}	53.44^{d}
	Old leaves	9.73^{c}	19.15^{d}	26.83^{d}	38.18^{d}	50.71^{bc}	56.24^{c}	57.82^{c}
	Whole	17.01^{a}	27.48^{a}	34.89^{a}	44.16^{b}	51.45^{bc}	53.42^{d}	53.82^{d}
SEM		0.59	0.35	0.35	0.41	1.41	0.36	0.56

Means with different superscripts along the same column are significantly ($P < 0.05$) different.

Appendix 5.3. Nitrogen losses (%) from nylon bags incubated in the rumen of cows for the edible fractions of *A. angustissima* and *L. pallida* harvested at 2-months interval.

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	14.37^{b}	29.23^{b}	39.28^{b}	50.68^{b}	58.30^{c}	59.91^{b}	60.26^{c}
	Old leaves	15.30^{b}	31.78^{a}	42.50^{a}	55.28^{a}	63.48^{a}	65.19^{a}	65.55^{a}
	Whole	13.38^{b}	29.58^{b}	38.14^{b}	51.21^{b}	61.79^{b}	64.78^{a}	65.84^{a}
L. pallida	Young leaves	17.37^{ab}	27.72^{c}	33.15^{c}	43.54^{c}	54.89^{d}	59.81^{b}	61.86^{b}
	Old leaves	18.45^{a}	26.08^{d}	37.11^{b}	45.75^{c}	51.91^{e}	53.52^{c}	53.99^{d}
	Whole	14.42^{b}	30.46^{b}	40.90^{ab}	52.13^{b}	58.90^{c}	60.12^{b}	60.34^{c}
SEM		0.83	0.41	0.77	0.82	0.39	0.27	0.38

Means with different superscripts along the same column are significantly ($P < 0.05$) different.

Appendix 5.4. Nitrogen losses (%) from nylon bags incubated in the rumen of cows for the edible fractions of *A. angustissima* and L. pallida harvested at 3-months interval.

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	16.16^{ab}	30.25^{ab}	39.35^{b}	49.83^{b}	58.44^{b}	61.46^{c}	62.62^{c}
	Old leaves	15.93^{ab}	30.65^{a}	41.64^{a}	55.94^{a}	68.47^{a}	72.37^{a}	73.59^{a}
	Whole	14.98^{b}	23.92^{b}	31.54^{c}	43.54^{c}	58.57^{b}	66.35^{b}	70.66^{b}
L. pallida	Young leaves	16.76^{ab}	25.43^{b}	32.05^{c}	40.96^{c}	49.19^{c}	51.99^{e}	52.95^{d}
	Old leaves	17.27^{ab}	29.37^{ab}	38.18^{b}	49.27^{b}	58.40^{b}	61.09^{c}	61.91^{c}
	Whole	18.78^{a}	24.56^{b}	29.66^{c}	38.14^{c}	49.95^{c}	57.22^{d}	61.73^{c}
SEM		1.16	1.85	1.57	1.45	0.42	0.43	0.63

Means with different superscripts along the same column are significantly ($P < 0.05$) different.

Appendix 5.5. Nitrogen losses (%) from nylon bags incubated in the rumen of cows for the edible fractions of *A. angustissima* and *L. pallida* harvested from the control plots.

Browse Species	Edible Fraction	Incubation time (hours)						
		0	6	12	24	48	72	96
A. angustissima	Young leaves	14.78^{b}	26.28^{bc}	35.13^{b}	47.37^{b}	59.21^{bc}	63.53^{b}	65.09^{b}
	Old leaves	15.44^{b}	26.01^{bc}	34.17^{b}	48.34^{ab}	61.72^{a}	66.45^{a}	69.70^{a}
	Whole	15.22^{b}	27.75^{b}	37.06^{a}	49.22^{a}	59.82^{b}	63.53^{b}	64.18^{b}
L. pallida	Young leaves	16.32^{b}	25.93^{c}	33.60^{b}	44.66^{c}	56.35^{d}	61.18^{c}	63.17^{b}
	Old leaves	20.04^{a}	30.47^{a}	38.43^{a}	49.12^{a}	58.99^{c}	62.35^{bc}	63.50^{b}
	Whole	16.51^{b}	24.30^{c}	30.63^{c}	40.01^{d}	50.27^{e}	54.81^{d}	56.77^{c}
SEM		1.05	0.56	0.49	0.34	0.23	0.42	0.43

Means with different superscripts along the same column are significantly ($P < 0.05$) different.

Appendix 6. Estimated cost and benefit analysis for dairy cow fed grass hay supplemented with browse leaf meals or cottonseed meal

Item	Cost/benefit (Tshs)			
	Ration 1	Ration 2	Ration 3	Ration 4
Gross Return	1556	1634	1650	1988
Variable costs				
1. Nursery management (mgt)				
➢ Polythene tube	72.96	56.45	64.61	-
➢ Sowing mixture	1.94	1.51	1.72	-
➢ Pot filling	24.32	18.82	21.54	-
➢ Browse seeds	2.43	1.88	2.15	-
➢ Routine nursery mgt.	36.48	28.23	32.30	-
2. Field establishment and routine mgt.				
➢ Land clearing	6.08	4.70	5.38	-
➢ Ploughing and ridging	22.8	17.64	20.19	-
➢ Transplanting	12.16	9.41	10.77	-
➢ Weeding	22.8	17.64	20.19	-
3. Fodder harvesting and processing				
➢ Cutting	24.32	18.82	21.54	-
➢ Drying under shade	6.08	4.70	5.38	-
➢ Threshing and packing	12.16	9.41	10.77	-
4. Hominy meal	54.25	60.00	57.50	81.5
5. Cotton seed meal	-	-	-	181.5
6.Transport cost of cotton seed meal	-	-	-	400
7. Mineral mixture	63	63	63	63
8. Feeding and milking animals	600	600	600	600
Fixed cost				
Land	6.08	4.70	5.38	-
Storage	7.30	5.65	6.46	-
Total cost that vary				
➢ 1st year of harvesting fodder banks	975.16	922.56	948.88	1326
➢ 2nd year of harvesting and onwards	795.98	783.92	790.22	1326
Net Return				
➢ 1st year of harvesting fodder banks	580.08	711.44	701.12	662.00
➢ 2nd year of harvesting and onwards	760.02	850.08	859.78	662.00
Net return over control	98.02	188.08	197.78	-

Ration: 1 = Basal feed + *L. pallida* leaf meal, 2 = Basal feed + *A. angustissima* leaf meal, 3 = Basal feed + 50% *L. pallida* and 50% *A. angustissima* and 4 = Basal feed + cotton seed meal

Appendix 7. ANOVA tables

Appendix 7.1 ANOVA tables for experiment 1

7.1.1 Fodder yields

7.1.1.1. ANOVA for variation between cutting regimes in *L pallida* old leaves yield per cutting

Source of variation	df	Type 1 ss	ms	F value	Pr > F
Rep	2	0.08	0.04	0.82	0.4837
Cutting Regime	3	4.16	1.39	27.30	0.0007
Residual	6	0.30	0.05		
Total	11	4.55			

R square = 0.93 CV = 20.37 Root MSE = 0.22 Mean = 1.11

7.1.1.2. ANOVA for variation between cutting regimes in *L pallida* whole edible fractions yield per cutting

Source of variation	df	Type 1 ss	ms	F value	Pr > F
Rep	2	0.09	0.04	0.58	0.5880
Cutting Regime	3	4.36	1.45	19.19	0.0018
Residual	6	0.45	0.08		
Total	11	4.91			

R square = 0.91 CV = 21.81 Root MSE = 0.28 Mean = 1.26

7.1.1.3. ANOVA for variation between cutting regimes in *A. angustissima* old leaves yield per cutting

Source of variation	df	Type 1 ss	ms	F value	Pr > F
Rep	2	1.51	0.76	2.32	0.1794
Cutting Regime	3	16.98	5.66	17.38	0.0023
Residual	6	1.95	0.36		
Total	11	20.44			

R square = 0.90 CV = 33.85 Root MSE = 0.57 Mean = 1.68

7.1.1.4. ANOVA for variation between cutting regimes in *A. angustissima* whole edible fractions yield per cutting

Source of variation	df	Type 1 ss	ms	F value	Pr > F
Rep	2	1.91	0.96	2.51	0.1617
Cutting Regime	3	18.13	0.04	15.84	0.0030
Residual	6	2.29	0.38		
Total	11	22.33			
R square = 0.89	CV = 32.93	Root MSE = 0.62	Mean = 1.87		

7.1.1.5. ANOVA for variation between cutting regimes in *A. angustissima* old leave yield in the wet season

Source of variation	df	Type 1 ss	ms	F value	Pr > F
Rep	2	5.32	2.66	5.02	0.0524
Cutting Regime (CR)	3	9.48	3.16	5.97	0.0311
Residual	6	3.18	0.53		
Total	11	17.98			
R square = 0.82	CV = 20.69	Root MSE = 0.73	Mean = 3.51		

7.1.1.6. ANOVA for variation between cutting regimes in *A. angustissima* whole edible fraction yield in the wet season

Source of variation	df	Type 1 ss	ms	F value	Pr > F
Rep	2	6.53	3.27	6.31	0.0334
Cutting Regime (CR)	3	7.50	2.50	4.88	0.0454
Residual	6	3.10	0.52		
Total	11	17.13			
R square = 0.81	CV = 17.62	Root MSE = 0.72	Mean = 4.08		

7.1.2. Nitrogen contents in edible fractions

7.1.2.1 ANOVA for variation between cutting regimes in nitrogen content in *A. angustissima* young leaves in the wet season

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.36	0.18	8.99	0.0157
Cutting Regime	3	1.59	0.53	26.27	0.0008
Residual	6	0.12	0.02		
Total	11	2.09			
R square = 0.94	CV = 3.28	Root MSE = 0.14	Mean = 4.34		

7.1.2.2 ANOVA for variation between cutting regimes in nitrogen content in *L. pallida* young leaves in the wet season

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.92	0.46	7.11	0.0261
Cutting Regime	3	1.71	0.57	8.83	0.0128
Residual	6	0.39	0.06		
Total	11	3.02			
R square = 0.87	CV = 5.94	Root MSE = 0.25		Mean = 4.28	

7.1.2.3.ANOVA for variation between cutting regimes in nitrogen contents in *L. pallida* old leaves in the wet season

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.19	0.09	1.46	0.3046
Cutting Regime	3	1.43	0.48	7.31	0.0199
Residual	6	0.39	0.06		
Total	11	2.01			
R square = 0.87	CV = 5.93	Root MSE = 0.26		Mean = 4.24	

7.1.2.4. ANOVA for variation between cutting regimes in nitrogen contents in *L. pallida* whole edible fractions in the wet season

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.29	0.14	2.62	0.1521
Cutting Regime	3	0.83	0.28	5.09	0.0435
Residual	6	0.33	0.05		
Total	11	1.44			
R square = 0.77	CV = 7.32	Root MSE = 0.23		Mean = 3.18	

7.1.2.5. ANOVA for variation between cutting regimes in nitrogen contents in *L. pallida* whole edible fractions in the dry season

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.11	0.06	2.23	0.18
Cutting Regime	3	0.40	0.13	5.33	0.0396
Residual	6	0.15	0.03		
Total	11	0.67			
R square = 0.77	CV = 5.36	Root MSE = 0.16		Mean = 2.96	

7.1.2.6. ANOVA for variation between plant fractions and seasons in nitrogen content in *A. angustissima* harvested at 1-month interval

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.15	0.075	1.31	0.3062
Plant fraction	2	3.08	1.543	26.87	< .0001
Season	1	0.13	0.132	2.29	0.1558
Residual	12	0.69	0.06		
Total	17	4.06			
R square = 0.83	CV = 6.11	Root MSE = 0.24		Mean = 3.92	

7.1.2.7. ANOVA for variation between plant fractions and seasons in nitrogen content in *A. angustissima* harvested at 2-month interval

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.14	0.07	2.02	0.1759
Plant fraction	2	0.60	0.30	8.50	0.0050
Season	1	0.002	0.002	0.05	0.8349
Residual	12	0.425	0.04		
Total	17	1.17			
R square = 0.64	CV = 5.13	Root MSE = 0.19		Mean = 3.67	

7.1.2.8. ANOVA for variation between plant fractions and seasons in nitrogen content in *A. angustissima* harvested at 3-month interval

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.02	0.01	0.51	0.6151
Plant fraction	2	0.83	0.42	17.30	0.0003
Season	1	0.06	0.06	2.44	0.1439
Residual	12	0.29	0.02		
Total	17	1.21			
R square = 0.76	CV = 4.17	Root MSE = 0.16		Mean = 3.72	

7.1.2.9. ANOVA for variation between plant fractions and seasons in nitrogen content in *A. angustissima* harvested from the control plots

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.27	0.13	2.92	0.0925
Plant fraction	2	2.05	1.02	22.36	< .0001
Season	1	0.47	0.48	10.40	0.0073
Residual	12	0.55	0.05		
Total	17	3.35			
R square = 0.83	CV = 5.47	Root MSE = 0.21		Mean = 3.91	

7.1.2.10.ANOVA for variation between plant fractions and seasons in nitrogen content in *L. pallida* from 1-month cuttings

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.46	0.22	3.41	0.0672
Plant fraction	2	2.67	1.33	19.78	0.0002
Season	1	0.45	0.45	6.76	0.0233
Residual	12	0.81	0.067		
Total	17	4.38			
R square = 0.82	CV = 7.48	Root MSE = 0.26		Mean = 3.46	

7.2.11. ANOVA for variation between plant fractions and seasons in nitrogen content in *L. pallida* from 2-month cuttings

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.15	0.08	1.52	0.26
Plant fraction	2	2.05	1.03	20.13	0.0001
Season	1	0.24	0.24	4.63	0.0526
Residual	12	0.61	0.05		
Total	17	3.05			
R square = 0.79	CV = 7.46	Root MSE = 0.23		Mean = 3.03	

7.2.12. ANOVA for variation between plant fractions and seasons in nitrogen content in *L. pallida* from 3-month cuttings

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.85	0.42	2.99	0.0882
Plant fraction	2	4.65	2.33	16.47	0.0004
Season	1	0.01	0.02	0.11	0.7500
Residual	12	1.69	0.14		
Total	17	7.21			
R square = 0.76	CV = 11.19	Root MSE = 0.38		Mean = 3.36	

7.2.13. ANOVA for variation between plant fractions and seasons in nitrogen content in *L. pallida* from the control plots cuttings

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.79	0.39	4.23	0.0508
Plant fraction	2	2.55	1.28	13.54	0.0008
Season	1	2.73	2.73	28.88	0.0002
Residual	12	1.13	0.09		
Total	17	7.22			
R square = 0.84	CV = 8.55	Root MSE = 0.31		Mean = 3.60	

7.1.3. Mineral contents in edible fractions

7.1.3.1 ANOVA for variation between cutting regimes in phosphorus content of *A. angustissima* old leaves

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.005	0.002	13.00	0.0066
Cutting Regimes	3	0.008	0.003	15.62	0.0031
Residual	6	0.001	0.0002		
Total	11	0.01			
R square = 0.92	CV = 6.96	Root MSE = 0.01		Mean = 0.19	

7.1.3.2.ANOVA for variation between cutting regimes in phosphorus content of *A. angustissima* whole edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.003	0.001	3.49	0.0988
Cutting Regimes	3	0.030	0.01	26.87	0.0007
Residual	6	0.002	0.0004		
Total	11	0.04			
R square = 0.93	CV = 9.04	Root MSE = 0.02		Mean = 0.21	

7.1.3.3. ANOVA for variation between cutting regimes in phosphorus content of *L. pallida* young leaves

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.02	0.01	5.13	0.0502
Cutting Regimes	3	0.07	0.02	11.66	0.0063
Residual	6	0.011	0.002		
Total	11	0.11			
R square = 0.88	CV = 11.81	Root MSE = 0.044		Mean = 0.37	

7.1.3.4. ANOVA for variation between cutting regimes in potassium content of *A. angustissima* old leaves

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.24	0.12	25.01	0.0012
Cutting Regimes	3	0.18	0.06	12.51	0.0054
Residual	6	0.03	0.005		
Total	11	0.45			
R square = 0.93	CV = 5.10	Root MSE = 0.67		Mean = 1.37	

7.1.3.5. ANOVA for variation between cutting regimes in potassium content of *A. angustissima* whole edible fraction

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.05	0.03	1.44	0.3087
Cutting Regimes	3	0.40	0.13	7.20	0.0205
Residual	6	0.11	0.02		
Total	11	0.57			
R square = 0.80	CV = 9.94	Root MSE = 0.13		Mean = 1.37	

7.1.3.6. ANOVA for variation between cutting regimes in potassium content of *L. pallida* young leaves

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.03	0.01	0.60	0.5804
Cutting Regimes	3	0.69	0.23	9.78	0.0100
Residual	6	0.142	0.02		
Total	11	0.89			
R square = 0.84	CV = 7.71	Root MSE = 0.15		Mean = 2.00	

7.1.4 ANOVA table for Fiber contents in edible fractions

7.1.4.1. ANOVA for variation between cutting regimes and seasons in NDF content of *A. angustissima* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	7.15	3.58	0.45	0.6388
Plant fraction (PF)	2	352.44	176.22	22.29	< .0001
Cutting regime (CR)	3	247.69	82.57	10.45	< .0001
Season (S)	1	126.27	126.27	15.97	0.0002
CR*S	3	392.14	130.71	16.54	< .0001
PF*CR*S	14	362.14	25.87	3.27	0.0012
Residual	46	363.61	7.90		
Total	71	1851.46			
R square = 0.80	CV = 6.17	Root MSE = 2.81		Mean = 45.59	

7.1.4.2. ANOVA for variation between cutting regimes and seasons in ADF content of *A. angustissima* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	70.57	35.28	3.98	0.0255
Plant fraction (PF)	2	92.35	46.18	5.20	0.0092
Cutting regime (CR)	3	187.07	62.35	7.03	0.0005
Season (S)	1	102.58	102.58	11.56	0.0014
CR*S	3	487.10	162.37	18.30	< .0001
PF*CR*S	14	235.86	16.87	1.90	0.0520
Residual	46	408.17	8.87		
Total	71	1563.69			
R-square = 0.74	CV= 10.14		Root MSE = 2.98		Mean = 29.38

7.1.4.3. NOVA for variation between cutting regimes and seasons in ADL content of *A. angustissima* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	4.97	2.48	1.13	0.3318
Plant fraction (PF)	2	39.17	19.58	8.91	0.0005
Cutting regime (CR)	3	150.03	50.01	22.76	< .0001
Season (S)	1	76.32	76.32	34.73	< .0001
CR*S	3	11.54	3.85	1.75	0.1700
PF*CR*S	14	58.85	4.20	1.91	0.0501
Residual	46	101.09	2.19		
Total	71	441.96			
R-square = 0.77	CV= 8.94		Root MSE = 1.48		Mean = 16.57

7.1.4.4. ANOVA for variation between cutting regimes and seasons in hemicellulose content of *A. angustissima* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	58.33	29.18	5.48	0.0073
Plant fraction (PF)	2	86.30	43.15	8.11	0.0010
Cutting regime (CR)	3	64.16	21.39	4.02	0.0127
Season (S)	1	6.54	6.54	1.23	0.2733
CR*S	3	695.76	231.92	43.59	< .0001
PF*CR*S	14	242.06	17.29	3.25	0.0013
Residual	46	244.74	5.32		
Total	71	1397.91			
R- square = 0.82	CV = 14.08		Root MSE = 2.31		Mean = 16.38

7.1.4.5. ANOVA for variation between cutting regimes and seasons in cellulose content of *A. angustissima* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	30.07	15.03	2.45	0.0972
Plant fraction (PF)	2	152.84	76.42	12.47	< .0001
Cutting regime (CR)	3	403.04	134.34	21.92	< 0.0001
Season (S)	1	9.48	9.48	1.55	0.2197
CR*S	3	266.84	88.95	14.51	< .0001
PF*CR*S	14	258.76	18.48	3.02	0.0024
Residual	46	281.92	6.12		
Total	71	1402.96			

R- square = 0.80 CV = 20.99 Root MSE = 2.47 Mean = 11.79

7.1.4.6. ANOVA for variation between cutting regimes and seasons in NDF content of *L. pallida* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	61.01	30.51	2.79	0.0717
Plant fraction (PF)	2	255.75	127.88	11.70	< .0001
Cutting regime (CR)	3	165.23	55.08	5.04	0.0042
Season (S)	1	1.77	1.77	0.16	0.6894
CR*S	3	104.60	34.87	3.19	0.0322
PF*CR*S	14	752.47	53.75	4.92	< .0001
Residual	46	502.57	10.92		
Total	71	1843.41			

R-square = 0.73 CV = 7.30 Root MSE = 3.31 Mean = 45.27

7.1.4.7. ANOVA for variation between cutting regimes and seasons in ADF content of *L. pallida* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	14.42	7.21	0.81	0.4493
Plant fraction (PF)	2	38.15	19.08	2.15	0.1276
Cutting regime (CR)	3	90.31	30.10	3.40	0.0255
Season (S)	1	56.25	56.25	6.35	0.0153
CR*S	3	118.31	39.44	4.45	0.0079
PF*CR*S	14	497.01	35.50	4.01	0.0002
Residual	46	407.47	8.86		
Total	71	1221.93			

R-square = 0.67 CV = 10.02 Root MSE = 2.98 Mean = 29.71

7.1.4.8. ANOVA for variation between cutting regimes and seasons in ADL content of *L. pallida* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	17.16	8.58	3.30	0.0457
Plant fraction (PF)	2	219.28	109.64	42.21	< .0001
Cutting regime (CR)	3	328.73	109.58	42.18	< .0001
Season (S)	1	94.03	94.03	36.20	< .0001
CR*S	3	9.75	3.25	1.25	0.3021
PF*CR*S	14	111.84	7.99	3.08	0.0020
Residual	46	119.49	2.60		
Total	71	900.27			
R- square = 0.87	CV = 8.53	Root MSE = 1.61		Mean = 18.90	

7.1.4.9. ANOVA for variation between cutting regimes and seasons in hemicellulose content of *L. pallida* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	59.33	29.66	2.38	0.1036
Plant fraction (PF)	2	151.72	75.86	6.09	0.45
Cutting regime (CR)	3	50.42	16.81	1.35	0.2699
Season (S)	1	38.11	38.11	3.06	0.0869
CR*S	3	221.76	73.92	5.94	0.0016
PF*CR*S	14	335.51	23.97	1.93	0.0484
Residual	46	572.67	12.45		
Total	71	1429.53			
R-square = 0.60	CV = 22.69	Root MSE = 3.53		Mean = 15.55	

7.1.4.10. ANOVA for variation between cutting regimes and seasons in cellulose content of *L. pallida* edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	38.92	19.46	2.93	0.0637
Plant fraction (PF)	2	104.86	52.43	7.88	0.0011
Cutting regime (CR)	3	283.84	94.61	14.23	< .0001
Season (S)	1	1.12	1.12	0.17	0.6838
CR*S	3	65.56	21.85	3.29	0.0289
PF*CR*S	14	502.31	35.88	5.39	< .0001
Residual	46	305.93	6.65		
Total	71	1302.54			
R- square = 0.77	CV = 24.39	Root MSE = 2.58		Mean = 10.57	

7.1.4.11. ANOVA for variation between species and cutting regimes in NDF content

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	27.91	13.96	6.91	0.0082
Spp	1	179.96	179.96	89.12	< .0001
Cutting regime (CR)	3	382.44	127.48	63.13	< .0001
Spp*CR	3	93.37	31.12	15.41	0.0001
Residual	14	28.27	2.02		
Total	23	711.96			
R- square = 0.96	CV = 3.07		Root MSE = 1.42		Mean = 46.27

7.1.4.12. ANOVA for variation between species and cutting regimes in ADF content

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	1.40	0.70	0.35	0.7081
Spp	1	0.02	0.03	0.01	0.9081
Cutting regime (CR)	3	106.7	35.57	17.97	< .0001
Spp*CR	3	201.88	67.29	34.00	< .0001
Residual	14	27.71	1.97		
Total	23	337.72			
R- square = 0.92	CV = 4.68		Root MSE = 1.41		Mean = 30.07

7.1.4.13. ANOVA for variation between species and cutting regimes in ADL content

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.34	0.17	1.82	0.1979
Spp	1	38.35	38.36	406.09	< .0001
Cutting regime (CR)	3	52.96	17.65	186.92	< .0001
Spp*CR	3	21.71	7.24	76.64	< .0001
Residual	14	1.32	0.09		
Total	23	114.70			
R- square = 0.98	CV = 1.64		Root MSE = 0.31		Mean = 18.79

7.1.4.14. ANOVA for variation between species and cutting regimes in hemicellulose content

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	30.86	15.43	6.01	0.0131
Spp	1	130.15	130.15	50.66	< .0001
Cutting regime (CR)	3	226.99	75.66	29.45	< .0001
Spp*CR	3	13.42	4.47	1.74	0.2043
Residual	14	35.96	2.57		
Total	23	437.40			
R- square = 0.92	CV = 10.13	Root MSE = 1.60		Mean = 15.82	

7.1.4.15. ANOVA for variation between species and cutting regimes in cellulose content

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	3.99	1.99	1.25	0.3161
Spp	1	37.00	37.00	23.22	0.0003
Cutting regime (CR)	3	126.47	42.16	26.45	< .00001
Spp*CR	3	93.82	31.28	19.62	< .0001
Residual	14	22.31	1.59		
Total	23	283.60			
R- square = 0.92	CV = 11.13	Root MSE = 1.26		Mean = 11.34	

7.1.6 Dry matter degradability

7.1.6.1 ANOVA for 48 hrs degradability as a variate in edible fractions harvested at 1- month interval during the wet season.

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	4.46	2.23	1.26	0.3263
Species (Spp)	1	6.53	6.53	3.68	0.0841
Plant fractions (PF)	2	247.27	123.63	69.65	< .0001
Spp*PF	2	17.61	8.80	4.96	0.0319
Residual	10	17.75	1.78		
Total	17	293.62			
R-square = 0.94	CV = 1.67	Root MSE = 1.33		Mean = 49.9	

7.1.6.2 ANOVA for 48h degradability as a variate in edible fractions harvested at 2-months interval during the wet season.

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.12	0.06	0.12	0.8917
Species (Spp)	1	143.19	143.19	267.62	< .0001
Plant fractions (PF)	2	204.72	102.36	191.29	< .0001
Spp*PF	2	11.67	5.83	10.90	0.0031
Residual	10	5.35	0.54		
Total	17	365.06			

R-square = 0.99 CV = 1.31 Root MSE = 0.73 Mean = 55.74

7.1.6.3. ANOVA for 48h degradability as a variate in edible fractions harvested at 3-months interval during the wet season.

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.35	0.17	0.50	0.6219
Species (Spp)	1	14.01	14.01	40.37	< .0001
Plant fractions (PF)	2	53.12	26.56	76.53	< .0001
Spp*PF	2	1.83	0.92	2.64	0.1199
Residual	10	3.47	0.35		
Total	17	72.78			

R-square = 0.95 CV = 1.17 Root MSE = 0.59 Mean = 50.51

7.1.6.4. ANOVA for 48h degradability as a variate in edible fractions harvested from the control plots during the wet season.

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.73	0.37	0.98	0.4078
Species (Spp)	1	34.17	34.17	91.96	< .0001
Plant fractions (PF)	2	30.30	15.15	40.77	< .0001
Spp*PF	2	0.76	0.38	1.02	0.3940
Residual	10	3.72	0.37		
Total	17	69.67			

R-square = 0.94 CV = 1.12 Root MSE = 0.61 Mean = 54.45

7.1.6.5. ANOVA for 48h degradability as a variate in edible fractions harvested at 1-month interval during the dry season

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	1.63	0.81	3.23	0.0828
Species (Spp)	1	20.89	20.89	82.97	< .0001
Plant fractions (PF)	2	62.04	37.02	123.22	< .0001
Spp*PF	2	2.64	1.32	5.24	0.0278
Residual	10	2.52	0.25		
Total	17	89.71			
R-square = 0.97	CV = 1.08	Root MSE = 0.50	Mean = 46.54		

7.1.6.6. ANOVA for 48h degradability as a variate in edible fractions harvested at 2-months interval during the dry season

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.09	0.05	0.35	0.7143
Species (Spp)	1	11.09	11.09	79.65	< .0001
Plant fractions (PF)	2	98.76	49.38	354.59	< .0001
Spp*PF	2	13.44	6.72	48.26	< .0001
Residual	10	1.39	0.14		
Total	17	124.78			
R-square = 0.99	CV = 0.77	Root MSE = 0.37	Mean = 48.27		

7.1.6.7. ANOVA for 48h degradability as a variate in edible fractions harvested at 3-month interval during the dry season

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	1.61	0.80	2.11	0.1715
Species (Spp)	1	6.91	6.91	18.17	0.0017
Plant fractions (PF)	2	119.62	59.81	157.37	< .0001
Spp*PF	2	7.77	3.89	10.23	0.0038
Residual	10	3.80	0.38		
Total	17	139.70			
R-square = 0.97	CV = 1.36	Root MSE = 0.62	Mean = 45.35		

7.1.6.8. ANOVA for 48h degradability as a variate in whole edible fractions harvested at different cutting regimes during the wet and dry seasons.

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.64	0.32	0.85	0.4370
Seasons (SE)	1	396.81	396.81	1052.78	< .0001
Cutting Regimes (CR)	3	268.48	89.49	237.44	< .0001
Species (SPP)	1	49.59	49.59	131.58	< .0001
SE*CR	3	62.65	20.88	55.41	< .0001
CR*SPP	3	5.09	1.69	4.51	0.0100
SE*CR*SPP	4	28.87	7.22	19.15	< .0001
Residual	30	11.31	0.38		
Total	47	823.44			

R-square = 0.98 CV = 1.24 Root MSE = 0.61 Mean = 49.62

7.1.6.9.ANOVA for 48 hours nitrogen degradability as a variate in the whole edible fractions

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	7.29	3.64	0.72	0.5026
Cutting Regime (CR)	3	182.99	60.99	12.10	0.0004
Species (spp)	1	0.06	0.06	0.01	0.9168
CR*Spp	3	278.38	92.79	18.41	<. 0001
Residual	14	70.57	5.04		
Total	23	539.28			

R-square = 0.86 CV = 4.03 Root MSE = 2.25 Mean = 55.71

7.2. ANOVA tables for experiment 2

7.2.1. ANOVA for variation between treatment methods in CT contents in old leaves of *L. pallida.*

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	3	24.67	8.22	54.67	< 0.0001
Treatment methods	6	28.49	4.74	31.57	< 0.0001
Residual	18	2.71	0.15		
Total	27	55.87			

R-square = 0.95 CV = 8.96 Root MSE = 0.39 Mean = 4.33

7.2.2. ANOVA for variation between treatment methods in CT content in whole edible fraction of *L. pallida.*

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	3	32.30	10.76	85.54	< 0.0001
Treatment methods	6	24.77	4.13	32.79	< 0.0001
Residual	18	2.26	0.13		
Total	27	59.34			
R-square = 0.96	CV = 8.30	Root MSE = 0.35		Mean = 4.27	

7.2.3. ANOVA for variation between treatment methods in CT content in young leaves of *A. angustissima*

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	3	1.22	0.41	89.51	< 0.0001
Treatment methods	6	3.72	0.62	136.11	< 0.0001
Residual	18	0.08	0.004		
Total	27	5.02			
R-square = 0.98	CV = 3.99	Root MSE = 0.07		Mean = 1.69	

7.2.4. ANOVA for variation between treatment methods in CT content in old leaves of *A. angustissima*

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	3	0.19	0.06	26.30	< 0.0001
Treatment methods	6	1.64	0.27	113.05	< 0.0001
Residual	18	0.04	0.002		
Total	27	1.88			
R-square = 0.98	CV = 3.94	Root MSE = 0.04		Mean = 1.25	

7.2.6 ANOVA for variation between treatment methods in CT content in whole edible fractions of *A. angustissima*

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	3	1.26	0.42	141.28	< 0.0001
Treatment methods	6	3.22	0.54	180.45	< 0.0001
Residual	18	0.05	0.003		
Total	27	4.54			
R-square = 0.98	CV = 3.39	Root MSE = 0.05		Mean = 1.61	

7.2.7. ANOVA for variation between treatment methods in mimosine content in young leaves of *A. angustissima*

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	1.13	0.57	6.01	0.0155
Treatment methods	6	59.99	9.99	106.02	< 0.0001
Residual	12	1.13	0.09		
Total	20	62.26			

R-square = 0.98 CV = 8.15 Root MSE = 0.31 Mean = 3.77

7.2.8. ANOVA for variation between treatment methods in mimosine content in old leaves of *A. angustissima*

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.18	0.09	6.30	0.0135
Treatment methods	6	43.27	7.21	511.58	< 0.0001
Residual	12	0.17	0.01		
Total	20	43.62			

R-square = 0.99 CV = 4.41 Root MSE = 0.12 Mean = 2.69

7.2.9. ANOVA for variation between treatment methods in mimosine content in whole edible fraction of *A. angustissima*

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Rep	2	0.29	0.15	6.21	0.0141
Treatment methods	6	54.77	9.12	378.61	< 0.0001
Residual	12	0.29	0.02		
Total	20	55.36			

R-square = 0.99 CV = 5.13 Root MSE = 0.16 Mean = 3.02

7.3. ANOVA tables for experiment 3

7.3.1. ANOVA for variation between rations in DM intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	23.60	7.89	7.77	< .0001
Ration	3	20.81	6.94	6.85	0.0002
Residual	183	154.84	1.01		
Total	159	199.25			

R-square = 0.22 CV = 9.64 Root MSE = 1.00 Mean =10.42

7.3.2. ANOVA for variation between rations in OM intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	19.07	6.36	7.58	< .0001
Ration	3	19.89	6.63	7.91	< .0001
Residual	183	128.23	0.84		
Total	159	1.67.22			
R-square = 0.23	CV = 9.96	Root MSE = 0.92	Mean = 9.20		

7.3.3. ANOVA for variation between rations in CP intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	43218.32	14406.12	8.04	< .0001
Ration	3	4481.60	1493.87	0.83	0.4772
Residual	183	274127.66	1791.68		
Total	159	321827.59			
R-square = 0.15	CV = 4.12	Root MSE = 42.32	Mean = 1026		

7.3.4. ANOVA for variation between rations in estimated energy intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	1172.72	390.91	7.88	< .0001
Ration	3	19994	664.94	13.40	<. 0001
Residual	183	7590.76	49.61		
Total	159	10758.31			
R-square = 0.29	CV = 7.85	Root MSE = 7.04	Mean = 89.72		

7.3.5. ANOVA for variation between rations in Ca intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	186.75	62.25	7.83	< .0001
Ration	3	2175.45	725.15	91.25	< .0001
Residual	183	1215.88	7.95		
Total	159	3578.08			
R-square = 0.66	CV = 7.32	Root MSE = 2.82	Mean = 38.48		

7.3.6. ANOVA for variation between rations in P intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	407.53	135.84	8.26	<.0001
Ration	3	2066.93	688.98	41.88	<.0001
Residual	183	2516.86	16.45		
Total	159	4991.31			
R-square = 0.50	CV = 5.30	Root MSE = 4.06	Mean = 76.58		

7.3.7. ANOVA for variation between rations in milk yields

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	14.56	4.85	16.32	<.0001
Ration	3	110.47	36.82	123.83	<.0001
Residual	183	45.50	0.30		
Total	159	170.53			
R-square = 0.73	CV = 6.39	Root MSE = 0.54	Mean = 8.54		

7.4. ANOVA table for experiment 4

7.4.1. ANOVA for variation between period and ration in DM digestibility

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	663.65	221.22	8.97	<.0001
Ration	3	3547.07	1182.36	47.93	<.0001
Residual	183	3774.28	24.67		
Total	159	7984.99			
R-square = 0.53	CV = 9.50	Root MSE = 4.97	Mean = 52.27		

7.4.2. ANOVA for variation between period and ration in OM digestibility

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	616.48	205.49	8.82	<.0001
Ration	3	3631.29	1210.43	51.96	<.0001
Residual	183	3563.89	23.29		
Total	159	7811.67			
R-square = 0.54	CV = 8.75	Root MSE = 4.83	Mean = 55.17		

7.4.3. ANOVA for variation between period and ration in nitrogen digestibility

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	12948.35	431612	1.15	0.3307
Ration	3	969996.56	323332.	86.20	< .0001
Residual	183	573920.89	19		
Total	159	1556865.81	3751.17		

R-square = 0.0.63 CV = 13.51 Root MSE = 61.25 Mean = 453.5

7.4.4. ANOVA for variation between period and ration in nitrogen intake (g/day)

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	1106.54	368.85	8.04	< .0001
Ration	3	782.40	260.80	5.69	0.0010
Residual	183	7017.96	45.87		
Total	159	8906.90			

R-square = 0.21 CV = 4.10 Root MSE = 6.77 Mean = 165.01

7.4.5. ANOVA for variation between period and ration in nitrogen intake per $BW^{0.75/day}$

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	0.03	0.01	7.97	< .0001
Ration	3	0.02	0.0008	5.61	0.0011
Residual	183	0.21	0.0001		
Total	159	0.26			

R-square = 0.21 CV = 1.03 Root MSE = 0.04 Mean = 3.58

7.4.6. ANOVA for variation between period and ration in total nitrogen excreted

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	9821.92	3273.97	21.73	< .0001
Ration	3	142228.73	4742.91	31.48	< .0001
Residual	183	23053.14	150.67		
Total	159	47103.79			

R-square = 0.51 CV = 8.04 Root MSE = 12.27 Mean = 152.64

7.4.7. ANOVA for variation between period and ration in faecal nitrogen excreted

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	46324.49	15441.49	4.29	0.0062
Ration	3	959278.67	319759.62	88.75	< .0001
Residual	183	551262.45	3603.02		
Total	159	1556865.8			

R-square = 0.64 CV = 10.98 Root MSE = 60.03 Mean = 546.5

7.4.8. ANOVA for variation between period and ration in urinary nitrogen excreted

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	32011.24	10670.41	16.36	< .0001
Ration	3	50093.61	16697.87	25.61	< .0001
Residual	183	99768.84	652.08		
Total	159	181873.69			

R-square = 0.45 CV = 18.64 Root MSE = 25.54 Mean = 136.97

7.4.9.ANOVA for variation between period and ration in milk nitrogen excreted

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	118425.49	39475.16	67.08	< .0001
Ration	3	142981.67	47660.56	80.91	< .0001
Residual	183	90043.96	588.52		
Total	159	351451.12			

R-square = 0.74 CV = 10.04 Root MSE = 24.26 Mean = 241.67

7.4.10. ANOVA for variation between period and ration in milk nitrogen excreted/kg N intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	2529.76	843.25	79.71	< .0001
Ration	3	3128.13	1042.71	98.57	< .0001
Residual	183	1618.49	10.58		
Total	159	7276.39			

R-square = 0.78 CV = 8.20 Root MSE = 3.25 Mean = 39.67

7.4.11. ANOVA for variation between period and ration in faecal nitrogen excreted/kg N intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	599.87	199.96	1.47	0.2257
Ration	3	30.76	10255.31	75.25	< .0001
Residual	183	20851.09	136.28		
Total	159	52216.88			

R-square = 0.60 CV = 12.91 Root MSE = 11.67 Mean = 90.42

7.4.12. ANOVA for variation between period and ration in urinary nitrogen excreted/kg N intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	775.87	258.62	14.65	< .0001
Ration	3	1250.13	416.71	23.60	< .0001
Residual	183	2701.00	17.65		
Total	159	4726.99			

R-square = 0.43 CV = 18.64 Root MSE = 4.20 Mean = 22.55

7.4.13. ANOVA for variation between period and ration in nitrogen g/day

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	15648.74	5216.25	49.63	< .0001
Ration	3	8703.37	2901.12	27.60	< .0001
Residual	183	16081.16	105.11		
Total	159	40433.27			

R-square = 0.60 CV = 82.85 Root MSE = 10.25 Mean = 12.37

7.4.14. ANOVA for variation between period and ration in nitrogen g/kg N intake

Source of variation	df	Type 1 ss	ms	F value	Pr>F
Period	3	526748.51	175582.84	45.18	< .0001
Ration	3	316057.75	105352.58	27.11	< .0001
Residual	183	594595.78	3886.25		
Total	159	1437402.03			

R-square = 0.59 CV = 83.27 Root MSE = 62.34 Mean = 74.86