"DUAL-PURPOSE GOAT PRODUCTION: EVALUATION OF PROTEIN-RICH FORAGES AS SUPPLEMENTARY FEED"

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University

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DEDICATION

THIS THESIS IS DEDICATED TO MY BELOVED PARENTS

MR. AND MRS. KINUTHIA

For their love, guidance, care and protection - may the almighty GOD
bless them mightily and give them long life
AMEN AND AMEN

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AND UNTO GOD FOR BLESSING THE WORK OF MY HANDS.

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ABBREVIATIONS AND ACRONYMS

ADF	Acid Detergent Fibre
ADG	Average Daily Gain
ADL	Acid Detergent Lignin
ANFs	Anti-Nutritive Factors
AOAC	Association of Official Analytical Chemists
ARF	Agricultural Research Fund
ATP	Adenosine triphosphate
BP	By-pass protein
BWT	Birth Weight
Ca	Calcium
Cl	Chlorine
cm	centimeters
Co	Cobalt
CP	Crude Protein
CPI	Crude Protein Intake
Cu	Copper
DCPI	Digestible Crude Protein Intake
DDMI	Digestible Dry Matter Intake
DIM	Days-in-milk
DM	Dry Matter
DMD	Dry Matter Digestibility
DMI	Dry Matter Intake
DOM	Digestible Organic Matter
DOMI	Digestible Organic Matter Intake
DOMR	Organic matter fermented in the rumen
ED	Effective Degradability
EE	Ether Extract
F	Fluorine
FAO	Food and Agriculture Organization
Fe	Iron
FE	Feed Utilization Efficiency
g/d	grams per day
GIT	Gastro-intestinal tract
g/kg	grams per kilogram
GLC	Gas liquid chromatography
ha	hectare
I	Iodine
ICRAF	International Centre for Research in Agroforestry
IDP	Intestine degradable protein
K	Potassium
KARI	Kenya Agricultural Research Institute
KDPG	Kenya Dual-Purpose Goat
KEFRI	Kenya Forestry Research Institute
kg	kilogram
km	kilometres
LWC	Live-weight change
LWT	Live-weight

m	metres
m.a.s.l	metres above sea level
ME	Metabolizable energy
mg	milligram
Mg	Magnesium
mg 100ml^{-1}	milligrams per 100 millilitres
ml	millilitre
mm	millimetre
mmol 100ml^{-1}	millimoles per 100 millilitres
Mn	Manganese
Mo	Molybdenum
MP	Microbial protein
MT	Metric tonnes
N	Nitrogen
Na	Sodium
NAS	National Academy of Sciences
NAHRC	National Animal Husbandry Research Centre
NDF	Neutral Detergent Fibre
NH_3-N	Ammonia-Nitrogen
°C	degrees Celsius
OM	Organic Matter
OMD	Organic Matter Digestibility
OMI	Organic Matter Intake
%	per cent
P	Phosphorus
PD	Potential Degradability
PEG	Polyethylene glycol
pH	Potential of Hydrogen
PRFs	Protein-rich forages
rpm	revolutions per minute
S	Sulphur
Se	Selenium
SED	Standard error of difference
SNF	Solids-not-fat
RDP	Rumen degradable protein
UDP	Rumen-undegradable protein
UV	Ultra-violet
VFA	Volatile fatty acids
WWT	Weaning Weight
$W^{0.75}$	Metabolic Body Weight
YWT	Yearling Weight
Zn	Zinc

Abstract

Protein-rich forages (PRFs) could be cheaper alternative crude protein supplements for ruminants compared to commercial concentrates which are unaffordable to many smallholder farmers. However, effect of supplementation with PRFs on performance of the Kenya dual-purpose goats (KDPGs) in the country has not been well evaluated. Therefore, the objective of this study was to investigate the effects of supplementing KDPGs on a basal diet of Rhodes grass (*Chloris gayana*) hay (confined feeding) (CF) or on natural pastures (free-range) (FR) with different levels of two (2) PRFs, *Calliandra calothyrsus* and Lucerne (*Medicago sativa*) on nutrients intake, lactation performance, pre-weaning kid performance and post-weaning weight gain. To achieve this, four (4) experiments were conducted.

In experiment 1, to investigate the effects of supplementation on milk yield (MY), birth weight (BWT), pre-weaning average daily gain (pre-ADG) and weaning weight (WWT), 55 pregnant DPGs (25 for FR and 30 for CF) were selected at random from a flock of 200 does. They were randomly allocated to five (5) treatment diets four (4) weeks prior to kidding. Composition of the diets was:- T1, (control) - Rhodes grass hay or grazing only for CF or FR respectively; T2 and T3, 250 and 500 gd^{-1} of *C. calothyrsus* respectively; T4 and T5, 250 and 500 gd^{-1} of Lucerne respectively. For CF, daily milk yields were significantly lower at 260, 414, 640, 370 and 521 gd^{-1} for T1 to T5 respectively than FR. The respective values for FR were 355, 568, 813, 508 and 693 gd^{-1}. Kids born to supplemented does had a significantly higher BWT than the control, 1.9, 2.5, 3.3, 2.2 and 2.9 kg for T1 to T5 respectively, for CF, and 2.1, 3.0, 3.8, 2.7 and 3.3 kg for FR. The kids pre-ADG reflected the trend in MY and BWT at 47.8, 64.3, 91.5, 53.8 and 72.9 gd^{-1} for T1 to T5 respectively, for CF, and 57.4, 78.3, 112.4, 66.3 and 90.7 gd^{-1} for FR. Kids born to the supplemented does also had higher ($P<0.05$) WWT than the control. The respective WWT (kg) for T1 to T5 were 7.8, 9.5, 13.3, 8.4 and 10.7 for CF; and 9.0, 11.7, 14.7, 10.1 and 13.5 for FR. Under both management systems, at both levels of supplementation, animals on *Calliandra* performed significantly ($P<0.05$) better than those on Lucerne based diets in MY, BWT, pre-ADG and WWT. These results indicated that supplementation with PRFs improved MY, BWT, Pre-ADG and WWT and that animals on FR performed significantly ($P<0.05$) better compared to those on CF, while those on *Calliandra* had significantly ($P<0.05$) better performance than those on Lucerne based diets

In experiment 2, to investigate the effects of supplementation with PRFs on post-weaning performance, 60 weaner DPGs (30 for each management system) were randomly allocated to 5 treatment diets for 8 months as follows:- T1 (control) - Rhodes grass hay or grazing only for CF or FR respectively. T2 and T3, 100 and 200 gd^{-1} of *C. calothyrsus* respectively; T4 and T5, 100 and 200 gd^{-1} of Lucerne respectively. For CF, the respective values for post-ADG (gd^{-1}) for T1 to T5 were, 17.4, 30.8, 56.8, 26.1 and 40.1. The respective values for FR were, 32.2, 46.1, 61.3, 41.1 and 50.0. The values for YWT (kg) for CF were 12.0, 14.6, 20.0, 12.8 and 16.3 for T1 to T5 respectively. For FR the respective values were 15.6, 19.6, 23.0, 17.3 and 21.4. Supplementation significantly ($P<0.05$) increased post-weaning growth. At both levels of supplementation, under both management systems weaners on *Calliandra* performed significantly ($P<0.05$) better than those on Lucerne based diets in post-ADG and YWT, while those under FR performed significantly ($P<0.05$) better than those under CF.

In experiment 3, to investigate the effects of supplementation with PRFs on *in-vivo* digestibility, N balance and rumen fermentation parameters, Rhodes grass hay was supplemented with graded levels of *C. calothyrsus* and Lucerne. Five (5) mature dual-purpose castrates surgically fitted with rumen cannulae were fed on a basal diet of Rhodes grass hay in a 5 x 5 Latin square design. The 5 treatment diets were T1, control (Rhodes grass hay only); T2 and T3, 250 and 500 gd^{-1} of *C. calothyrsus* respectively; T4 and T5, 250 and 500 gd^{-1} of Lucerne respectively. Supplementation increased ($P<0.05$) OM *in-vivo* digestibility 60.3, 70.1, 72.3, 68.5 and 71.2% for T1 to T5 respectively; and N retention, the respective values of N retained were 4.1, 34.8, 52.3, 29.5 and 43.5% of N intake for T1 to T5. At similar levels of supplementation, N retention was higher ($P<0.05$) in animals on *Calliandra* than those on Lucerne based diets and increased ($P<0.05$) with level of supplementation. Supplementation increased concentration of rumen NH_3-N 12.4, 13.2, 17.9, 12.6 and 16.4 mg $100ml^{-1}$ and VFA 10.6, 11.4, 14.9, 10.9 and 13.7 mmol $100ml^{-1}$ for T1 to T5 respectively and lowered rumen pH 6.8, 6.5, 6.4, 6.5 and 6.5 for T1 to T5 respectively. These results indicated that supplementation with PRFs increased *in-vivo* digestibility, N balance and rumen fermentation. At both levels of supplementation these values were higher for *Calliandra* than Lucerne based diets and increased with level of supplementation.

In experiment 4, to investigate the effects of supplementation with PRFs on rumen degradation characteristics five (5) mature dual-purpose castrates surgically fitted with rumen cannulae were fed on a basal diet of Rhodes grass hay in a 5 x 5 Latin square design. The 5 treatment diets were similar to experiment 3. Supplementation increased ($P<0.05$) OM disappearance and potential degradability (PD) and effective degradability (ED) of OM and CP in the rumen, with level of supplementation.

The available organic matter fermented in the rumen (DOMR) increased ($P<0.01$) from 193.5 for the control to 372.0, 570.4, 332.0 and 494.6 gd^{-1} for T2 to T5 respectively. By-pass protein (BP) increased ($P<0.01$) from 494.5 for the control to 524.4, 540.3, 523.7 and 535.5 g kg^{-1}CP for T2 to T5, the respective values of intestine degradable protein (IDP) were 188.7, 256.6, 286.3, 241.0 and 262.2 g kg^{-1}CP for T1 to T5 respectively. For each of the parameters the values were higher for *Calliandra* than Lucerne based diets at both levels of supplementation and increased with level of supplementation for both legumes.

It was concluded that supplementation improved ($P<0.05$) animal performance in terms of milk yield and growth rate through improved nutrients intake, *in-vivo* digestibility, N retention, rumen fermentation and rumen degradability and that *Calliandra* was a better supplement for goats than Lucerne.

CHAPTER 1

General introduction and objectives

1.1 *General introduction and objectives*

The high increase in human population in Kenya, estimated at 2.9% per annum (National Development Plan, 1997 - 2001) has resulted in land subdivision for human settlement. One of the effects of this, is a reduction in land available for fodder production. This imposes a serious constraint on the rearing of cattle in Kenya as in other developing countries. Under these conditions, smaller animals, like goats, become attractive alternative sources of milk and meat for the growing population (Peacock, 1996). Additionally, reduced fodder availability has led to increased use of highly lignified non-conventional feedstuffs such as crop by-products, weeds, tree twigs and industrial by-products as livestock feed (Peacock, 1996). These by-products are poorly utilized by animals due to high fibre and lignin content (Van Soest, 1994; McDonald, *et al.*, 1995; Kaitho, 1997; Kariuki, 1998; Muia, 2000). Goats have been shown to utilize such fibrous products more efficiently than cattle (Semenye and Hutchcroft, 1992). The goat is thus more suitable for the smallholder farmer than both the sheep and cattle because of its reported efficient digestive system and consumption of a considerably wider spectrum of plant species (Peters and Horst, 1992; Semenye and Hutchcroft, 1992).

Under the majority of smallholder production systems, both quantity and quality of available feeds varies with season following the rainfall pattern The most critical quality parameters that limit animal performance, especially during the dry season, are the low crude protein and high fibre contents of the feeds available then. Supplements that correct for these deficiencies have been shown to improve efficiency of utilization of the available low quality fibrous forages and thus the performance of animals (Muia, 2000). Unfortunately, the high cost of commercial concentrates, make them unaffordable to smallholder farmers with limited resources (Ademosun, 1994). Irungu, (1999) observed that in Kenya, the cost and availability of good quality supplemental feed is a major constraint to their increased utilization by smallholder farmers.

Search for cheaper alternative supplementary feeds has led to identification of protein-rich forages (PRFs) whose production in smallholder farming systems is feasible and can provide a good quality protein supplement that would stimulate high animal performance during the dry season (Njwe and Kona, 1996). However, it is necessary to evolve strategies of production that sustain adequate food crop yields and high productivity of livestock while ensuring greater integration of crop and livestock production and sustainability. Introduction of forage legumes into the farming system has been suggested as one such strategy as they not only provide high quality feed for livestock but also sustain soil fertility (Njwe and Kona, 1996). In addition PRFs have various other uses as live hedges, shade, boundary demarcation, soil conservation, source of timber and fuel wood and fallow improvement, which promote their adoption (Roothaert *et al.*, 1997).

In the recent past a number of exotic PRFs have been introduced into Africa. These include *Leucaena leucocephala, L. pallida, L. diversifolia Sesbania sesban* and *S. goetzei*. *Calliandra calothyrsus* was introduced in Kenya in 1980 (ICRAF, 1992). These fodder trees have shown good adaptation to local climatic conditions, good foliage yields and good acceptability by animals (Palmer and Ibrahim, 1996; Paterson *et al.*, 1996). *C.calothyrsus* yields well in a range of environments (12.4 - 26.2 t DM/ha/yr), tolerates acidic soils and has a high CP content (20 - 30% DM) (Palmer and Ibrahim, 1996; Paterson *et al.*, 1996). Supplementation of grass-based diets with *C. calothyrsus* has been shown to improve growth rate in dairy heifers and to increase milk yield in dairy cattle (Paterson *et al.*, 1996, Roothaert *et al.*, 1997; Roothaert, 1999). Increased dry matter intake (DMI) and growth in sheep and goats supplemented with *C. calothyrsus* has been reported. (Ebong, 1996; Palmer and Ibrahim, 1996; Kaitho, 1997).

Lucerne (*Medicago sativa*) is a well-established leguminous fodder in the country and has a high CP content (16 - 21% DM) (Kariuki, 1998; Odongo *et al.*, 1999). Its annual yield is estimated at 0.9 - 1.4 t DM/ha/yr (Odongo *et al.*, 1999; Wanyama *et al.*, 2000). It is mainly grown in medium and large-scale farms and is fed in the form of hay as a dairy cattle supplement especially during the dry season. It is available in many parts of the country and has been shown to improve growth rate and milk production in cattle (Kariuki, 1998). However, little information is available in the country on its use as a supplement in goat production.

Rhodes grass (*Chloris gayana*) hay is one of the main fodder grasses widely available in the country (Kariuki, 1998; Muia, 2000). It is a high yielder with annual yields estimated at 5 - 15 t DM/ha/yr (Kariuki, 1998; Odongo *et al.*, 1999; Wanyama *et al.*, 2000). Its use even on smallholder farms has been on the increase and is particularly important during the dry season when feeds are scarce. However, when fed alone, intake is limited by its low DM digestibility (50 - 54%) and energy digestibility (53 - 68%) and low CP content 7 - 8% (Minson, 1990; Odongo *et al.*, 1999). There is therefore, need to feed it with supplements, especially protein, to improve its utilization by animals and thus the resulting animal performance.

The Kenya Dual-Purpose Goat (KDPG) used in this study is a 4-way cross (East African x Galla x Toggenburg x Anglo-Nubian). This goat was developed in Kenya with the objective of improving milk and meat production of the indigenous breeds in the country, the Small East African and Galla, through crossing them with the two temperate breeds, Toggenburg and Anglo-Nubian with superior milk and meat performance (Mwandotto *et al.*, 1991; 1992). The goat was chosen for this study because as farm holdings continue to decrease the animal has become an economically important alternative to cattle as a source of milk and in smallholder farming systems the KDPG has been shown to perform better in terms of milk production and growth than the indigenous breeds.

From the fore going discussion, very few studies have evaluated and reported on the value of *C.calothyrsus* as a supplement to low quality grass-based diets in ruminants, particularly goats. Therefore the potential of *C. calothyrsus* for milk production, birth weight, pre- and post-weaning kid performance in goats, remains poorly understood. Therefore, the main objective of this study was to investigate the effects of supplementation of Rhodes grass (*Chloris gayana*) hay with *C. calothyrsus* and to compare its potential as a supplement with the more conventional leguminous species, Lucerne (*Medicago sativa*), on performance of the Kenya dual-purpose goats under confined feeding and free-range management systems.

The specific objectives were to determine the effects of:-

i, Supplementing Kenya dual-purpose goats with graded levels of *C. calothyrsus* and Lucerne on nutrients intake, milk yield and composition, live-weight change, birth weight of kids and growth rate of suckling kids under confined feeding and free-range management systems.

ii, Supplementing weaner goats with graded levels of *C. calothyrsus* and Lucerne on nutrients intake and weight gain under confined feeding and free-range management systems.

iii, Supplementing a basal diet of Rhodes grass hay with graded levels of *C. calothyrsus* and Lucerne on *in-vivo* digestibility, N balance, rumen fermentation parameters and rumen degradation characteristics in Kenya dual-purpose goats.

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CHAPTER 2

Potential of the goat and nutritive value of protein-rich forages (PRFs) as supplementary feed: a review

Potential of the goat and nutritive value of protein-rich forages (PRFs) as supplementary feed: a review

2.1 *Introduction*

The projected increase in human population in the developing world coupled with limited availability of land for increased food and forage production suggest that agricultural production will need to be intensified if the current human and animal nutritional standards are to be maintained and improved as is necessary in many parts of the world (Prasad and Sengar, 2002). In many ruminant production systems in the developing world, native or natural pastures make up the bulk of the feed (Muia, 2000) The seasonal nature of forage supply together with the low intake and poor digestibility of the forage, are major factors contributing to the low productivity of ruminants (Kaitho, 1997). Various attempts have been made to improve the nutritive value of low quality roughages for example through chemical treatment (Oosting, 1993; Manyuchi *et al.*, 1994; Van Soest, 1994; McDonald *et al.*, 1995; Shashi-Saijpaul *et al.*, 1996; Shashi-Saijpaul *et al.*, 1998; Methu, 1998; Woyengo 2001), use of enzymes (Kahlon and Dass, 1987; Lawrence and Abada, 1987; Al Saghier and Campling, 1991), by supplementation with urea, protein and energy sources (Al Saghier and Campling, 1991; Kabatange and Shayo, 1991; Tuen et al., 1991; Oliveros *et al.*, 1993; Oosting, 1993; Manyuchi *et al.*, 1994; Mackie and Morrison, 1995; Chandrasekharaiah *et al.*, 1996; Tolera and Sundstol, 2000) and by genetic selection of the plants (Orskov, 1989). However, conventional protein supplements, enzymes and chemical treatment of roughages may not be practical or economical in most tropical countries and production systems due to high cost (Mero and Uden, 1990).

Protein-rich forages (PRFs) have a great potential as sources of non-conventional feed supplements that are not fully exploited in livestock feeding (Kaitho, 1992). The importance of tree fodder is universal throughout the tropics. In tropical Africa, trees, occupy a significant place in the life of the people mainly for environmental protection, as well as produce-oriented purposes such as timber, poles, fuel-wood and important sources of fodder during the dry season and droughts (Kaitho, 1992; Paterson *et al.*, 1996).

Protein-rich forages are fed as tender shoots and twigs and also fruits and pods (Palmer and Ibrahim, 1996). They form an important component of the diet, especially for a variety of herbivores and have traditionally been used as sources of fodder for domesticated livestock in Asia, Africa and the Pacific (Kaitho, 1997). They are found in all agro-ecological zones, but within the prevailing ecosystems, they are more important in the arid and semi-arid environments where inadequate feeds are a major constraint for survival and production of animals (Kaitho, 1997). In comparison with herbaceous legumes, PRFs offer advantages in terms of superior persistence, higher yields, resistance to mismanagement and the ability to retain high quality during the dry season. During such periods, grasses, which are the major feed resource for livestock dry up and deteriorate both in quality and quantity (Paterson *et al.*, 1996). The PRFs are generally richer in protein, minerals and vitamins than grasses, especially in the dry season and are therefore, suitable for supplementing low quality grasses (Ademosun, 1994). The advantages of using PRFs as forage include availability and accessibility on farm thus a reduction in the requirements for purchased concentrates reducing the cost of feeding (Kaitho *et al.*, 1993). In many situations they form part of complex interactions between plants, animals and crops, the positive aspects of which help to balance a plant-animal-soil ecosystem from which there is a sustainable source of feeds (Ash, 1990). The foliage of some is also used as vegetables by humans while the roots, bark or stems and leaves of others are used for medicinal purposes (Ash, 1990).

These forages provide more rumen degradable N and by-pass N, digestible energy and minerals than grasses (Ash, 1990; Ademosun, 1994). They are reported to have nutritional diversity in terms of chemical composition and their effect on rumen microbes and the host animal. These differences could be attributed to age, concentration of anti-nutritional factors and form (fresh or dry) of presentation. These factors determine their chemical composition, palatability, intake, the extent and rate of degradation, digestibility and nutrient utilization by ruminants (D'Mello, 1992). Although not all PRFs are legumes, more than 200 species of leguminous trees and shrubs are reported to be useful for fodder with most species being tropical or sub-tropical in origin. The most commonly used species come from the genera *Acacia, Albizia, Calliandra, Desmanthus, Gliricidia, Leucaena, Prosopis* and *Sesbania* (Brewbaker, 1986; Palmer and Ibrahim, 1996). Inspite of the considerable diversity, past research and development activities have tended to work on a very narrow range of the available germplasm, in which *Leucaena leucocaphala* and *Gliricidia sepium* in Asia and Africa and *Erythrina poeppigiana* in Latin America have been prominent. This is unfortunate as the narrow focus has tended to overlook many other valuable trees like *Acacia* species (Kaitho, 1997). Over reliance on a few species also poses a danger of serious effects of future disease/pest emergence and may lead to loss of biological diversity due to a narrow genetic base which could also lead to inbreeding and a depression in productivity (Paterson *et al.*, 1996).

The importance of PRFs in the diet of herbivores is reflected in reports from Africa, Latin America and Australia. In Northern Africa, PRFs form 60 - 70% of rangeland production and 40% of the total available animal feeds in the region (Kaitho, 1997). This fodder may be obtained either from passive production systems where naturally occurring woody species are cut or browsed opportunistically as and when they occur, or from more active, planned agroforestry systems where selected tree species are planted and managed in conjunction with crops on the farm for more sustained fodder production (Nair, 1990).

Many indigenous tree species are used as fodder in the sub-Saharan region. In Kenya, there is wide use of PRFs, for example, a survey on 50 farms in the coffee zone of Embu region showed that nine local species were commonly used as fodder. Of these, *Commiphora zimmermanii* (on 70% of the farms surveyed), *Croton macrostachyus* (46%), *Ficus* species (38%) and *Trema orientalis* (18%) were the most common (Thijssen *et al.*, 1993a; 1993b). In West Africa, *Prosopis africana* and *Pterocarpus* are priority species for tree improvement research (ICRAF, 1994). *Acacia nilotica*, *Balanites aegyptica* and *Zizyphus mauritania* are promising in a number of dry areas for live fences and fodder production (ICRAF, 1994). In Eastern Zambia, *Zizyphus abyssinica* and *Diplorynchus condylocarpon* have shown promise for the supplementation of goat diets (Phiri *et al.*, 1992), while in Tanzania *Margaritaria discoides* can serve a similar purpose (Otsyina *et al.*, 1994). In India PRFs are the principal feeds for goats and contribute 60 - 70% of the forage requirements of which, the leguminous types of browses are especially important (Atta-Krah, 1990).

2.2.0 Goat production in the tropics and its potential

2.2.1 Origin and domestication

The goat (*Capra hircus*) is the first ruminant to be domesticated by man (Epstein, 1971; Kamo, 1973; Payne and Wilson, 1999) and second oldest species (Zeuner, 1963). It is thought to have been the first animal to be domesticated for economic purposes (Peacock, 1996). Domestication of the goat is considered to have occurred in the mountainous areas of South-western Asia on the borders of present day Iran and Iraq where agriculture was already advanced at about 9000 - 7000 BC (Epstein, 1971; Kamo, 1973). From there goats spread into all the tropical zones and most temperate areas. It is adapted to and found in a wide spectrum of ecological zones, from hot and cold dry areas to humid tropics. The goat is reported to have the widest range of adaptability among livestock species (Epstein, 1969). Higher concentrations are found in the tropics and dry zones compared to the temperate regions (Gall, 1981; Payne, 1990). As a dairy animal, the goat is regarded as the oldest, in view of its convenience for milking (Devendra and Burns, 1983).

Immediately after domestication, physical differentiation into breeds and types began. Early physical changes affected the ears, horns, colour and hair type as a result of natural mutation and from selection by goat keepers within the environment in which the goats were reared, usually in relative isolation (Peacock, 1996). Early goat keepers must also have selected for the production characteristics, which were appropriate to their needs. New blood probably entered goat populations when people migrated for economic reasons or in times of conflict. There is a huge range of size, colour and hair type among the modern breeds of goats (Peacock, 1996).

2.2.2 *Numbers and distribution*

Goat population in the world is estimated at about 768 million goats and are found in all agro-ecological zones (FAO, 2003). The vast majority of the goats (about 96%) are found in the developing countries of Asia, Africa and South America (Table 2.1). In East Africa, Kenya has an estimated goat population of 12.1 (MLFD, 2004), Tanzania 12.6 and Uganda 6.9 million goats (FAO, 2003). In the country, the highest goat population, (54.6%) is found in the vast Rift Valley province, (Table 2.2), followed by Eastern province (24.3%), (MLFD, 2004). The highest goat populations in the country correspond with areas of low human population densities.

Table 2.1 World goat population and distribution

Continent	Population (1000 head)	Percentage of total population
Asia	484126	63.0
Africa	223466	29.1
South America	22068	2.9
Europe	14911	2.0
North & Central America	14098	1.8
Former Soviet Union	8379	1.1
Oceania	883	0.1
World Total	767931	100.0
Developing countries	738922	96.2
Developed countries	29009	3.8

Source: FAO, (2003): FAO, Production Yearbook. Vol 57. pp. 213

Table 2.2 Goat population and distribution in Kenya

Province	Population (1000 head)	Percentage of total population
Rift Valley	6583.4	54.6
Eastern	2932.5	24.3
Coast	1111.6	9.2
Nyanza	888.1	7.4
Central	317.4	2.6
Western	213.1	1.8
Nairobi	12.2	0.1
Total	12058.3	100.0

Source: MLFD, (2004): Ministry of Livestock and Fisheries Development. Annual report, Department of Livestock Production, Nairobi, Kenya.

2.2.3 *Production systems*

Goats are kept under both extensive and intensive production systems (Payne, 1990). Under extensive systems, they are kept together with cattle mainly by pastoralists on communally owned pastures (Payne, 1990; Wilson, 1991b). The pastoral systems are mainly found in arid and semi-arid areas of Africa, where low rainfall causes varying degrees of nomadism among the local inhabitants (Payne and Wilson, 1999). The system is characterized by a marked seasonality in feed supply (Payne, 1990; Wilson, 1991b). In the intensive systems, goats are grazed either in paddocks, strip-grazed, tethered or zero-grazed (Peacock, 1996). Zero grazing is the most commonly practiced system in tropical high potential areas, characterized by high human population density and small farm sizes (Semenye *et al.*, 1989).

2.2.3.1 *Extensive systems*

The extensive systems include traditional pastoralism and ranching, which have been adopted to exploit the extensive arid and semi-arid regions of the tropical world (Payne and Wilson, 1999). Currently, in the tropics and sub-tropics, the practice of traditional pastoralism is almost entirely confined to certain regions in West, East and North-east Africa, Western Asia and the North West of the Indian sub-continent (Devendra, 1993; Steinfeld and Maki-Hokkonen, 1995; Wilson, 1995). Traditional pastoral systems differ but there is a continuum between those systems in which the livestock owners practice little or no cropping, through forms of partial nomadism and transhumance to systems in which sedentary cultivation is the norm but some members of the family move with the family livestock within a limited grazing area for specific periods of the year. In almost all these systems it is usual for the pastoralists to own and herd sheep and goats. The latter may be run with the cattle but are more often herded separately, often by women and/or children (Payne and Wilson, 1999). According to the degree of nomadism traditional pastoral systems produce milk, meat and sometimes blood from domestic animals and varying quantities of food from crops (Behnke and Scoones, 1993; Scoones, 1995).

Extensive systems are characterized by a marked seasonality in feed supply in terms of both quality and quantity, which reflects seasonality of rainfall. Typically there is only one wet season, followed by a long dry season. Annual rainfall may vary from 700 mm to a level as low as 200 mm. Goats may be kept in large flocks and may or may not be mixed with sheep or other species. Goats are valued for their ability to survive periods of drought better than cattle and sheep. There is likely to be marked variability in production from year to year, because of the highly variable rainfall (Peacock, 1996). During the dry season, low protein and energy levels and high fibre content of the pastures limit production and may cause weight loss. There may be occasional mineral deficiencies water is scarce, causing infrequent watering and further reducing milk production (Wilson, 1991b). Typical constraints to goat production in this system also include high pre-weaning kid mortality rates, as high as 30% or higher in periods of drought, long parturition intervals, up to two years, and occasional epidermic diseases such as contagious caprine pleuropneumonia (CCPP) causing mortality rates of up to 100% (Lebbie *et al.*, 1996).

2.2.3.2 *Semi-intensive systems*

These are rain-fed systems in which crop agriculture is integrated with livestock production. Geographically they are located in different regions of the tropical highlands, humid and sub-humid tropics, semi-arid tropics and sub-tropics, having evolved from some form of pastoralism in the drier areas or from shifting cultivation in the more humid areas, but they all have certain features in common (Payne, 1990). These systems are found on the margins between areas of cultivation and pastoral areas. The emphasis is on keeping livestock to provide the bulk of the family's food and income with crops supplementing this to some extent. Livestock keepers may grow an opportunistic crop or a regular crop during the wet season and may move all, or part of their stock during the dry season (Wilson, 1995). In general the holdings are small, the economy is a mixture of semi-subsistence and cash, cattle are primarily used for work purposes, though milk production is very important, whilst sheep and goats are usually reared in small numbers (Wilson, 1995). The Fulani ethnic group in West Africa is an example of typical agro-pastoralists (Peacock, 1996).

The major problem in the system is the relatively low output of crops and forage due to limited rainfall with a resulting short growing season, high pre-weaning mortality rates and occasional epidermic diseases (Wilson, 1995). An additional constraint in many areas of Africa is the high incidence of trypanosomosis (Ademosun, 1994; Wilson 1995; Lebbie *et al.*, 1996; Payne and Wilson, 1999). Supplementation has been practiced with reported positive results. Nianogo *et al.*, (1996) observed improved daily weight gain when growing lambs on a semi-intensive grazing system were supplemented with energy and protein sources.

2.2.3.3. *Intensive systems*

In Kenya, intensive systems are mainly found in the high potential areas with high human population densities and small farm sizes (Semenye *et al.*, 1989). These areas include Central province, Central Rift Valley, Nyanza and Western provinces (MLFD, 2004). There are also landless families, both within and outside urban areas who husband livestock under very intensive conditions and sell some part of the produce while many in larger urban areas husband livestock under back-yard conditions to provide food for their families (Payne and Wilson, 1999).

Other intensive systems are found in the highlands of Africa where mixed farming is practiced and farm sizes are small (Peacock, 1996). In these systems mainly geared towards milk production from cattle, goats often scavenge on the poorer quality feeds such as crop residues and grazing on steep hillsides. Human population pressure is high and increasing in the highlands, which has led to seasonal tethering or year-round confinement of goats and the need to develop cut-and-carry systems of feeding (Preston, 1990; Payne and Wilson, 1999). During the dry season when feed is scarce, the animals are occasionally supplemented depending on the availability of supplemental feed. Nianogo *et al.*, (1996) observed that when entire Mossi growing lambs on intensive feeding system, were supplemented on wheat bran and cotton seed cake, daily weight gain increased by 68.5%. PRFs have also been used as supplementary feed in this system with reported positive results especially during the dry season when crop residues are scarce and grasses highly lignified. In Zambia, Phiri *et al.*, (1994) observed that supplementation of local goats under cut-and-carry system with *Calliandra calothyrsus*, *Leucaena leucocephala*, *Sesbania sesban* and *Gliricidia sepium*, improved growth rate.

Common problems in goat production in the highlands of Africa include high pre-weaning kid mortality rates, poor reproductive performance and low milk production as a result of low intake of poor quality feed, small flock sizes which lead to poor conception rates and high levels of in-breeding (Payne, 1990). There are also several serious disease constraints such as internal parasites including gastro-intestinal parasites and liver flukes, mange, CCPP and external parasites (Lebbie *et al.*, 1996).

2.2.4 Goat breeds

Goat breeds are divided into two major categories, temperate and tropical breeds (Mowlem, 1992). Temperate breeds include the Saanen, Toggenburg, Alpine and Anglo-Nubian among others while tropical breeds include the East African, Galla and West African Dwarf (Mowlem, 1992). Other tropical breeds are Damascus, Barbari, Malabari and Jamnapari from India; Dera Din Panah and Kamori from Pakistan and Nubian from Sudan and Egypt (Payne and Wilson, 1999). In general, temperate breeds perform better in terms of milk production and growth rates than tropical breeds (Stemmer *et al.*, 1995).

However, tropical breeds have better survivability under the harsh tropical climatic conditions than the temperate breeds and tend to be more prolific (Mtenga *et al.*, 1994).

Many attempts have been made to improve the indigenous tropical breeds by crossbreeding with temperate types for milk, meat or fibre production. Outstanding among the European improver breeds are the Alpine, Anglo-Nubian, Saanen and Toggenburg (Payne and Wilson, 1999). Crossbreeding of temperate and tropical breeds has resulted in crosses with higher performance than the tropical breeds and better survivability than the temperate breeds in tropical environments (Mwandotto *et al.*, 1991; 1992; Mtenga *et al.*, 1994; Stemmer *et al.*, 1995; Kinuthia, 1998). For example superiority in birth weight and growth rate of temperate x tropical crossbred offspring compared to pure-bred tropical breeds in the tropics has been reported (Ahuya *et al.*, 1987; Ruvuna *et al.*, 1987; Payne, 1990; Kinuthia, 1998).

The Anglo-Nubian is probably the most widely distributed of the temperate breeds and it has generally performed better than the others both as a pure breed and as crossbreed and for meat as well as milk (Mowlem, 1992). In Malaysia, highest mature body weights were obtained from ¾ Anglo-Nubian x ¼ local but the F1 generation was the best milk producer with a yield of 296 kg in 235 days. Saanen goats are preferred for milk elsewhere including Australia, India, Kenya, Israel, Venezuela and the West Indies (Payne and Wilson, 1999). The Saanen is a white Swiss breed. Mature females weigh 60 and males 85 kg. It is one of the best milk producers with a potential of up to 2000 kg per lactation (Mowlem, 1992). Additionally, possibilities for improving milk or meat production exist through use of some tropical breeds such as the Jamnapari and Beetal of India, the Galla of Northern Kenya or the Boer of Southern Africa (Payne and Wilson, 1999).

Tropical breeds capable of producing 1.3 - 3.0 kg of milk daily include Damascus, Barbari, Malabari, Jamnapari, Dera Din Panah, Kamori and Nubian (Payne and Wilson, 1999). Of the meat goats, the Boer is outstanding, as females have grown to weigh as much as 75 and mature castrates 100 kg without supplementary feeding. Mohair is a valuable product of Angora goats in many areas with tropical type climates (Wilson, 1997).

The Kenya Dual-Purpose Goat (KDPG) is a synthetic (composite) dual-purpose breed (Ahuya *et al.*, 1987; Ruvuna *et al.*, 1987; Semenye and Hutchcroft, 1992). It is a 4-way cross developed to improve milk and meat production of the indigenous breeds in Kenya. the Small East African and Galla, through crossing them with two temperate breeds, Toggenburg and Anglo-Nubian (Ahuya *et al.*, 1987; Ruvuna *et al.*, 1987; Mwandotto *et al.*, 1991; 1992). Breeding activities were focused on developing a new breed (KDPG) by combining the dairy merit of the two European breeds with the adaptation qualities to tropical environment of the two local breed types (Ruvuna *et al.*, 1987, Semenye *et al.*, 1989).

The mean adult weight of KDPG is 40 kg and a mean daily milk yield of 1.5 kg/day has been reported for lactation lengths of 100 to 160 days (Ruvuna *et al.*, 1987; Semenye and Hutchcroft, 1992). Under the same environment KDPG performs better than the two indigenous breeds (East African and Galla), but lower than the two temperate breeds (Toggenburg and Anglo-Nubian). Mwandotto *et al.*, (1991; 1992), recorded lactation yields of 17, 48 and 80 - 133 kg for East African, Galla and KDPG respectively. The same authors recorded longer lactation lengths of 113 - 159 days for KDPG compared to 66 and 87 for East African and Galla goats respectively. A study conducted in Western Kenya, revealed that unlike the local goat types KDPG was capable of producing milk in excess of kid requirements (Semenye *et al.*, 1989). The on-farm daily yields of KDPG ranged from 0.6 - 2.7 kg with lactation lengths ranging from 65 to 300 days (Semenye *et al.*, 1989). Ahuya *et al.*, (1987) reported improved birth and weaning weight of the KDPG kids compared to indigenous goat kids.

2.2.5 Economic importance of the goat

The goat is a multi-purpose animal, producing milk, meat, skin, hair and manure to fertilize smallholder farms (Semenye *et al.*, 1989; Wilson, 1991a; Wilson, 1992). In Kenya, goat meat is more popular than both beef and mutton and in terms of palatability and delicacy it is preferred to beef (Schwartz and Said, 1981). In Kenya, although goats have been kept primarily for meat, a study in Western Kenya showed that goat milk was readily accepted either as fresh or soured milk and that some people preferred goat to cow's milk (Semenye and Hutchcroft, 1992). Similarly, in Malawi, Cooper *et al*., (1996) observed that goat milk was acceptable to many people and was, in deed, preferred to that of the cow or the sheep

Meat from small ruminants accounts for about 30% of the meat consumed in Africa (Okello *et al*., 1996). Goats could thus play an important role in the provision of animal protein to supplement other sources such as beef, chicken, pork and fish (Okello *et al*., 1996). Economically, it has a low purchase price compared to cattle and is therefore a low risk investment (Semenye and Hutchcroft, 1992; Ademosun, 1994). It is easily sold for emergency cash needs or slaughtered for consumption at home or festival occasions and recreational activities (Payne, 1990; Semenye and Hutchcroft, 1992). It supplies both, milk and meat in quantities suitable for immediate use, a special advantage due to the difficult storage situation in the tropics in the absence of refrigeration, or adequate transportation (Ademosun, 1994). The size of the animals also make them ideal for smallholder families because little capital investment in buildings or other materials is required for their upkeep, and space and maintenance requirements are low (Ademosun, 1994). In addition, due to their shorter generation interval and high prolificacy with a high twinning rate (Alexandre *et al*., 1999, Awemu *et al*., 1999) they are more efficient producers of both milk and meat than cattle (Payne, 1990).

Apart from the food value of goat products, goats have also been used for fulfillment of various social and religious obligations by many communities for centuries (Devendra and Burns, 1983). Additionally, its skin and hair strengthen its economic value. In many areas of the world, goatskin makes leather of high quality (Wilson, 1992). Other uses of goatskin include making clothes, containers and tents, while the hair is used to make coarse hair tents, judges' wigs and fish lures (Devendra and Burns, 1983; Peacock, 1996). In bushy areas, goats have been used to control bush encroachment and as a herding guide for sheep (Devendra and Burns, 1983; Peacock, 1996). Goats have also been used for transport in mountainous regions such as Nepal, Bhutan and Sikkim and due to their small size and convenience in research they are important as experimental animals (Devendra and Burns, 1983). These values help in offsetting labour costs and in risk diversification (Payne, 1990). Table 2.3 shows world production (1000 MT) of goat meat, milk and goatskins, and Table 2.4 the same products for the East African countries.

Table 2.3 World goat production of meat, milk and goatskins

Continent	Goat meat (1000 MT)	Goat meat %	Milk (1000 MT)	Milk %	Goatskins (1000 MT)	Goatskins %
Asia	3083	73.4	6291	52.5	715	78.5
Africa	825	19.6	2793	23.3	141	15.5
South America	83	2.1	183	1.5	14	1.5
Europe	94	2.2	1883	15.7	19	2.1
North & Central America	55	1.3	174	1.5	10	1.1
Former Soviet Union	43	1.0	663	5.5	7	0.8
Oceania	17	0.4	N/A	N/A	5	0.5
World Total	4200	100.0	11987	100.0	911	100.0
Developing countries	4051	96.5	9930	82.8	882	96.8
Developed countries	149	3.5	2057	17.2	29	3.2

Source FAO, (2003) FAO, Production Yearbook Vol 57. pp 226; 241; 252 N/A=Not available

Table 2.4 Goat production of meat, milk and goatskins for the East African countries

Country	Goat meat (1000 MT)	Goat meat %	Milk (1000 MT)	Milk %	Goatskins (1000 MT)	Goatskins %
Kenya	31	35.6	98	49.5	10	47.6
Tanzania	31	35.6	100	50.5	6	28.6
Uganda	25	28.8	N/A	N/A	5	23.8
Total	87	100.0	198	100.0	21	100.0

Source: FAO, (2003). FAO, Production Yearbook Vol 57. pp 226; 241; 252 N/A=Not available

2.2.6 *Dairy potential of the goat*

The goat has a high dairy potential and is capable of providing surplus milk for human consumption in addition to kid's requirements (Mowlem, 1992; Mtenga *et al.*, 1994; Stemmer *et al.*, 1995; Cooper *et al.*, 1996; Peacock, 1996; Kinuthia, 1998). The world's annual goat milk production is estimated at about 12 million metric tonnes (FAO, 2003).

There is wide variation in milk yield and lactation length within and among breeds (Banda, 1994; Karua and Banda, 1994; Lyatuu *et al.*, 1994; Mtenga *et al.*, 1994; Stemmer *et al.*, 1995). Table 2.5 shows lactation performance of various breeds as reported by different researchers in different countries.

Table 2.5 Lactation performance of different goat breeds in different parts of the world

Breed	Country	Lactation yield (kg)	Lactation length (days)	Reference
British-Alpine	Britain	1099	365	Wilkinson and Barbara, (1987)
British-Saanen	Britain	1243	365	Wilkinson and Barbara, (1987)
Saherian	Burkina Faso	64	98	Nianogo and Ilboudo, (1994)
¾ Alpine x ¼ East African	Burundi	310	253	Schmidt and Jauner, (1989)
Alpine	Burundi	456	248	Schmidt and Jauner, (1989)
Damascus	Cyprus	500-560	190-290	Devendra and Burns, 1983
Jamnapari	India	200-562	170-200	Devendra and Burns, 1983
Barbari	India, Pakistan	150-228	180-252	Devendra and Burns, 1983
Beetal	India, Pakistan	140-228	208	Devendra and Burns, 1983
Toggenburg (T)	Kenya	521	240	Odenya and Maleche, (1985)
East African (EA)	Kenya	17	66	Mwandotto *et al.*, (1991)
Galla (G)	Kenya	48	87	Mwandotto *et al.*, (1991)
4-way crosses (EAxGxTxN)	Kenya	80-133	113-159	Mwandotto *et al.*, (1991; 1992)
E.African x Saanen	Malawi	83	84	Karua and Banda, (1994)
E.African	Malawi	37	84	Karua and Banda, (1994)
Local Malawi	Malawi	74	84	Banda, (1994)
Boer	Malawi	78	84	Banda, (1994)
Local Malawi x Boer	Malawi	85	84	Banda, (1994)
Kambing Katjang (KK)	Malaysia	18-144	90-180	Stemmer *et al.*, (1995)
¾ Anglo-Nubian (N) x ¼ KK	Malaysia	237	207	Stemmer *et al.*, (1995)
½ Anglo-Nubian x ½ KK	Malaysia	296	235	Stemmer *et al.*, (1995)
Local Crosses	Malaysia	26	180	Stemmer *et al.*, (1995)
German Fawn x KK	Malaysia	289	365	Stemmer *et al.*, (1995)
Criollo	Mexico	124	166	Torres-Acosta *et al.*, (1995)
West African Dwarf	Nigeria	38	126	Devendra and Burns, 1983
Damani	Pakistan	104	105	Devendra and Burns, 1983
Boer x Kamorai x E.African	Tanzania	90-175	236	Lyatuu *et al.*, (1994)
Angora	Turkey	35-68	123-164	Devendra and Burns, 1983
Kilis	Turkey	280	260	Devendra and Burns, 1983

Within the tropics temperate breeds yield more milk than tropical breeds but require higher nutritional management while the crosses were intermediate in performance (Mtenga *et al.*, 1994, Stemmer *et al.*, 1995). In Malaysia, Stemmer *et al.*, (1995) reported that milk yield and lactation length of the local goat (Kambing Katjang) were significantly lower than those of its crosses with German Fawn. Similarly, Karua and Banda, (1994) reported significantly higher yields for East African x Saanen crosses compared to East African in Malawi. Additionally, dairy performance is also affected by environmental factors mainly nutritional management and seasonal changes (Kimenye and Karimi, 1989; Mwandotto *et al.*, 1991).

For human consumption, goat milk is nutritionally superior to cow's milk because it has smaller fat globules, which are naturally homogenized. The globules are contained in a more perfect state of emulsion with a higher proportion of shorter and medium chain fatty acids than cow milk, making it more digestible and useful to infants (Peacock, 1996). Nutritionally, goat's milk approximates more in its composition and digestibility to human milk, compared to that of the cow (Table 2.6) (Gall, 1981; Mowlem, 1992; Peacock, 1996).

Table 2.6 Comparative chemical composition (%) of cow, goat, sheep and human milk

Content	Cow	Goat	Sheep	Human
Butter fat	3.6	4.5	5.6	4.6
Protein	2.9	3.6	4.5	3.4
SNF	8.0	8.9	10.1	9.1
Total solids	11.6	13.4	15.7	13.7

Source. Gall, (1981); Mowlem, (1992), Peacock, (1996)

It is also suggested that goat milk may have some anti-allergic properties and is tolerable to those with allergic reactions to cow milk and those suffering from duodenal and peptic ulcers (Peacock, 1996). In some countries special value is attached to goat milk and its products including cheese, yoghurt and butter (Payne and Wilson, 1999). In general, goat milk is richer in its mineral content than cow milk but lower than sheep milk (Table 2.7).

Table 2.7 Comparative mineral composition ($mg^{-1}kg$) of milk from cows, sheep and goats

Mineral	Cow	Goat	Sheep
Macro-elements			
Calcium	1199	1552	2056
Potassium	1678	1627	1568
Sodium	575.53	442.51	509.51
Magnesium	104.96	141.58	193.53
Micro-elements			
Copper	0.155	0.404	0.411
Iron	0.441	0.666	0.770
Zinc	4.206	4.765	5.660
Manganese	0.026	0.155	0.089

Source Rincon, F. (1994). Journal of Dairy Research, (1994). **61**: 151-154

2.3.0 Constraints to goat production

2.3.1 Goat nutrition and feeding management

Availability of adequate feeds for small ruminants is the most important limiting factor affecting their performance in the tropics, particularly during the dry season. As a result small ruminants are seldom allowed to express their genetic potential (Ademosun, 1994). Thus, a generally low level of production is common in most parts of the tropics, which is consistent with inefficiencies in the nutritional management (Devendra, 1986). The limitations imposed by scarcity of feeds are particularly serious in Africa where goats are mainly kept in arid and semi-arid regions with perennial seasonal feed shortages, fragile ecologies and potential environmental degradation (Devendra, 1986).

The main feed resources for goats are natural pastures often consisting of coarse grasses and browse plant species. During the dry season available pastures are of low nutritional value deficient in energy, protein and minerals and the browse species, which can provide higher levels of proteins and carbohydrates are sparsely dispersed. This is aggravated by lack of alternative feed during this critical period (Okello *et al.*, 1996). The seasonal availability of forages impacts negatively on the performance of small ruminants. For example, Mwandotto *et al.*, (1991) observed that goats kidding during the wet season yielded more milk than those kidding during the dry season and related this to increased forage availability during the wet season. Kimenye and Karimi, (1989) working with Galla and East African goats in a semi-arid zone in Kenya recorded seasonal effects on daily milk yield, where yields recorded during the wet season were double those recorded during the dry season.

The number of young born alive per kidding as well as growth rate of kids are important factors of productivity contributing to the total weight weaned per dam (Awemu *et al.*, 1999) and both are increased by improved nutrition of the dam. However, Devendra and Burns, (1983) noted that while, prolificacy (kids/kidding) is a useful indicator of the maternal ability of the doe, the number of kids reared to weaning is of great practical importance, as a doe which, although prolific, fails to rear her kids to weaning has a low reproductive efficiency. Kid rearing ability of a doe can be improved through supplementation to boost milk production (Devendra and Burns, 1983). It is a well-established fact that females with high milk output promote faster growth rate and better survivability of their young (Cisse et al., 1996; Nianogo and Ilboudo, 1994). A combination of efficient nutrition and sound management practices are thus imperative for high productivity (Devendra. 1986).

During the dry season, both quantity and quality of available forage is low (Ademosun, 1994) such that unless the animals have access to supplementary feeds they lose weight (Peacock, 1996) The use of protein-rich forages (PRFs) such as *Gliricidia sepium* and *Leucaena leucocephala* as supplementary feeds for small ruminants has been successful in reducing the impact of seasonal feed deficiencies leading to improvements in animal performance (Ademosun, 1994). Kaitho, (1997) recorded increased DMI and growth in sheep and goats fed teff straw (*Eragrostis tef*) a high fibre low protein crop by-product, supplemented with graded levels of *Dolichos lablab, Leucaena leucocephala, Sesbania goetzei* and *Sesbania sesban*. Similarly, Ebong, (1996) reported improved DMI and growth rate in goats fed Elephant grass (*Pennisetum purpureum*) supplemented with graded levels of *Calliandra* leaf meal. Njwe and Kona, (1996) recorded significant increases in DMI, OMI and CPI; and DM, OM and CP digestibility, in West African African Dwarf sheep fed Elephant grass supplemented with stylo (*Stylosanthes guianensis*) and soybean meal Similar findings were reported by Njoya and Awa, (1996) in ewes, Nantoume *et al*., (1996) in rams, Hove and Mpovu, (1996) in sheep and Toppo *et al*., (1997) in steers. Therefore, based on results from various studies it can be argued that supplementation with PRFs could contribute to improved goat performance

2.3.2 Diseases, parasites and mortality

In most production systems, performance of small ruminants is negatively affected by low levels of management not only in their nutrition but also disease and parasites control (Okello *et al*., 1996). This has led to a high prevalence of diseases and parasites, particularly in the more humid areas leading to high mortality rates amongst kids and lambs thus diminishing the benefits of their high reproductive performance (Ademosun, 1994) Mtenga *et al*., (1994) reported a pre-weaning mortality rate of 41% for E African, Boer x E African and Kamorai x E. African in Tanzania, and Awemu *et al*., (1999) a rate of 38% for Red Sokoto kids in Nigeria

The high mortality of young stock and thus poor reproductive efficiency of dams in many livestock production systems in Africa was attributed to poor management, including poor feeding which predispose the animals to diseases (Awemu *et al.*, 1999). Additionally, high kids and lamb mortality is also caused by lack of shelter which expose them to cold weather conditions in the wet areas especially at night and vulnerability to predators at night (Wilson, 1995)

Parasitism ranks high among the factors that limit the productivity of small ruminants especially in the humid areas although its effect is often underestimated (Ademosun, 1994). The problem of parasitism is compounded by the fact that, under the traditional systems, livestock are usually reared extensively, which increases infestation while making control measures difficult. Young animals are the most affected and parasitism could aggravate other conditions such as nutritional stress and susceptibility to disease (Ademosun, 1994; Lebbie *et al.*, 1996). Internal parasites such as gastro-intestinal parasites and liver flukes and contagious diseases such as contagious caprine pleuropneumonia, foot and mouth disease and lumpy skin disease are a serious problem in many parts of Africa (Lebbie *et al.*, 1996). The two most serious external parasites are ticks and mites (Peacock, 1996). The irritation affects feeding reducing intake and dermatitis that accompany mange infestation can reduce the value of the skins and the meat for consumption as food (Lebbie *et al.*, 1996).

2.4.0 Protein-rich forages (PRFs)

2.4.1 Agronomic characteristics of PRFs

Leguminous protein-rich forages (PRFs) have root nodules that fix N in the soil and also absorb more N into their aerial structures (leaves, stems and fruits/pods) than grasses (Minson, 1990; Palmer and Ibrahim, 1996). Many are tree crops with the advantage of being deep rooted and can therefore produce green fodder during the dry season (Palmer and Ibrahim, 1996; Paterson *et al.*, 1996; Roothaert *et al.*, 1997; Roothaert, 1999). Additionally, most PRFs are strongly perennial, for example *Calliandra* and *Leucaena* stands have been reported to continue growing for at least 40 years (Palmer *et al.*, 1994). Thus forage supplied by PRFs can buffer seasonal gaps from other feed sources. During the dry season, deep-rooted PRFs continue to grow, exploiting soil moisture and nutrients from deep soil layers long after the top soil layer has dried up (Kaitho, 1997) for example, after establishment, *Calliandra* has been demonstrated to maintain production throughout the year (Palmer *et al.*, 1994). However, the agronomic qualities of different species of PRFs vary greatly. Usually, the species chosen have other desirable, multipurpose characteristics (Sabiiti and Mugerwa, 1992; Otieno, 1993).

Development of systems where there is intensive use of PRFs for animal production is relatively recent in comparison to intensive animal production systems based on grass and herbaceous legume species (Norton, 1994a). Thus, the scientific knowledge on agronomic factors that affect the productivity of PRFs is less well known and confined to relatively few species (Palmer and Ibrahim, 1996). The species that have received the most attention are leguminous species, which have shown an ability to remain productive under repeated cutting at frequent intervals, have good nutritive value and are reasonably well eaten by animals.

There are many desirable agronomic characteristics of PRFs that are relevant to their potential as animal feed. The most important of these attributes are that it should have good nutritive value and reasonable palatability and acceptability to animals; easy to establish and to nodulate; exhibit good competitive ability against weeds; remain productive under repeated cutting and be well adapted to the particular climatic features of the environment (Palmer and Ibrahim, 1996). Other desirable attributes are that it should require little or no fertilizer; be resistant to pests and diseases; adequate seed production or vegetatively propagated; perennial with production throughout the year; maintains or improves soil fertility and have multipurpose uses (Palmer and Ibrahim, 1996). It is therefore essential to select and evaluate PRFs that meet these criteria. Particular interest has been shown in leguminous species that have potential for wood and forage production and green manuring on degraded or infertile land (Norton, 1994a), since the better soils and environments are mostly used for cropping.

2.4.2 Nutritive value of PRFs

The main features of PRFs are their high CP, vitamins and mineral content (Ademosun, 1994; Kaitho, 1997). The concentration of CP in the leaves and fruits of the majority of PRFs is above 10% even in the dry season when it tends to decrease (Kaitho, 1997). They are also good sources of calcium and phosphorus, two of the major elements required and limiting performance in animals (Kaitho, 1992). PRFs, however, are seldom utilized as sole diets and in most situations their practical use is as supplements to enhance intake of high fibre feeds and crop residues like cereal straws and hays, and thus the performance of animals on such feeds (Kaitho, 1992; Oosting, 1993).

The value of forages as feed supplements depends on their capacity to provide the nutrients deficient in the basal diet (Preston and Leng, 1987). For ruminants subsisting on high fibre roughages such as mature tropical grasses and crop residues, the first limiting nutrient for microbial activity is N which must not only be present in adequate quantities in the feed but must also be available to the micro-organisms (Tamminga, 1989). For effective utilization of supplemental N by the rumen microorganisms a synchronous availability of energy is necessary (McDonald *et al.*, 1995). On high fibre mature tropical grasses this may also constitute a limiting factor (McDonald *et al.*, 1995; Van Soest, 1994). The lower NDF and ADF content of PRFs, which translates to higher digestibility, would also supplement energy supply thus promote higher microbial activity (McDonald *et al.*, 1995; Van Soest, 1994). The nutritive value of forage is a function of its chemical composition, mineral content, presence of toxins or anti-nutritive factors and digestibility (Ivory, 1990).

2.4.2.1 Chemical composition of PRFs

Chemical composition is a major determinant of nutritive value of forages and could affect ruminant performance at both plant and animal levels (Minson, 1990). At the forage level, species could differ in quality and in the extent and rate of ruminal degradation and hence influence the yield of fermentable substrate (Minson, 1990). Table 2.8 presents chemical composition (g kg^{-1}DM) of some selected PRFs.

At the animal level, quality could affect voluntary feed intake and animal performance in terms of milk yield or body weight gain (Kariuki, 1998). Chemical composition of PRFs has been documented by various authors (Minson, 1990, Kaitho, 1997; Kariuki, 1998). Much of the information available is from proximate analysis and is of limited value as a predictor of nutritive value (Topps, 1992). Analyses based on detergent extraction are more useful since plant dry matter is separated into a completely digestible fraction (Neutral detergent solubles) representing cell contents, and a partially digestible fraction (Neutral detergent fibre) representing plant cell walls (Van Soest, 1994). The cell wall is composed primarily of structural carbohydrates, cellulose and hemicellulose and the extent to which it is degraded by rumen microflora is the most important factor affecting forage utilization (Paterson *et al.*, 1994; Van Soest, 1994).

Table 2.8 Chemical composition (g kg^{-1}DM) of some selected PRFs.

Species	CP	NDF	ADF	ADL	Ash	Reference
Acacia albida	143	374	279	45	27	Tanner *et al.*, (1990)
Acacia nilotica	130	316	225	53	49	Tanner *et al.*, (1990)
Acacia tortilis	136	324	242	48	47	Tanner *et al.*, (1990)
Acacia siberiana	127	370	282	58	52	Tanner *et al.*, (1990)
	212	412	340	160		Nsahlai *et al.*, (1995)
Acacia saligna	128	573	429	207		Nsahlai *et al.*, (1995)
Acacia aneura	110	511	396	206	35	Goodchild, (1990)
Acacia seyal	206	228	172	69		Reed *et al.*, (1990)
Acacia plectostachyus	185	410	289	64	61	Kariuki, (1998)
Albizia chinensis	211	354	246		145	Ash, (1990)
Cajanus cajan	201	539	371	175		Nsahlai *et al.*, (1995)
Calliandra calothyrsus	173	302	229	84	40	Ahn, (1990)
	224	530	480	120	121	Kariuki, (1998)
	212	495	297	133	78	Kariuki, (1998)
Chamaecytisus palmensis	178	342	235	64		Nsahlai *et al.*, (1995)
	184	341	204	69		Bonsi, (1995)
Desmodium intortum	183	714	432	112	111	Kariuki, (1998)
	127	599	352	89	108	Kariuki, (1998)
Desmodium uncinatum	179	729	389	131	96	Kariuki, (1998)
Erythrina bentipoene	155	495	393	65		Nsahlai *et al.*, (1995)
Erythrina variegate	175	532	425	68		Nsahlai *et al.*, (1995)
	264	457	343	9	91	Rajaguru, (1990)
Gliricidia sepium	183	656	357		59	Ash, (1990)
Leucaena diversifolia	308	246	114	41	75	Siaw *et al.*, (1993)
Leucaena leucocephala	188	453	190	79		Nsahlai *et al.*, (1995)
	294	216	104	32	83	Siaw *et al.*, (1993)
	258	309	234	87	69	Goodchild, (1990)
	216	498	369	98	105	Kariuki, (1998)
Leucaena pallida	206	420	245	105		Nsahlai *et al.*, (1995)
	326	211	113	38	73	Siaw *et al.*, (,1993)
Leucaena pulverulenta	277	192	107	37	87	Siaw *et al.*, (1993)
Leucaena revolute	324	242	141	52	68	Siaw *et al.*, (1993)
	269	405	234	93		Nsahlai *et al.*, (1995)
Medicago sativa	206	426	296	72	89	Kariuki, (1998)
	167	408	347	64	156	Kariuki, (1998)
	190	455	447	66	153	Kariuki, (1998)
Sesbania sesban	356	203	108	24	94	Siaw *et al.*, (1993)
	241	206	141	25		Bonsi, (1995)
	199	321	237	61	146	Kariuki, (1998)
	155	551	106	29	73	Kariuki, (1998)
Trifolium semipilosum	219	398	327	21	80	Kariuki, (1998)
Vernonia amygdalina	148	312	277	61		Bonsi, (1995)

CP, Crude protein; NDF, Neutral detergent fibre; ADF, Acid detergent fibre, ADL, Acid detergent lignin

The high variability in chemical composition and mineral content of PRFs could be attributed to within species variability and other factors such as plant age, plant part, harvesting regime, season, location, soil fertility and other management practices (Kariuki, 1998). Tropical PRFs generally have good nutrient profiles, a high CP content of 15 to 30% DM, and a low NDF (20 - 35% DM) and ADF (15 - 30%) content. The comparative values for mature tropical grasses are low CP content of 3 to 4% DM (Minson, 1990; Norton, 1994a) and a high NDF (60 - 80% DM) and ADF (40 - 50% DM) content (Minson, 1990, Van Soest, 1994, McDonald *et al.*, 1995; Kariuki, 1998). Feeds containing less than 6% CP are considered deficient as they cannot provide the minimum ammonia-nitrogen levels (5 - 25 mg $100ml^{-1}$) required by rumen microbes for microbial amino acids synthesis (Preston and Leng, 1987; Minson *et al.*, 1993). Most PRFs have a CP content higher than 6% and may be judged adequate in protein (Kaitho, 1997).

PRFs have higher concentration of minerals and vitamins than grasses (Ademosun, 1994). Minerals are essential for growth and for production of meat, milk and fibre by livestock (Wilson, 1992). In tropical countries, mineral deficiencies or imbalances are a major limitation to ruminant production (Conrad *et al.*, 1982). Such imbalances and deficiencies have been identified for some minerals and through feeding livestock with the appropriate supplements marked improvements in performance has been reported (Semenye, 1987). Conrad *et al.*, (1982) cited 12 reports from tropical countries of increased calving percentage following supplementation with phosphorus, which had previously been diagnosed as deficient. However, little information is available in literature on mineral content of PRFs particularly the local species (Kaitho, 1997). Table 2.9 presents the content of the most commonly limiting mineral elements (g kg^{-1}DM) of some selected PRFs.

Table 2.9 Concentration ($g\ kg^{-1}DM$) of the most commonly limiting mineral elements of some selected PRFs.

Species	S	P	K	Ca	Ca:P	Reference
Acacia aneura	1.2	1.3				Ahn *et al*., (1989)
Acacia angustissima	1.4	1.3				Ahn *et al*., (1989)
Albizia chinensis	1.8	2.0				Ahn *et al*. (1989)
	1.8	1.9				Robertson, (1988)
Albizia lebbeck	2.0	1.6				Ahn *et al*., (1989)
		2.0		18.0	9.0	Brewbaker, (1986)
Cajanus cajan		2.4		8.9	3.7	Gohl, (1981)
Calliandra calothyrsus	1.9	1.5				Ahn *et al*., (1989)
	2.0	1.4				Robertson, (1988)
Chamaecytisus palmensis		1.4	5.3	4.5	3.2	Borens & Poppi, (1990)
		1.7	7.2	4.8	2.8	Borens & Poppi, (1990)
	1.5	1.2	5.9	10.5	8.8	Bonsi, (1995)
Codanocalyx gyroides	1.2	1.4				Ahn *et al*., (1989)
Enterolobium cyclocarpum	2.7	1.7				Ahn *et al*., (1989)
		1.4		6.7	4.8	Gohl, (1981)
Leucaena leucocephala	2.2	1.6				Ahn *et al*., (1989)
	2.6	1.9				Robertson, (1988)
		1.6	13.0	23.0	14.4	Brewbaker, (1986)
		2.9		5.4	1.9	Gohl, (1981)
	2.3	1.8	11.4	20.0	11.1	Bonsi, (1995)
Medicago sativa		4.0		7.6	1.9	Kariuki, (1998)
		3.8		7.5	2.0	Kariuki, (1998)
Samanea saman	2.8	1.5				Ahn *et al*., (1989)
		2.1		14.2	6.8	Gohl, (1981)
Sesbania grandiflora		3.3		23.3	7.1	Brewbaker, (1986)
		4.7		13.2	2.8	Gohl, (1981)
Sesbania sesban	2.7	2.4				Ahn *et al*., (1989)
	2.1	2.7	14.6	17.4	6.4	Bonsi, (1995)
		4.3	27.8			Gohl, (1981)
Vemonia amygdalina	2.2	0.7	21.1	11.7	16.7	Bonsi, (1995)

S, Sulphur; P, Phosphorus; K, Potassium; Ca, Calcium

2.4.2.2 *Toxins and anti-nutritive factors*

Anti-nutritive factors (ANFs) have been defined as chemical features of plants, which result in lower levels of animal productivity than would be expected from proximate and mineral analysis of the forage (Kumar, 1992). They may also reduce digestibility of OM and protein thus adversely affecting growth and milk production (Jones *et al*., 1989; Seresinhe and Iben, 2003). ANFs include polyphenolic compounds such as tannins (Gupta and Haslam, 1989; Woodward and Reed, 1989; Schofield *et al*., 2001), alkaloids, saponins, toxic amino acids such as mimosine and various other toxic agents (Tanner *et al.*, 1990; Kumar, 1992). Table 2.10 shows the ANFs in the leaves of common PRFs

Table 2.10 Anti-nutritional factors in the leaves of common PRFs

Anti-nutritional substances	Species
1 Non-protein Amino acids	
Mimosine	*Leuceanae leucocephala*
Indospecine	*Indigofera spicta*
2 Glycosides	
Cyanogens	*Acacia giraffae*
	A cunninghamii
	A sieberiana
	Bambusa bambos
	Bartena fistulosa
	Manihot esculenta
Saponins	*Albizia stipulata*
	Bassia latifolia
	Sesbania sesban
3. Phytohemagglutinins	
Ricin	*Bauhinia purpurea*
	Ricinus communis
Robin	*Robinia pseudoacacia*
4 Polyphenolic compounds	
Tannins	*Acacia aneura*
	A. cyanophylla
	A nilotica
	A salicina
	A siebenana
	Albizia chinensis
	Calliandra calothyrsus
	C portoncensis
	Chamaecystisus palmensis
	Gliricidia sepium
	Leucaena leucocephala
	Sesbania grandiflora
	S sesban
5. Alkaloids	
N-methyl-B-phenethylamine	*Acacia berlandieri*
Sesbanine	*Sesbania vesicana*
	S drummondii
	S punicea
6 Triterpenes	
Azadirachtin	Azadirachta indica
Limonin	*Azadirachta indica*
7 Oxalate	Acacia aneura

Source Dicko & Sikena, 1992 FAO Animal Production and Health paper, No 102

Many of the tropical PRFs contain high levels of secondary plant metabolites (ANFs) (Kumar and Vaithiyanathan, 1990; Reed *et al.*, 1990; Khazaal *et al.*, 1994; Mueller-Harvey, 2001; Schofield *et al.*, 2001). Tannins are the most common secondary compounds in tropical PRFs, which when present in sufficient amounts decrease palatability (Norton, 1994b) and feed intake by ruminants (Woodward and Reed, 1989). Thus in some PRFs the utility as animal feed of leaves, pods and potentially edible twigs is limited by the presence of ANFs (Norton, 1994b).

Being an ANF is not an intrinsic characteristic of a compound but depends upon the digestive process of the ingesting animal and the adaptation of the animal to the substance (Barry and Blaney, 1987). Thus effects of ANFs vary with animal species and in general non-ruminants are more susceptible to toxicity than ruminants, for example trypsin inhibitors, are important ANFs for non-ruminants but do not exert adverse effects in ruminants because they are degraded in the rumen (Kumar, 1992). Additionally, effect of toxins on animals may depend on the type of pre-feeding treatment applied (wilting, drying, grinding, chemical treatment), age of the plant foliage, site of the harvest or location and the plant part fed (leaves, stems or pods) (Ash, 1990; D'Mello, 1992). ANFs, which have been implicated in limiting the utilization of PRFs, include glycosides, phytohemagglutinins, polyphenolics, alkaloids, triterpenes, oxalic acid (oxalate) and non-protein amino acids such as mimosine (Table 2.10).

There are various methods applied to alleviate the negative effects of ANFs on animals; these include feeding PRFs as supplements rather than as sole feed, thus reducing the amount consumed (Smith, 1992). Another approach used with high tannin feeds is inclusion of tannin binders such as polyvinyl polypyrrolidone, polyvinyl pyrrolidone and polyethylene glycol (PEG) with such feeds (Makkar *et al.*, 1995; Hove and Mpovu, 1996 Getachew *et al.*, 2000; Jones and Palmer, 2000; Baba *et al.*, 2002). These chemicals have tannin-complexing properties preferentially binding to plant tannins thereby freeing plant proteins for digestion Use of tannin-binders has been shown to improve intake, digestion and performance in ruminants (Pritchard *et al.*, 1988; Bhatta *et a*l., 2002; Villalba and Provenza, 2002).

Another approach to alleviate effects of ANFs is inoculation with rumen bacteria and fungi or bacteria capable of degrading these compounds (Allison *et al.*, 1990; Lee *et al.*, 2000). For example, Jones and Lowry, (1984) reported that Australian goats lacked the rumen micro-organisms capable of degrading 3,4-dihydroxypyridine (DHP) the rumen by-product of the toxic mimosine, but when inoculated with the relevant micro-organisms isolated from the rumen of Hawaiian goats (Jones and Megarrity. 1986), the toxicity of Leucaena was eliminated. This approach could be used to alleviate toxic effects from other potentially useful shrub genera such as *Indigofera* and *Crotalaria*. Rumen microbes can also be genetically manipulated to impart capacity to metabolize ANFs (Russell and Wilson, 1988). Additionally, continued exposure to particular compounds has been reported to cause adaptation of rumen microbes to degrading such compounds. For example, when Ethiopian sheep were adapted to ingestion of *Acacia anguistissima* leaves, it was found that the rumen microorganisms were capable of degrading 4-N acetyl-2, 4-diaminobutyric acid (ADAB) a compound found in the leaves (Robertson *et al*., 2004). Fortunately, with the cut-and-carry system the animal raiser has a great deal of control over the quantity of potentially toxic materials that are fed to the animal and therefore reducing the impact of ANFs on animal performance (Jones and Lowry, 1984). Under free-range conditions, animals consume a wide range of plant species, thus the proportion consumed of each plant is low and any deleterious effects would be minimized by neutralization with nutrients/chemicals from other plants. Additionally, animals have instinct and with time learn to avoid dangerous species within the available flora (Murley, 1981).

2.4.2.3 Digestibility

Dry matter digestibility (DMD) of a feed is related to its chemical composition and has been shown to be closely related to the proportion and extent of lignification of plant cell walls (NDF) (McDonald *et al*., 1995; Van Soest, 1994). PRFs with a low NDF content (20 - 35%) are usually of high digestibility and species with high lignin content are often of low digestibility (McDonald *et al*., 1995; Van Soest, 1994). The chemical composition of forages is in turn affected by climate and its seasonal variability, soil conditions, species and stage of growth among other factors

Climate and seasonal variations greatly affect forage chemical composition hence digestibility (Semenye, 1987). In many parts of the tropics, inadequate rainfall results to moisture stress in plants (Wilson, 1983). This hampers nutrient absorption and due to the high temperatures in the tropics, rapid physiological maturation is induced leading to rapid lignification (Minson, 1990). Lignin content, which increases with physiological maturity of plants, is known to be negatively correlated with digestibility (Van Soest, 1994). Additionally, soil type has some influence upon the life of forage for example sandy soils would dry faster than cotton soils after the rains thus less soil moisture available to the plant (Palmer *et al*., 1994). Consequently, due to the interaction of climate and soil characteristics, wide seasonal differences in forage quality and digestibility have been reported (Semenye, 1987). During the dry season, range grasses have a low crude protein and a high fibre content (NDF and ADF) and lignin, all of which are associated with low digestibility (Ivory, 1990; Van Soest, 1994).

Plant species differ in their ability to take up nutrients from the soil and transfer them into their aerial portions, (Semenye, 1987). Due to this, chemical composition, hence digestibility of different forage species has been reported to differ. For example crude protein content of different grass species growing on the same soil differ (Minson, 1990; Van Soest, 1994).

Stage of forage growth is another important determinant of digestibility (Palmer and Ibrahim, 1996). In the early stages of growth, the forage has a high proportion of leaves, has a low content of structural carbohydrates and is less lignified and thus of high digestibility (Mannetje, 1983). As growth continues stems develop progressively in an inverse relationship with the proportion of leaves, there is an increase in structural carbohydrates, which become increasingly lignified hence reduced digestibility (Mannetje, 1983; Palmer and Ibrahim, 1996). The leaf to stem ratio is of importance because livestock select for leaves (Semenye, 1987). Leaf nutrients are less lignified and are therefore more digestible than those in the stem (Mannetje, 1983; Van Soest, 1994). Thus, in general forage quality and hence digestibility, decrease with age of the forage (Semenye, 1987). Dicko and Sikena, (1992) observed that more frequent cutting reduced crude fibre content while crude protein content and *In-vitro* dry matter digestibility (IVDMD) increased.

2.5.0 *Nutritive value of Calliandra calothyrsus and Lucerne (Medicago sativa)*

2.5.1 *Origin and agronomic characteristics of Calliandra calothyrsus*

Calliandra calothyrsus is a legume native to sub-humid Central America from Southern Mexico to North-western Panama approximately between 8 - 16°N (Kaitho, 1992; ICRAF, 1994). It belongs to the family leguminosae and subfamily caesalpinioideae. It is a shrub or a tree 4 - 12 m high, with a trunk diameter of up to 30 cm, a blackish-brown bark and a dense canopy (Kaitho, 1992). The genus *Calliandra* has about 100 species some of which are cultivated as ornamentals, flowers are insect pollinated and seeds mature 2 months after pollination. There are 3 - 15 seeds per pond and about 14 - 19 seeds per gram (Westphal and Jansen, 1989). Annual forage biomass yields have been reported to be in the range of 12.4 - 26.2 t DM/ha/yr (Palmer and Ibrahim, 1996, Paterson *et al.*, 1996).

Calliandra was introduced in Kenya in the early 1980's through projects with fuel-wood development oriented objectives (ICRAF, 1992). Use of the species as a fuel-wood crop and for fodder has contributed to its popularity with Kenyan farmers. Under favourable conditions it attains a height of 6 m in less than a year after establishment. A multiple branching habit coupled by rapid growth after coppicing makes the species a reliable source of fuel and forage (ICRAF, 1992). It grows in a wide range of altitudes 400 - 1800 metres above sea level (m a.s.l) in areas with an average annual precipitation from 700 - 3000 mm and with 1 - 7 dry months per year (Lowry and Macklin, 1989). *Calliandra* appears to have some tolerance to cool climate as it is planted in Kenya at altitudes up to 2400 m a.s.l (Kaitho, 1992). Additionally, it does well in a large variety of soil types ranging from deep volcanic, sandy loams to alluvial soils and shallow or eroded metamorphic sandy clays. It is well adapted to acidic soils of low fertility (Palmer and Ibrahim, 1996; Paterson *et al.*, 1996) and is resistant to most common pests and diseases (Paterson *et al.*, 1996). It has been widely promoted for use in tropical and subtropical environments because of its capacity to produce large quantities of highly nutritious and highly palatable forage (Palmer and Ibrahim, 1996).

In the Kenyan highlands where most of the country's small-scale dairying is found, altitude as well as soil acidity limit growth of common fodder trees such as *Leucaena*, *Gliricidia* and *Sesbania* species. However, *Calliandra* has been introduced successfully and is doing well under these conditions. The high biomass production potential and high protein content (200 - 300 g kg^{-1}DM)

(Paterson *et al.*, 1996) make it a promising fodder to supplement low quality roughages (Kaitho *et al.*, 1993). In Kenya *Calliandra* flowers and fruits throughout the year but most seeds are produced in the dry season. Use of inorganic fertilizer and/or manure, particularly on infertile soils is reported to improve the early growth and yield of *Calliandra* (Kaitho, 1992).

Other uses of *Calliandra* include reforestation, soil stabilization and improvement and minor secondary production (paper, honey) (Palmer and Ibrahim, 1996). *Calliandra* has been used to rehabilitate erosion prone areas such as recently cleared forests and steep slopes with high erosion risks (Kan and Hu, 1987). It is well suited to this role because of its early rapid growth and its ability to fix atmospheric nitrogen. The combination of a deep and well-developed lateral rooting habit provides a structure to stabilize the soil (Kan and Hu, 1987). *Calliandra* has been used as a green manure to improve the fertility status of soil in rotation with sugar cane and in alley cropping with corn (Gichuru and Kang, 1989).

Leaf harvesting of *Calliandra* for fodder can normally start after the first year depending on altitude, moisture and daily temperature. Forage is usually cut by hand; only the leaves and young stems of *Calliandra* are used as fodder (Ella *et al.*, 1989). Its potential as a source of high quality leaf protein to supplement low quality forages and crop residues is receiving increasing attention. For this purpose it has been planted in fences, rows or in small blocks to provide fodder, usually under a cut-and-carry regime (NAS, 1983).

2.5.2 Origin and agronomic characteristics of Lucerne (Medicago sativa)

Lucerne (*Medicago sativa*) is a legume of South-west Asian origin (Boonman, 1993). *Medicago sativa* complex comprises of two interfertile species *M. sativa* (purple-flowered) and *M. falcata* (yellow-flowered) and was domesticated for feeding animals. Lucerne is the most common and valued forage legume in the world grown for hay, pasture and silage for livestock feed (Boonman, 1993).

Lucerne is an erect perennial with trifoliate leaves and an extremely deep root system, allowing it to be grown with as little as 550 mm of annual rainfall (Basbag *et al.*, 2004; Maureira *et al.*, 2004). It is very responsive to phosphorus and sulphur and may grow under slightly acidic conditions if top-dressed with lime. Old stands cut for hay can respond to potash (Paolo, 2006). It is quite widely used as a pasture plant in sub-coastal and inland sub-tropical areas. It combines with many grass species to provide protein-rich grazing. Stands for hay should be cut when the new shoots are less than 2 cm in length. Lucerne can be used in ley farming systems to improve the protein status and yield of succeeding crops (Boonman, 1993).

Lucerne is sown into well-prepared, fine firm seedbeds, using inoculated seed. Seed rates are 0.5 - 2 kg when sown with grasses; in pure stands, seed rates should be up to 8 kg/ha in rain-grown conditions and 12 - 15 kg/ha under irrigation. Lucerne grows best in warm, temperate climates and also in the subtropics, it requires fertile well-drained soils and is intolerant to water logging (Paolo, 2006). Frequent defoliation can hinder the replenishment of sufficient carbohydrates in the storage organs and thereby, negatively affect herbage yields and stand survival (Fornasier *et al.*, 2003). Its importance is increasing with the rise in public interest in sustainable agriculture because it is a low input energy efficient crop that helps to improve soil tilth. Furthermore it occupies a significant economic position in the animal feed markets of the world (as hay, dehydrated forage, pellets and silage products (Torricelli *et al.*, 2000).

In Kenya, Lucerne is grown under zero-grazing production systems in Central Kenya region as a protein source to supplement Napier grass (MALD, 1994). During the dry season when there is little plant growth at the farms, Lucerne is purchased from commercial stores (Boonman, 1993). It is used as a high quality feed and is normally harvested and transported to dairy cattle in a cut-and-carry system or it is dried and fed as hay or ensiled (Douglas, 1986). An estimated annual yield of 0.9 - 1.4 t DM/ha/yr has been reported in Kenya (Odongo *et al.*, 1999; Wanyama *et al.*, 2000).

2.5.3 *Palatability of Calliandra calothyrsus and Medicago sativa and animal performance*

There are varying reports on the acceptability of *Calliandra* to domestic animals. However, it appears to be generally accepted by animals (NAS, 1983, Palmer and Ibrahim, 1996). Palmer and Schlink, (1992) reported a voluntary feed intake of 59 g dry weight/$kgW^{0.75}$ in sheep which suggests good palatability of freshly, harvested or grazed material. Under cut-and-carry management systems, *Calliandra* should be fed with minimum delay after harvesting to maximize voluntary intake and when fed as a supplement contributing 30 - 40% of total diet, no problem with acceptability was observed (Palmer and Ibrahim, 1996). In Embu, Kenya, dairy heifers on a basal diet of Napier grass supplemented with fresh *Calliandra* at a rate of 25% of the daily DM intake, gained weight at an average rate of 0.46 kg per day. Similarly, in the same area supplementation of dairy cows with *Calliandra* increased both milk yield and butter fat content (Paterson *et al.*, 1996). Similar results with *Calliandra* as a supplement for dairy cattle were reported in Maseno Kenya (Veen van der, 1993; Veen van der and Swinkels, 1993).

In Zambia, acceptance of *Calliandra* by local goats was superior to that of *Sesbania sesban* and *Gliricidia sepium* (Phiri *et al.*, 1994). In Zimbabwe, both sheep and goats consumed in excess of 0.4 kg DM day^{-1} when *Calliandra* was offered as the sole diet, which was again superior to the intake of *Cajanus cajan* hay and a number of *Acacia* species. A further experiment showed that local goats kept during the dry season on poor quality, unimproved pasture hay supplemented with 0.14 kg day^{-1} of *Calliandra* DM gained weight at a rate of 24 g day^{-1} Contemporaries on the hay alone lost 20 g day^{-1} (Dzowela *et al.*, 1994). Supplementation of Napier grass with *Calliandra* improved nutrients intake and weight gain in heifers (Kariuki, 1998). Palmer and Schlink, (1992) reported increase in wool production from 35 mg^{-1}100cm^{-2}day^{-1} in sheep on a basal diet of grass hay to 53, 76 and 106 mg^{-1}100cm^{-2}day^{-1} when the level of fresh *Calliandra* in the diet was increased to contribute 16, 28 and 35% (on DM basis) respectively.

Lucerne is well established as a forage crop, which is highly palatable to ruminants. Muhikambele *et al*, (1996) reported improved growth rate and digestibility when growing goats were supplemented with Lucerne. When fed to heifers as the sole diet, a daily weight gain of 670 g day^{-1} was recorded compared to 500 g day^{-1} for those on Napier grass and Sweet potato vines respectively (Kariuki, 1998). The CP, DM and OM intake, potential and effective degradability were also higher for Lucerne. Similarly, when Napier grass was supplemented with Lucerne, nutrients intake in heifers increased, while ADG increased from 410 to 520 g day^{-1} (Kariuki, 1998).

2.5.4 *Chemical composition of Calliandra calothyrsus and Medicago sativa*

Calliandra has a good nutrient profile, high CP content and low fibre (NDF, ADF) contents. Paterson *et al*., (1996) gave a CP range of 200 - 300 g kg^{-1}DM. Other values of CP content reported for *Calliandra*, are 119 g kg^{-1}DM (Hove *et al*., 2001); 180 g kg^{-1}DM (Seresinhe and Iben, 2003) and 200 g kg^{-1}DM (Ahn *et al*., 1989; McSweeney *et al*., 2001). Thijssen *et al*., (1993a, 1993b) reported a higher CP level of 310 g kg^{-1}DM. Differences in chemical composition of forages in various studies are expected due to variations in climatic conditions, soil types and age at cutting. For example, Kaitho *et al*., (1993), recorded decreased CP content of *Calliandra* forage from 282 to 235 g kg^{-1}DM with increase in cutting interval from 12 to 48 weeks and suggested that this could have been due to increase in fibre content (NDF and ADF) and lignification with age. The fibre components increased from 455 to 495 g kg^{-1}DM for NDF and from 220 to 309 g kg^{-1}DM for ADF for the same cutting intervals. *Calliandra* is also rich in minerals. Kaitho, (1992) observed that *Calliandra* leaves contained sufficient levels of phosphorus, potassium, sulphur, calcium and magnesium to meet the requirements of ruminants. Lucerne has a high CP content with values reported from different regions in the range of 164.5 - 190.1 g kg^{-1}DM (Basbag *et al*., 2004) and 199.9 - 217.0 g kg^{-1}DM (Torricelli *et al*., 2000). The CP levels reported in Kenya were in the range of 160 - 210 g kg^{-1}DM (Kariuki, 1998; Odongo *et al*., 1999). Chemical composition (g kg^{-1}DM) of *Calliandra* and Lucerne (*Medicago sativa*) as reported by various authors is shown in Table 2.11, while mineral content (g kg^{-1}DM) is shown in Table 2.12.

Table 2.11 Chemical composition (g kg^{-1}DM) of *Calliandra calothyrsus* and *Medicago sativa*

Species	CP	NDF	ADF	ADL	Ash	EE	Reference
Calliandra calothyrsus	282	455	220	90	54	13	Kaitho *et al*., (1993)
	258	475	297	133	54	14	Kaitho *et al*., (1993)
	235	495	309	140	62	20	Kaitho *et al*., (1993)
	212	259	209	69	43		Robertson, (1988)
	224	530	480	120	121		Kariuki, (1998)
	212	495	297	133	78		Kariuki, (1998)
	173	302	229	84	40		Ahn, (1990)
	225	505	446	190			Kaitho, (1997)
	220				45	25	Ahn *et al*., (1989)
Medicago sativa	206	426	296	72	89		Kariuki, (1998)
	167	408	347	64	156		Kariuki, (1998)
	190	455	447	66	153		Kariuki, (1998)

CP, Crude protein; NDF, Neutral detergent fibre; ADF, Acid detergent fibre, ADL, Acid detergent lignin; EE, Ether extract.

Table 2.12 Mineral concentration (g kg^{-1}DM) of *Calliandra calothyrsus* and *Medicago sativa*

Species	P	K	S	Na	Ca	Mg	Ca:P	Reference
Calliandra calothyrsus	1.9	10.1	3.4	0.2	9.6	2.9	5.1	Panjaitan, (1988)
	1.9	8.5	3.2	0.2	11.5	3.4	6.1	Panjaitan, (1988)
	1.6	10.5	3.2	0.5	8.3	2.2	5.2	Panjaitan, (1988)
	1.7	10.4	3.5	0.6	8.0	2.3	4.7	Panjaitan, (1988)
	1.9	12.2	3.1	0.3	8.1	2.3	4.3	Panjaitan, (1988)
	1.4	10.6	2.6	0.3	5.9	1.9	4.2	Panjaitan, (1988)
	1.5		1.9					Ahn *et al.*, (1989)
	1.4		2.0					Robertson, (1988)
Medicago sativa	4.0				7.6		1.9	Kariuki, (1998)
	3.8				7.5		2.0	Kariuki, (1998)

P, Phosphorus; K, Potassium; S, Sulphur; Na, Sodium; Ca, Calcium; Mg, Magnesium

2.5.5 *Digestibility of Calliandra calothyrsus and Medicago sativa*

In feeding trials conducted with both sheep and goats on fresh material, the *in-vivo* estimates of DM digestibility of *Calliandra* were in the order of 60% (Ahn *et al.*, 1989). Young *Calliandra* leaves have been reported to be highly digestible (Palmer and Schlink, 1992). However, digestibility, decreased with increase in cutting interval. Kaitho *et al.*, (1993), observed that while the *in-sacco* DM, OM and CP undegradable residues and by-pass protein, increased with increase in cutting age from 12 to 48 weeks, water soluble fraction, rate of degradation, RDP and IDP decreased. They suggested that these changes were due to increased lignification with age. Similar findings were reported by Mahyuddin *et al.*, (1988) and Ahn *et al.*, (1989).

Palmer and Schlink, (1992) recorded *in-sacco* DM degradability of *Calliandra* at 57 and 75% after 48 and 96 hours incubation respectively. Perez-Maldonado, (1994) reported *in-vivo* OM digestibility of dried *Calliandra* to be 52.4% in a feeding trial with sheep, while Palmer and Schlink, (1992) reported *in-vivo* OM digestibility of 60% for both fresh and wilted *Calliandra* in sheep. Inclusion of *Calliandra* in a wheat straw diet fed to sheep, increased DMI and OMI and DM and OM digestibility (Palmer and Schlink, (1992). From these findings it can be argued that *Calliandra* is more digestible compared to forages that would normally be available during the dry season and its inclusion in a low quality diet improved digestibility. Tables 2.13 and 2.14 show some reported DM and CP degradation characteristics and Table 2.15 some reported values of *in-vitro* and *in-vivo* digestibility and *in-sacco* degradability estimates of *Calliandra* and *Medicago sativa*

Table 2.13 Some reported DM degradation characteristics of *Calliandra calothyrsus* and *Medicago sativa*

Species	W	D	k_d	U	Reference
Calliandra calothyrsus	322		1.36	126	Perez-Maldonado, (1994)
	287		1.32	223	Kaitho *et al.*, (1993)
	281		1.01	293	Palmer and schlink, (1992)
	223	485	3.3	292	Robertson, (1988)
	287		1.4	223	Palmer and Ibrahim, (1996)
Medicago sativa	263	611	4.2	126	Boonman, (1993)
	215	483	3.0		Douglas, (1986)

W=water soluble fraction (gkg^{-1}DM*); D=slowly but potentially degradable fraction (gkg^{-1}DM*); k_d=rate of degradation (%h^{-1}); U=truly undegradable residue (gkg^{-1}DM*) (336 hour incubation); gkg^{-1}DM*=gkg^{-1} of original forage DM

Table 2.14 Some reported CP degradation characteristics of *Calliandra calothyrsus* and *Medicago sativa*

Species	CP	W	k_d	U	D	BP	RDP	IDP	Reference
Calliandra calothyrsus	224	265	3.9	291	444	516	484	219	Perez-Maldonado, (1994)
	225	221	3.0	280	499	745	255	465	Kaitho, (1997)
	282	221	1.93	98					Kaitho *et al.*, (1993)
	255	183	2.78	167					Robertson, (1988)
	231	193	2.45	271					Palmer and Ibrahim, (1996)
Medicago sativa	206	275	3.1	232	493	395	605	330	Douglas, (1986)

W=water soluble fraction (gkg^{-1}CP*); D=slowly but potentially degradable fraction (gkg^{-1}CP*); k_d=rate of degradation (%h^{-1}); U=truly undegradable residue (gkg^{-1}CP*) (336 hour incubation); BP=By-pass protein (gkg^{-1}CP*); RDP=Rumen degradable protein (gkg^{-1}CP*); IDP=Intestine degradable protein (gkg^{-1}CP*); gkg^{-1}CP*=gkg^{-1} of original forage CP

Table 2.15 Some reported values of *in-vitro* and *in-vivo* digestibility and *in-sacco* degradability estimates of *Calliandra* and *Medicago sativa*

Species	Degradability %		Digestibility (%)				
	In-sacco (48 hrs)		*In-vitro*		*In-vivo*	Animal	
	DM	N	OM	DM	OM	species	Reference
Calliandra calothyrsus	57.3	44.8					Dzowela *et al*., (1995)
			38.0				Kaitho *et al*., (1993)
			31.9				Kaitho *et al*., (1993)
			30.9				Kaitho *et al*., (1993)
				48.0			Topark-Ngarm & Gutteridge, (1986)
				35.0			Baggio and Heuveldop, (1984)
	52.7	35.9				goats	Ahn *et al*., (1989)
	59.0					cattle	Palmer and Schlink, (1992)
					60.0	sheep	Palmer and Schlink, (1992)
	57						Palmer and Schlink, (1992)
					52.4	sheep	Perez-Maldonado, (1994)
Medicago sativa					54.3	sheep	Kariuki, (1998)

2.5.6 *Effect of Calliandra and Lucerne supplementation on intake, digestibility and performance*

Supplementation with legumes has been reported to provide ruminally fermentable N, hence increased rumen NH_3-N concentration which promotes higher microbial activity with a resultant improvement in digestibility and feed intake, thus increased efficiency of utilization of the basal diet, which is reflected as improved animal performance (McDonald *et al*., 1995). In a study with growing goats, Ebong, (1996) observed increased DMI and OMI and increased DM and OM digestibility and growth rate when Elephant grass was supplemented with *Calliandra* leaf meal. DMI increased from 468.2 for the control (Elephant grass only diet) to 667.6 g day^{-1} for the supplemented goats, while DM and OM digestibility increased from 68.7 to 75.9% and 71.1 to 79.0% respectively. ADG improved from 27.1 (control) to 67.0 g day^{-1} (supplemented). Palmer and Schlink, (1992) reported increased DM intake in sheep from 38 g $DM^{-1}kgW^{0.75}$ for the control on grass hay only diet to 46, 48 and 54 g $DM^{-1}kgW^{0.75}$ when the hay was supplemented with *Calliandra* at 16, 28 and 35% of the total diet on DM basis respectively. Similarly, OM digestibility increased from 48 to 58, 62 and 63% for the same levels of supplementation while N digestibility increased from 41 to 51, 55 and 62% respectively. Live weight gain g day^{-1} increased from a daily loss of 27 g day^{-1} for the unsupplemented to a gain of 2, 39 and 52 g day^{-1} for the respective supplementation levels.

When dairy heifers on a basal diet of Napier grass were supplemented with 25% of daily DM intake with *Desmodium*, *Calliandra* and *Sesbania*, it was observed that those on *Calliandra* had higher DMI of 2.86 kg per 100 kg live weight compared to those on *Desmodium* (2.77) and *Sesbania* (2.62). *Calliandra* supplementation also gave higher ADG of 270 g day^{-1} compared to 235 and 224 g day^{-1} for *Desmodium* and *Sesbania* respectively (Kariuki, 1998). Reed *et al.*, (1990) reported similar findings. Roothaert *et al.*, (1997) and Roothaert, (1999) also showed that supplementation of dairy cows with *Calliandra* improved daily milk yield. When Lucerne supplemented a basal diet of Napier grass, DMI kg day^{-1} in heifers increased from 4.8 (control) to 5.7, 6.9 and 7.3 kg day^{-1} with Lucerne levels at 0 (control), 1.5, 2.5 and 3.5 kg day^{-1} respectively. The ADG increased from 0.32 kg day^{-1} for the control to 0.47, 0.63 and 0.65 kg day^{-1} respectively (Kariuki, 1998). Findings from these studies indicated that when *Calliandra* and Lucerne were supplemented to grass based diets efficiency of utilization of the basal diet improved. These responses have been attributed to the legume overcoming the depressing effects of low N concentration in grass on intake and by the legume providing rumen degradable N (Van Eys *et al.*, 1986) and rumen undegradable N (Flores *et al.*, 1979).

2.6 Conclusions

The economic importance of the goat and the potential of PRFs as supplementary feeds were reviewed. The goat is an economically important animal to many smallholder farmers in the tropics providing high quality food in form of milk and meat and cash to meet financial obligations and is a source of security during droughts and famine. However, nutritional management of the goat is still low in most tropical regions, hence its full economic potential has not been realized. This can be realized through improved nutritional management, which could be achieved through supplementation with PRFs. PRFs have the advantage of being inexpensive to establish, manage and feed and also have superior nutritional value compared to most tropical grasses especially during the dry season.

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CHAPTER 3

Effect of supplementing dual-purpose goats with graded levels of Calliandra calothyrsus and Lucerne (Medicago sativa) on nutrients intake, lactation performance, daily live-weight change and pre-weaning kid performance under two management systems

Effect of supplementing dual-purpose goats with graded levels of Calliandra calothyrsus and Lucerne (Medicago sativa) on nutrients intake, lactation performance, daily live-weight change and pre-weaning kid performance under two management systems

3.1 Abstract

A study was conducted to investigate the effects of supplementing Kenya dual-purpose goats (KDPGs) with two (2) protein-rich forages (PRFs), *Calliandra calothyrsus* and Lucerne (*Medicago sativa*) on nutrients intake, milk yield (MY), lactation length (LL), birth weight (BWT), pre-weaning average daily gain (pre-ADG) and weaning weight (WWT) under two management systems [confined feeding (CF) and free-range (FR)]. Fifty-five (55) pregnant DPGs (25 for FR and 30 for CF) were selected at random from a flock of 200 does. They were randomly allocated to 5 treatment diets 4 weeks prior to kidding. Composition of the diets was:- T1, (control) - Rhodes grass hay or grazing only for CF or FR respectively; T2 and T3, 250 and 500 gd^{-1} of *C.calothyrsus* respectively; T4 and T5, 250 and 500 gd^{-1} of Lucerne respectively. The overall mean daily MY (gd^{-1}), lactational MY (kg), LL (days), BWT (kg), Pre-ADG (gm) and WWT (kg) were 514, 123, 220, 2.8, 73.5 and 10.9 respectively. Average daily MY, for FR (587) was significantly ($P<0.05$) higher than CF (441). Under both systems, supplementation increased daily MY, for CF (T1, 260; Lucerne 446; *Calliandra* 527) and FR (T1 355; Lucerne 601; *Calliandra* 691). Increased level of supplementation significantly ($P<0.05$) increased MY, for CF from 414 (T2) to 640 (T3) for *Calliandra* and 370 (T4) to 521 (T5) for Lucerne; and for FR from 568 (T2) to 813 (T3) for *Calliandra* and 508 (T4) to 693 (T5) for Lucerne. Kids born under FR had significantly ($P<0.05$) higher average BWT (3.0) compared to CF (2.6). Supplementation increased BWT in both CF (T1 1.9; Lucerne 2.6; *Calliandra* 2.9) and FR (T1 2.1; Lucerne 3.0; *Calliandra* 3.4) Increase in level of supplementation increased BWT, for CF from 2.5 (T2) to 3.3 (T3) for *Calliandra* and from 2.2 (T4) to 2.9 (T5) for Lucerne; and for FR from 3.0 (T2) to 3.8 (T3) for *Calliandra* and from 2.7 (T4) to 3.3 (T5) for Lucerne. Kids with higher BWT also had higher pre-ADG, 47.8, 64.3, 91.5, 53.8 and 72.9 gd^{-1} for T1 to T5 respectively, for CF, and 57.4, 78.3, 112.4, 66.3 and 90.7 gd^{-1} for FR. Kids born of the supplemented does also had higher WWT than the control 7.8, 9.5, 13.3, 8.4 and 10.7 for T1 to T5 respectively for CF and 9.0, 11.7, 14.7, 10.4 and 13.5 for FR. Supplementation significantly ($P<0.05$) increased OMI (gd^{-1}), under CF from 557.9 (T1) to 821.7, 1102.4, 766.9 and 1025.3 for T2 to T5 respectively. At both levels of supplementation, under both management systems, animals on *Calliandra* performed significantly ($P<0.05$) better than those on Lucerne based diets in nutrients intake, MY, BWT, pre-ADG and WWT. These results indicated that supplementation with PRFs improved animal performance and that FR was superior to Rhodes grass hay offered under the CF system and *Calliandra* superior to Lucerne.

Key words: *dual-purpose goats; supplementation; protein-rich forages; milk yield; birth weight; average daily gain; weaning weight*

3.2 *Introduction*

The goat has a high reproductive potential (Payne, 1990). Unfortunately, goat production in the tropics is characterized by low productivity resulting from poor management of pasture lands and seasonal fluctuations in feed resources (Ademosun, 1994). Periodic droughts and extensive dry spells during the dry season, which cause nutritional stress, result in low productivity of the goat (Ademosun, 1994). Additionally, due to little attention accorded to the goat under the traditional village systems in the tropics, its productive performance has remained low over the years (Devendra, 1986; Ademosun, 1994; Okello *et al.*, 1996). Therefore, to improve performance there is need to improve management systems especially nutritional management. There is evidence of improved performance due to supplementation with protein sources (Devendra, 1986). Huston, (1994), found that increased supplementation with crude protein increased growth rate in kids and also increased digestibility and intake in kids, yearlings and adult goats on rangeland.

Within the tropics, supplementation is especially crucial, during the dry season when feed is scarce and of poor quality, leading to poor digestibility and low intake, hence low productivity (Kaitho, 1997). Kimenye and Karimi, (1989) and Mwandotto *et al.*, (1991) observed seasonal effects on goat performance in Kenya, where milk yield was higher during the wet season. They related this to higher forage availability during the wet season. Ogwang and Karua, (1996), working with Swazi goats recorded improved growth rate on supplementation with protein sources and concluded that growth rate of goats under natural grazing could be improved by protein supplementation. Similarly, Solomon *et al.*, (1996) reported improved weight gain in Horro lambs on natural pastures when they were supplemented with a protein source.

Njwe and Kona, (1996) observed increased DMI and CPI, increased DM and CP digestibility and N retention and increased weight gain in sheep when Elephant grass was supplemented with protein sources. Protein supplementation improved intake and performance because the protein supplement increased nitrogen availability to the rumen microbes. This increased their multiplication and growth leading to improved digestibility and intake, hence improved animal performance, (Tchinda *et al.*, 1994). However, conventional protein supplements and cereal based concentrates are expensive and out of reach of many farmers (Mero and Uden, 1990; Njwe and Kona, 1996; Nguyen and Preston, 1997). Use of protein-rich forages (PRFs), as protein supplements has been shown to improve intake and performance (Tchinda *et al.*, 1994; Njwe and Kona, 1996; Kaitho, 1997; Nguyen and Preston, 1997), in addition to being affordable to smallholder farmers.

In Africa, many indigenous PRFs have been used as supplementary feeds over the years with reported positive responses (Thijssen *et al.*, 1993a; Thijssen *et al.*, 1993b). In the recent past many exotic PRFs have been introduced into Africa (ICRAF, 1992). *Calliandra calothyrsus*, a multi-purpose leguminous PRF, was introduced in Kenya in 1980 (ICRAF, 1992) and has been evaluated (Palmer and Ibrahim, 1996) in various studies. It thrives well in a range of environments and has a high foliage yield (12.4 - 26.2 t DM/ha/yr) (Palmer and Ibrahim, 1996). It is tolerant to acidic soils, has shown good adaptation to local climatic conditions (Palmer and Ibrahim 1996; Paterson *et al.*, 1996) and has a high CP content (200 - 300 gkg^{-1}DM) (Paterson *et al.*, 1996). It is a heavy seeder (ICRAF, 1992; Kaitho, 1992), thus easy to propagate (ICRAF, 1992). It has good acceptability and palatability by animals (Palmer and Ibrahim, 1996). Supplementation with *Calliandra* has been shown to improve growth rate in dairy heifers and to increase milk yield in dairy cattle (Paterson *et al.*, 1996; Roothaert *et al.*, 1997; Roothaert, 1999). Increased DMI and improved growth rate in goats supplemented with *Calliandra* has also been reported (Ebong, 1996; Kaitho, 1997). However, it has not been well evaluated as a supplementary feed for lactating goats.

Lucerne is a well-established leguminous fodder in the country and has a high crude protein content (160 - 210 g kg^{-1}DM) (Kariuki, 1998; Odongo *et al.*, 1999). Its annual yield is estimated at 0.9 - 1.4 t DM/ha/yr (Odongo *et al.*, 1999; Wanyama *et al.*, 2000). It is mainly grown in medium and large-scale farms and mostly fed in form of hay as a dairy cattle supplement. It plays a major role as a protein supplement during the dry season when feed is scarce. However, little information is available in Kenya on its use in goat production.

Rhodes grass (*Chloris gayana*) hay is one of the main grasses fed as a basal diet in the country. This is because of its wide availability and affordability to many smallholder farmers. It is a high yielding fodder grass with annual yields estimated at 5 - 15 t DM/ha/yr (Kariuki, 1998; Odongo *et al.*, 1999;

Wanyama *et al.*, 2000). Its use has been on the increase and has been particularly important during the dry season when crop residues such as bean haulms, sweet potato vines, banana residues and garden weeds are scarce. However, when fed alone, its intake is limited by its low DM digestibility (50 - 54%) and energy digestibility (53 - 68%) and low CP content 7 - 8% (Minson, 1990; Odongo *et al.*, 1999). Low dietary protein content has been reported to limit dry matter intake by compromising rumen microbial activity thus digestibility and rumen turnover rate with resultant sub-optimal supply of protein to the animal (Hove and Mpofu, 1996). There is therefore, need to supplement the hay to improve animal performance.

Therefore, the objectives of this study were to compare the potential of *Calliandra calothyrsus* as a legume supplement for the Kenya dual-purpose goat (KDPG) with the more conventional leguminous species Lucerne (*Medicago sativa*) and to determine the effects of feeding graded levels of *Calliandra calothyrsus* and Lucerne as legume supplements to lactating dual-purpose does on milk yield, lactation length and persistency, daily live-weight changes during lactation, milk composition and pre-weaning kid performance under two management systems.

3.3.0 Materials and methods

3.3.1 Experimental site

This study was conducted at the Kenya Agricultural Research Institute (KARI), Naivasha, Kenya, (0.40°S, 36.26°E, 1900 m altitude), located about 120 km Northwest of Nairobi. This is Agro-ecological zone Lower Highland 5 (Lower Highland Ranching zone) with bimodal rainfall. The mean annual rainfall is 620 mm received mainly from March to June and October to December for the long and short rains respectively. The mean annual temperature is 23°C with daily variations between 7 to 26°C, with higher temperatures pertaining during the dry months. The soils are of moderate fertility and slightly to, moderately alkaline (Jaetzold and Schimdt, 1983).

The free-range trial was conducted at the Ol-Magogo field-station, a sub-station of KARI Naivasha. The field-station is situated on the lower Eastern slopes of the Central Rift Valley in Kenya, in a natural thorn bush land savannah. The area lies on 0.37°S, 36.30°E, with an altitude of approximately 1700 m and has a semi-arid climate with strong desiccating winds during the dry season. The rainfall pattern is bimodal with the long rains in March to June and the short rains in October to December. The average annual rainfall stands at about 750 mm. The maximum temperatures are between 20°C and 30°C with the minimum between 12°C and 18°C with little variations between seasons. The soils are of moderate fertility and slightly to, moderately alkaline (Jaetzold and Schimdt, 1983).

3.3.2 Feed sources

3.3.2.1 Calliandra calothyrsus

Calliandra leaves were harvested in previously established experimental plots at Kenya Agricultural Research Institute (KARI) - Muguga farm and the neighbouring Kenya Forestry Research Institute (KEFRI). After harvesting, the branches were cut-off to stumps 1 ft above the ground. This was done to facilitate quick re-growth for the next harvest, which was every four (4) months. After harvesting, the leaves were dried for one (1) week under shade by spreading on plastic sheets on the ground, with frequent turning to prevent rotting. The dry leaves were packed in gunny bags and stored ready for feeding.

3.3.2.2 *Rhodes grass hay and Lucerne hay*

These were purchased from a farm next to KARI Naivasha Station. During the entire feeding trial, they were purchased in 3 large batches to minimize variation. Prior to feeding they were chopped using a motorized Chaff cutter set to cut at 2.5 cm length. The chopping was done to minimize wastage, ease weighing, ensure uniformity and to minimize selection by the animals.

3.3.3 *Forage sampling*

For the free-range flock, the most commonly preferred forage species were sampled. This was done with the aid of an experienced herdsman and by following the animals as they grazed. Twenty (20) most preferred species were sampled twice i.e. during the dry and the wet seasons. They were dried at room temperature for one (1) week then milled in a Wiley mill to pass through a 1 mm screen and stored in labeled airtight sample bottles for subsequent chemical analysis.

3.3.4 *Feed sampling*

From each of the three batches of Rhodes grass hay and Lucerne hay five (5) bales were chopped, mixed thoroughly and a sample of about 500 g taken. The samples were stored in labeled plastic bags. At the end of the experiment they were milled in a Wiley mill to pass through a 1 mm screen and stored in labeled airtight sample bottles for subsequent chemical analysis. *Calliandra* was similarly sampled, milled and stored.

3.3.5 *Experimental diets*

Composition of the 5 experimental treatment diets (T) as fed was as follows:- T1, control; T2 and T3, 250 and 500 g goat^{-1} day^{-1} of *Calliandra calothyrsus* respectively; T4 and T5, 250 and 500 g goat^{-1} day^{-1} of Lucerne (*Medicago sativa*) respectively. T1 was Rhodes grass hay only for the confined feeding, while for the free-range it was grazing only. All the goats under confined feeding were offered Rhodes grass hay *ad libitum* as the basal diet. These levels of supplementation were selected to ensure that supplement intake was within the recommended range of 30 - 40% of the daily DM intake (Van Soest, 1994; McDonald *et al.*, 1995; Palmer and Ibrahim, 1996; Kaitho, 1997).

3.3.6 *Experimental animals, housing, management and feeding*

Fifty-five (55) pregnant dual purpose does (average weight 38.3±6.79 kg) were selected at random from a flock of 200 does for experimental purposes. The goats used in the study, the Kenya dual-purpose goat (KDPG), is a 4-way cross, bred in Kenya with the objective of improving both milk and meat production potential of two indigenous breeds, East African and Galla, through crossing with two temperate breeds, Toggenburg and Anglo-Nubian, with higher milk and meat performance (Mwandotto *et al.*, 1991; 1992).

At the beginning of the trial the animals were sprayed with an acaricide (Triatix^R) to control ecto-parasites and after kidding dewormed with an antihelminthic (Nilzan^R) to control endo-parasites. During the experimental period they were sprayed fortnightly and dewormed after every 3 months. Four (4) weeks before the expected kidding date, the does were blocked according to parity and randomly allocated within blocks to the five treatment diets (6 does per treatment for the confined feeding trial) in a randomized complete block design (Steel and Torrie, 1996). They were housed in individual wooden pens measuring 1x3 m on a wooden slated floor. The Rhodes grass hay, water and mineral block (Maclik^R brick) were provided *ad libitum*. The daily offer of Rhodes grass hay was estimated using the previous day's intake and adding a 10% allowance (Kariuki, 1998). Each morning, the previous day's feed residues (refusals) were removed and weighed before fresh feed and water were offered. For the confined feeding trial, the feed (both hay and supplement) allowance for the day was offered in two meals at 08.00 and 14.00 hours. The hay was offered in troughs and the supplement in plastic buckets. The supplement was always offered first and all of it was consumed.

For the free-range trial (5 does per treatment), the animals were housed in similar facilities and the supplement fed in the same way as for the confined feeding trial. However, after the morning feeding (08.00 - 09.00 hours) and suckling of kids, the does were released for grazing. They were grazed for approximately 8 hours daily in a natural thorn bush land savannah. In the afternoon (16 00 hours) they were brought back to the night enclosure where the kids would suckle and the second portion of the ration offered. As for the confined feeding, the animals consumed the entire supplement on offer. Water and mineral block (Maclik^R brick) were provided within the night enclosure.

Under both management systems, after kidding, the kids remained with their dams for the first 3 days to allow them suckle colostrum *ad libitum*. After colostrum feeding, the kids were separated from their dams and housed in a separate kids' house with an extension shade for feeding and watering. During the day, the kids had access to fresh sweet potato vines, young Napier grass (4 weeks regrowth) and wilted Lucerne *ad libitum* from the age of two weeks to weaning (16 weeks). During this period kids were suckled *ad libitum* twice daily at 08.00 and 14.00 hours for the confined feeding trial; and 08.00 and 16.00 hours for the free-range system. After suckling the kids were taken back to their house.

3.3.7 ***Estimation of dry matter intake (DMI)***

Voluntary hay dry matter intake (for the confined trial) was estimated as the difference between the amount of hay offered and that refused, on daily basis, corrected for DM content. Intake of the supplement was the amount offered corrected for DM content since there were no refusals.

3.3.8 ***Milk sampling***

Milk sampling for the analysis of milk components was done after the eighth (8th), sixteenth (16th) and twenty-fourth (24th) weeks of lactation representing early, mid and late lactation. After morning milking, a 20 ml sample from each doe was collected. All the samples from each treatment diet were pooled into one composite sample and stored for subsequent chemical analysis. To prevent loss of moisture, the samples were stored in glass bottles with rubber stoppers. They were preserved with formalin solution (4% formaldehyde).

3.3.9 ***Data Collection***

Doe live-weight was taken on weekly basis from time of blocking (4 weeks prior to kidding) and throughout the lactation period. Post-partum weights were recorded immediately after kidding. On kidding, birth weight of the kids was taken using a Salter weighing balance to the nearest 50 g. Thereafter growth of the kids was monitored by weighing them once a week. Other parameters recorded at birth were sex of kid, type of birth (single or twins) and parity of dam. After kidding, kids were allowed to suckle colostrum *ad libitum* for the first 3 days. After colostrum feeding, milk yield was estimated weekly. This was done by allowing the kids to suckle and estimating the amount of suckled milk using the 'weigh-suckle-weigh method' (Cisse *et al.*, 1996) which was followed by hand stripping of any residual milk twice a week. The amount of hand stripped milk was measured using a 1 kg top loading balance to the nearest 1 g. Total milk yield for each doe was the sum of the suckled milk and the stripped milk.

Kids were weaned at the age of 4 months (16 weeks) and weaning weight was recorded. However, milk yield continued to be monitored after weaning by hand stripping the udder until drying. A doe was dried when yields fell below 50 g day^{-1} for three consecutive weeks and the drying date recorded. To eliminate the effect of late pregnancy on milk performance, the does were not served during the lactation period (Stemmer *et al.*, 1995).

3.3.10 Chemical analysis

3.3.10.1 *Feed samples*

Dry matter content of the samples was determined by drying approximately 1 g of each sample in an oven at 105°C for 12 hours. Ash content was determined by ashing the DM residue (AOAC, 1990). Organic matter was calculated as the difference between the DM and the ash. Calcium (Ca) and Phosphorus (P) were determined by standard methods (AOAC, 1990), using the '2380 Atomic Absorption Spectrophotometer' and the 'CE 4400 UV Visible Double Beam Scanning Spectrophotometer' for Ca and P determination respectively. Crude protein content of the samples was determined using the macrokjeldahl method according to AOAC, (1990). The NDF, ADF and ADL contents were determined by sequential analysis according to Van Soest, (1994). Hemicellulose and cellulose were determined by difference. Ether extract (EE) was determined by the Soxhlet Extraction method in di-ethyl ether (AOAC, 1990).

3.3.10.2 Milk samples

Milk samples were analyzed for butterfat (BF) content by Gerber method, total solids by Gravimetrical method. Lactose and total protein all according to Jenness and Patton, (1959). Solids-not- fat was determined by difference between BF% and total solids %. Minerals (Calcium and Phosphorus) were analyzed according to AOAC, (1990).

3.3.11 *Statistical analysis*

The average daily weight gain (ADG) (g/d) of the kids was calculated by regressing body weight (kg) of individuals measured at weekly intervals with time (in days). The least-squares and maximum likelihood procedures of Harvey, (2000), were used for the analysis of Milk yield (MY), lactation length (LL), daily live-weight change (LWC) of the does, birth weight (BWT), pre-weaning average daily gain (pre-ADG), weaning weight (WWT), milk composition and nutrients intake using the models below.

Factors fitted in the fixed statistical models included, treatment diet, sex of kid, type of birth, management system, parity and stage of lactation. Also fitted was first order interaction between management and treatment. For the purposes of data analysis these factors were coded as follows:- Treatment diet 1 - 5; sex of kid 1 and 2 for male and female respectively. Type of birth 1 and 2 for singles and twins respectively (there were no triplet births). Parity 1 - 5, stage of lactation 1 - 3, for early, mid and late lactation respectively, management system was defined as 1 and 2 for free-range and confined feeding respectively.

For the analysis of LWC, the following weight change parameters were used to determine weight changes across the lactation.

$Y1$ = Daily Live-Weight Change (LWC) g goat^{-1}day^{-1} - 4 weeks prior kidding to kidding
$Y2$ = Daily Live-Weight Change (LWC) g goat^{-1}day^{-1} - Kidding to weaning (16 weeks)
$Y3$ = Daily Live-Weight Change (LWC) g goat^{-1}day^{-1} - Weaning to drying

Model I:- Y_{ijklmn} = $\mu + f(LL)_{ijklmn} + M_i + T_j + SK_k + TB_l + P_m + (M*T)_{ij} + e_{ijklmn}$

[For analysis of daily (g) and lactational (kg) MY]

Model II:- Y_{ijklmn} = $\mu + f(MY)_{ijklmn} + M_i + T_j + SK_k + TB_l + P_m + (M*T)_{ij} + e_{ijklmn}$

[For analysis of LL (days) and LWC (g)].

Model III:- Y_{ijklmn} = $\mu + f(DWT)_{ijklmn} + M_i + T_j + SK_k + TB_l + P_m + (M*T)_{ij} + e_{ijklmn}$

[For analysis of BWT (kg)].

Model IV:- Y_{ijklmn} = $\mu + f(BWT)_{ijklmn} + M_i + T_j + SK_k + TB_l + P_m + (M*T)_{ij} + e_{ijklmn}$

[For analysis of Pre-ADG (g) and WWT (kg)]

Model V:- Y_{ijkl} = $\mu + f(MY)_{ijkl} + M_i + T_j + SL_k + (M*T)_{ij} + e_{ijkl}$

[For analysis of milk components].

Model VI:- Y_{ijk} = $\mu + T_i + e_{ijk}$ [To determine effect of treatment on nutrients intake]

Where,

μ = The underlying constant common to all observations.

M_i = Effect due to i^{th} management system ($i = 1,2$)

T_j = Effect due to j^{th} treatment diet ($j = 1,...,5$)

SK_k = Effect due to k^{th} sex of kid ($k = 1,2$).

TB_l = Effect due to l^{th} type of birth ($l = 1,2,$)

P_m = Effect due to m^{th} parity ($m = 1,\ldots,5$)

SL_k = Effect due to k^{th} stage of lactation ($k = 1,\ldots,3$).

$(M*T)_{ij}$= Effect due to interaction of i^{th} management system and j^{th} treatment diet ($ij = 1,.,10$)

e_{ijklmn} = The random error term, associated with each observation.

$f(LL)_{ijklmn}$= Linear and non-linear components of DIM (Days-in-milk) fitted as a covariate in model I to remove bias due to variation in lactation length with each animal.

$f(MY)_{ijklmn}$= Linear and non-linear components of lactational milk yield fitted as a covariate in model II (for analysis of LL, Y2 and Y3) and model V to remove bias due to variation in lactational milk yield with each animal.

$f(DWT)_{ijklmn}$= Linear function of weight of doe at kidding fitted as a covariate in model III to remove bias due to variation in weight of does at kidding.

$f(BWT)_{ijklmn}$= Linear function of birth weight, fitted as a covariate in model IV to remove bias due to variation in weight of kids at birth.

3.4.0 *Results and discussion*

Chemical composition of the feed ingredients (Rhodes grass hay, *Calliandra* and Lucerne) is presented in Table 3.1. The DM content was 921.47, 926.20 and 904.73 g kg^{-1} for Rhodes grass hay, *Calliandra* and Lucerne respectively. The CP contents were 77.47, 247.53 and 193.83 g kg^{-1}DM for the hay, *Calliandra* and Lucerne respectively. The CP content of hay was within the range of 40 - 112 g kg^{-1}DM for tropical grasses (Van Soest, 1994) but was higher than 43 g kg^{-1}DM (Woyengo, 2001), and lower than 83 g kg^{-1}DM (Biwott, 2000). The CP content of *Calliandra* was within the range of 200 - 300 g kg^{-1}DM reported by Paterson *et al.*, (1996), while that of Lucerne was within the range of 160 - 210 g kg^{-1}DM (Kariuki, 1998; Odongo *et al.*, 1999). The ME (MJ kg^{-1}DM) values estimated from chemical composition were higher for the legumes than that of hay and *Calliandra* higher than Lucerne. The levels of Calcium (Ca) and Phosphorus (P) were higher in Lucerne than *Calliandra* and hay. The Ca and P levels of *Calliandra* and Lucerne obtained in the current study corresponded with those reported elsewhere (Kaitho, 1997; Kariuki, 1998). The lower NDF concentration in Lucerne and *Calliandra* than hay was consistent with the general observation of lower NDF concentrations in legumes than grasses (Minson, 1990).

Table 3.1 Chemical composition (g kg^{-1}DM) of the feed ingredients

	Rhodes grass hay	*Calliandra calothyrsus*	Lucerne
Dry matter (g kg^{-1})	921.47±3.98	926.20±6.53	904.73±8.38
Chemical Composition (g kg^{-1}DM)			
Organic matter	827.30±3.47	854.87±4.44	800.07±5.91
Crude Protein	77.47±5.09	247.53±1.29	193.83±18.44
Calcium (Ca)	3.87±0.62	9.33±0.11	10.20±0.87
Phosphorus (P)	3.27±0.82	2.20±0.27	4.20±0.20
Neutral detergent fibre	723.40±1.31	405.33±10.02	520.60±6.87
Acid detergent fibre	405.53±6.22	219.80±12.00	363.00±2.20
Acid detergent lignin	66.07±0.64	56.73±3.58	77.20±1.47
Ash	94.17±0.51	71.33±2.09	104.66±4.89
Hemicellulose	317.87±5.11	197.53±9.98	152.60±9.07
Cellulose	339.47±6.31	133.07±8.42	290.80±2.73
Ether Extract (Crude fat)	12.27±0.31	14.20±3.33	9.00±1.00
*Estimated ME (MJ kg^{-1}DM)	9.08±0.01	9.92±0.38	9.53±0.20

*Estimated ME (MJ kg^{-1}DM) calculated using the equation:- OMD% = 91.9 - (0.355*NDF%) + (0.387*ADF%) - (2.17*ADL%) - (0.39*EE%); DOM% = (0.92*OMD%) - 1.2; ME = DOM%*0.15 (Muia, 2000). ADF = Acid detergent fibre; ADL = Acid detergent lignin; DOM = Digestible organic matter; EE = Ether extract; ME = Metabolizable energy; NDF = Neutral detergent fibre; OMD = Organic matter digestibility.

Chemical composition of the different treatment diets is shown in Table 3.2 and was estimated based on the ratio of hay to legume in each diet using the average composition values of each ingredient as consumed. The DM and OM contents increased progressively with increase in the proportion of *Calliandra* but decreased with increased levels of Lucerne. These differences were due to the lower DM and OM contents for Lucerne compared to *Calliandra* and Rhodes grass hay (Table 3.1).

Table 3.2 Chemical composition (g kg^{-1}DM) of the treatment diets

Treatment	T1	T2	T3	T4	T5	SED
Dry matter (g kg^{-1})	921.47^{ab}	922.58^{a}	923.13^{a}	917.35^{bc}	915.35^{c}	1.48
Chemical Composition (g kg^{-1}DM)						
Organic matter	827.30^{a}	833.75^{b}	836.96^{b}	820.62^{c}	817.36^{c}	1.29
Crude Protein	77.47^{a}	117.27^{b}	137.07^{c}	106.03^{d}	119.93^{e}	1.97
Calcium (Ca)	3.87^{a}	5.15^{b}	5.78^{bc}	5.42^{bc}	6.18^{c}	0.22
Phosphorus (P)	3.27	3.02	2.90	3.50	3.61	0.29
Neutral detergent fibre	723.40^{a}	648.96^{b}	611.93^{c}	673.63^{b}	649.39^{bc}	10.56
Acid detergent fibre	405.53^{a}	362.06^{b}	340.44^{c}	395.09^{ad}	390.01^{d}	5.62
Acid detergent lignin	66.07^{a}	63.88^{b}	62.80^{c}	68.80^{d}	70.13^{e}	0.28
Ash	94.17^{a}	88.83^{b}	86.17^{c}	96.73^{d}	97.99^{e}	0.25
Hemicellulose	317.87^{a}	289.71^{ab}	275.70^{ab}	277.31^{ab}	257.56^{b}	14.20
Cellulose	339.47^{a}	291.16^{b}	267.14^{c}	327.53^{d}	321.71^{d}	5.74
Ether Extract (Crude fat)	12.27^{a}	12.72^{b}	12.95^{b}	11.47^{c}	11.08^{c}	0.16
•Metabolizable Energy (MJ kg^{-1}DM)	9.05^{a}	10.52^{b}	10.85^{b}	10.28^{b}	10.68^{b}	0.30

•ME = DOM%*0.15 (Muia, 2000), DOM % obtained from the *in-vivo* digestibility trial; DOM = Digestible organic matter
SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$).

The metabolizable energy (ME) content estimated from the *in-vivo* OM digestibility ranged from 9.05 (T1) to 10.85 MJ kg^{-1}DM (T3). The supplemented diets had similar ME ($P>0.05$) and were significantly ($P<0.05$) higher than the control. The CP content was significantly ($P<0.05$) higher for the supplemented diets than the control. The range was 77.47 (T1) to 137.07 g kg^{-1}DM (T3) and increased with level of the supplement in the diet. At same levels of supplementation CP content was significantly ($P<0.05$) higher for *Calliandra* than Lucerne based diets. This was expected because *Calliandra* had higher CP content than Lucerne (Table 3.1). Supplementation lowered NDF and ADF levels as the levels for the legumes were lower than Rhodes grass hay (Table 3.1). ADL differed significantly ($P<0.05$) across the diets and was higher for Lucerne than *Calliandra* based diets. T5 had the highest levels of Calcium (Ca) and Phosphorus (P) at 6.18 and 3.61 g kg^{-1}DM respectively, reflecting the higher Ca and P contents of Lucerne than *Calliandra* and Rhodes grass hay (Table 3.1).

3.4.1 *Nutrients intake and goat performance*

Results of the estimated nutrients intake and milk yield, the lactation length, doe daily live-weight change and pre-weaning kid performance for the confined feeding management system are presented in Table 3.3. Figure 3.1 shows the trend in daily milk yield (g day^{-1}) for the confined feeding management system

Hay dry matter intake (HDMI) and Total dry matter intake (TDMI) g day^{-1} increased with supplementation and varied significantly ($P<0.05$) across the diets. Increase in level of supplementation significantly ($P<0.05$) increased TDMI for both supplements. When TDMI was expressed on metabolic body weight ($W^{0.75}$) basis, the same trend was observed across the diets. Total organic matter intake (TOMI) showed a similar trend to that of TDMI across the diets (Table 3.3). Metabolizable energy intake (MEI MJ day^{-1}) increased with level of supplementation and differed significantly ($P<0.05$) across the diets. The MEI for the control was below the minimum requirements for maintenance while the supplemented diets met this requirement of 6.6 MJ day^{-1} for a 40 kg goat (Peacock, 1996).

Total crude protein intake (TCPI) g day^{-1} increased with supplementation from 52.24 for the control diet to 115.73, 180.79, 98.71 and 149.80 g day^{-1} for T2, T3, T4 and T5 respectively (Table 3.3). At similar levels of supplementation does on *Calliandra* had significantly ($P<0.05$) higher TCPI than those on Lucerne based diets, increased supplementation levels significantly ($P<0.05$) increased TCPI in does on both supplements. These differences reflected the dietary CP content of the treatment diets (Table 3.2). When TCPI was expressed as digestible CPI (DCPI), intake for the supplemented goats was above the minimum requirements of 43 g day^{-1} for maintenance, while intake for the control group was below this requirement (Peacock, 1996).

Increase in DMI with supplementation on protein sources has been documented. Ebong, (1996) reported increased DMI and growth rate with increased *Calliandra* leaf meal levels in the diet of goats on a basal diet of Elephant grass (*Pennisetum purpureum*). Similarly, Kaitho, (1997) reported increased DMI and ADG in sheep and goats on a basal diet of teff straw (*Eragrostis tef*) supplemented with graded levels of *Leucaena pallida* and *Sesbania sesban*.

Table 3.3 Nutrients intake and goat performance under the confined feeding management system

	Treatments							
	T1	T2	T3	T4	T5	SED	NRQ	Significance
Nutrients intake								
- HDMI (g day^{-1})	674.32^{a}	753.93^{b}	853.98^{c}	708.31^{d}	801 82^{e}	19.70		***
- TDMI (g day^{-1})	674.32^{a}	985.48^{b}	1317.08^{c}	934.49^{d}	1254.19^{e}	19.70		***
- TDMI (g kg^{-1} W$^{0.75}$)	43.79^{a}	63.99^{b}	85.52^{c}	60.68^{b}	81.44^{c}	1.93		**
- TOMI (g day^{-1})	557 86^{a}	821.67^{b}	1102.39^{c}	766.94^{d}	1025.27^{e}	16.68		***
- TCPI (g day^{-1})	52.24^{a}	115.73^{b}	180.79^{c}	98.71^{d}	149.80^{e}	2.30		***
- ◊DCPI (g day^{-1})	32.96^{a}	81.47^{b}	137.76^{c}	68.21^{d}	106.96^{e}	1.58	43.0	***
- MEI (MJ day^{-1})	6.12^{a}	9.15^{b}	12.34^{c}	8.59^{d}	11.59^{e}	0.27	6.6	***
Milk yield (MY)								
- Daily MY (g goat^{-1} day^{-1})	259.94^{a}	413.54^{b}	639.78^{c}	370.15^{d}	521.49^{e}	10.51		***
- Lactation length (days)	114^{a}	145^{b}	232^{c}	124^{d}	210^{e}	15		*
- Lactational MY (kg)	29.63^{a}	59.96^{b}	148.43^{c}	45.90^{d}	109.51^{e}	7.37		***
LWC (g goat^{-1} day^{-1})								
- 4 wks prior kidding to kidding (Y1)	67.16^{a}	78.75^{b}	152.90^{c}	71.43^{b}	136.90^{c}	8.58		*
- Kidding to weaning (Y2)	-9.82^{a}	3.34^{b}	8.41^{c}	1.07^{b}	6.99^{c}	4.68		***
- Weaning to drying (Y3)	-2.35^{a}	23.36^{b}	37.84^{c}	11.57^{b}	27.63^{d}	4.22		**
Pre-weaning kid performance								
- Birth weight (kg)	1.93^{a}	2.47^{b}	3.32^{c}	2.17^{d}	2.90^{e}	0.05		***
- Pre-weaning ADG (g)	47.83^{a}	64.30^{b}	91.45^{c}	53.82^{d}	72.92^{e}	2.36		**
- Weaning weight (kg)	7.77^{a}	9.53^{b}	13.32^{c}	8.43^{d}	10.70^{e}	0.40		**
- ΔPost-partum doe weight (kg)	27.67^{a}	35.83^{b}	42.17^{c}	31.75^{d}	39.83^{e}	0.57		***

HDMI, Hay DM intake; TDMI, Total DM intake, TOMI, Total OM intake; TCPI, Total CP intake; DCPI, digestible CPI; MEI, Metabolizable energy intake; ADG, average daily gain; LWC, Live-weight change; NRQ, Nutrient requirements for maintenance of a mature goat (40 kg LWT) (Peacock, 1996); LWT, Live-weight. ◊DCPI, estimated from the *in-vivo* digestibility trial. ΔPost-partum doe weight (kg), taken immediately after kidding. SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$.

The low intake of nutrients for the control (hay only diet) could be ascribed to the high fibre content, low N and low digestibility. Hay intake increased with supplementation because the supplement increased the CP content of the diet, hence increased CP available to the rumen microbes, which improved incorporation of feed protein to microbial protein (Van Soest, 1994; McDonald *et al.*, 1995). This improved microbial activity and multiplication (Van Soest, 1994; McDonald *et al.*, 1995) with a resultant improvement in digestibility, increasing the passage rate of the digesta, which led to increased intake of the basal diet with supplementation, leading to improved milk yield and kid performance. Additionally, the higher rumen degradation (Chapter 6) of the supplemented diets resulted in a shorter feed residence period in the rumen and thus increased intake. Tchinda *et al.*, (1994) observed that inclusion of legumes in ruminant diets increased the efficiency of utilization of the low protein basal diet through a catalytic effect on feed utilization

At similar levels of supplementation intake, hence animal performance was higher for *Calliandra* than Lucerne based diets. The better performance of does and kids of does on *Calliandra* reflected the fact that as a constituent feedstuff it had a higher CP content and lower fibre components (NDF and ADF) and lignin content which resulted in a higher value diet than Lucerne (Tables 3.1 and 3.2). The superiority of *Calliandra* over Lucerne in this study may also have been because normally, only leaves and young shoots are fed (Ella *et al.*, 1989) (all the stalks were removed during threshing), unlike Lucerne hay, which was fed as the chopped whole plant. Leaf protein has been reported to be less lignified and fibrous hence more digestible than stem protein (Mannetje, 1983; Van Soest, 1994). High fibre and lignin contents have been reported to lower digestibility (Van Soest, 1994; McDonald *et al.*, Kaitho, 1997; Kariuki, 1998; Muia, 2000). Additionally, *Calliandra* based diets were more digestible (Chapter 5) and had higher rumen degradability (Chapter 6) hence higher passage rate than Lucerne based diets. All these factors contributed to making *Calliandra* a better supplement than Lucerne.

Legumes have been reported to provide a more efficient environment for digestion of cell wall carbohydrates, by supplying micronutrients such as peptides, amino acids, minerals and vitamins, which increase fungal biomass and the rate of bacterial colonization of the fibre (Tchinda *et al.*, 1994). Supplementation with legumes has also been reported to provide ruminally fermentable nitrogen and thus increased rumen ammonia concentration, which promotes higher microbial activity (Kaitho, 1997). This results in an increase in digestion and rumen turnover and passage rates hence increased feed intake with improvement in animal performance (McDonald *et al.*, 1995).

The improved nutrients intake of the does with supplementation resulted in higher lactational milk yields, daily LWC, longer lactations and improved kid performance (Tables 3.3 and 3.4, and Figures 3.1, 3.2, 3.4 and 3.5). Increase in daily and lactational milk yield improved with level of supplementation. For the confined feeding system, daily milk yield increased by 146 and 101% with supplementation at the higher level of 500 g day^{-1} of *Calliandra* and Lucerne respectively. The respective improvement in total lactation yield was even more pronounced at 401 and 270% (Table 3.3).

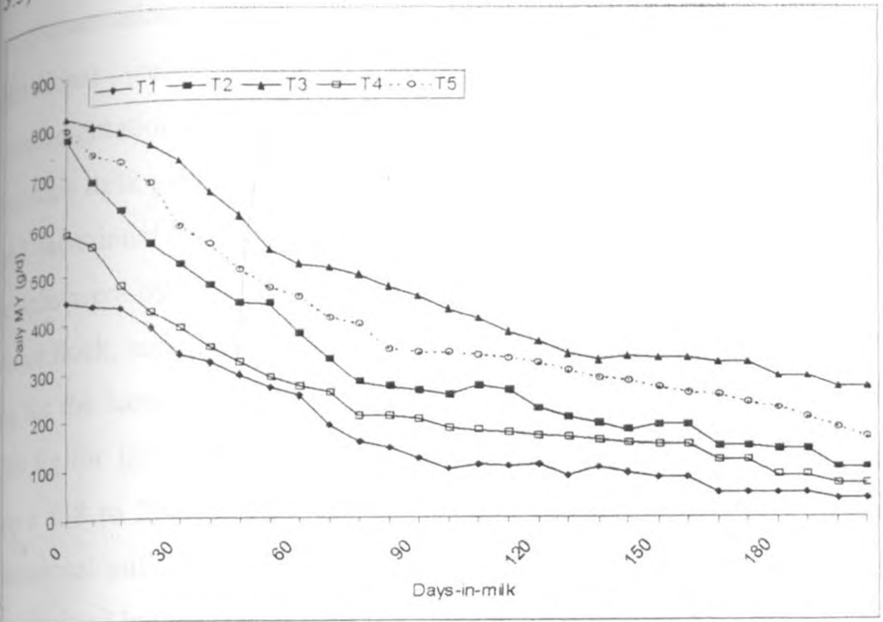

Figure 3.1 ***Daily milk yield (g day^{-1}) under the confined feeding management system***

Table 3.4 Supplement DMI, OMI and CPI and performance under the free-range management system

	Treatments					SED	Significance
	T1	T2	T3	T4	T5		
Supplement intake							
-SDMI (g day^{-1})	0	231.55	463.10	226.18	452.37	N/A	N/A
-SOMI (g day^{-1})	0	197.94	395.89	180.96	361.92	N/A	N/A
-SCPI (g day^{-1})	0	57.32	114.63	43.84	87.68	N/A	N/A
Milk yield (MY)							
- Daily MY (g goat^{-1}day^{-1})	354.82^{a}	568.07^{b}	813.21^{c}	508.07^{d}	692.57^{e}	11.20	***
- Lactation length (days)	231^{a}	266^{b}	325^{c}	249^{d}	307^{e}	13	**
- Lactational MY (kg)	81.96^{a}	151.11^{b}	264.29^{c}	126.51^{d}	212.62^{e}	9.86	***
LWC (g goat^{-1}day^{-1})							
- 4 wks prior kidding to kidding (Y1)	182.78^{a}	248.89^{b}	378.57^{c}	192.86^{d}	353.20^{c}	9.19	*
- Kidding to weaning (Y2)	-2.79^{a}	23.38^{b}	38.93^{c}	16.25^{b}	33.57^{c}	13.04	*
- Weaning to drying (Y3)	17.83^{a}	31.17^{b}	52.16^{c}	28.10^{b}	42.03^{d}	3.60	*
Pre-weaning kid performance							
- Birth weight (kg)	2.12^{a}	3.00^{b}	3.82^{c}	2.74^{d}	3.32^{e}	0.11	**
- Pre-weaning ADG (g)	57.37^{a}	78.27^{b}	112.41^{c}	66.25^{d}	90.65^{e}	2.09	***
- Weaning weight (kg)	8.98^{a}	11.68^{b}	14.70^{c}	10.06^{d}	13.52^{e}	0.24	***
- ΔPost-partum doe weight (kg)	32.80^{a}	43.60^{bd}	48.62^{c}	39.71^{b}	46.54^{cd}	1.38	**

SDMI, Supplement DM intake; SOMI, Supplement OM intake; SCPI, Supplement CP intake; ADG, average daily gain; LWC, Live-weight change; N/A, Not applicable; ΔPost-partum doe weight (kg), taken immediately after kidding. SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference (P<0.05); *, P<0.05; **, P<0.01; ***, P<0.001.

Similarly, for the free-range goats, daily milk yield increased by 129 and 95% at 500 g day^{-1} supplementation level for *Calliandra* and Lucerne respectively. The respective increases in lactational yields were 222 and 159% (Table 3.4). Under the confined feeding system, supplementation improved performance from the range of 210 to 270 g day^{-1} and 20 to 30 kg for lactation milk yield for the control diet to within the range of 360 to 680 g and 28 to 150 kg for daily and lactational milk yield respectively for the supplemented does. The corresponding lactation lengths were 69 to 215 days for the control and 90 to 300 days for the supplemented. For the free-range flock, supplementation improved milk yield from the range of 300 to 400 g day^{-1} and 55 to 90 kg for the lactational milk yield for the control to within the range of 500 to 840 g day^{-1} and 90 to 280 kg for lactational milk yield for the supplemented does. The corresponding lactation lengths were 138 to 250 days for the control and 240 to 350 days for the supplemented diets. The mean lactational milk yield (123.00 kg) obtained in this study correspond with the range of 78.40 - 120.00 kg obtained by Ruvuna *et al.*, (1987) for the same breed.

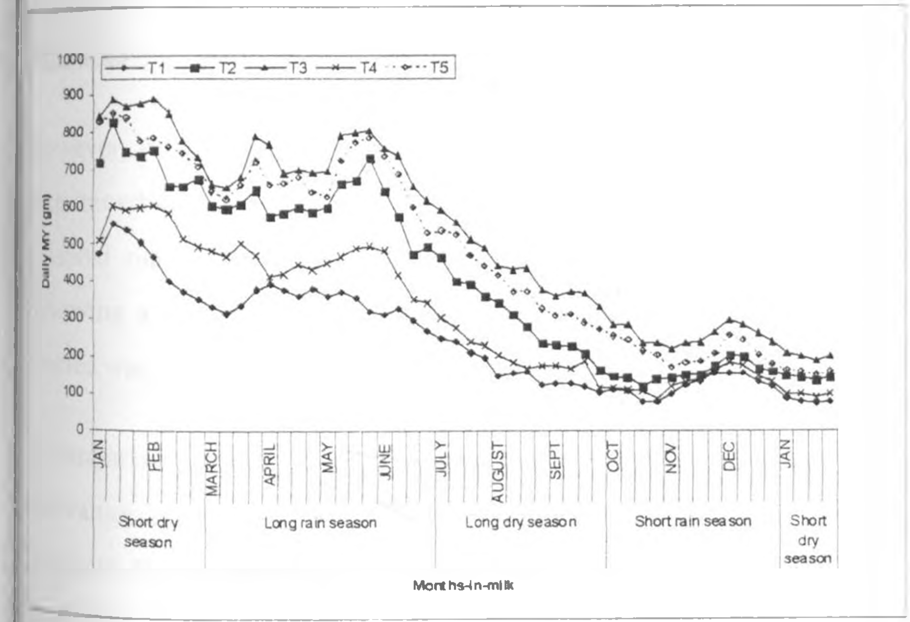

Figure 3.2 **Daily milk yield (g day^{-1}) under the free-range management system**

Under the free-range system, intake from pastures was not assessed but the better performance of the supplemented does suggested improved nutrition. Like the confined system, goats on *Calliandra* supplement had superior performance compared to Lucerne (Table 3.4; Figures 3.2 and 3.5). Results on performance of does and kids under the free-range system reflect those of does and kids under the confined system and the response to level of supplementation was similar.

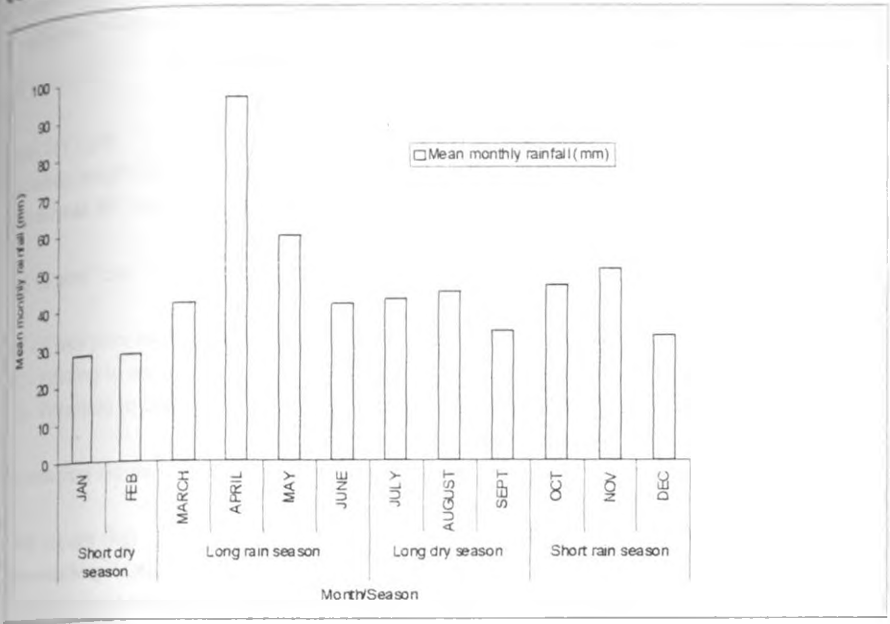

Figure 3.3 ***Mean monthly rainfall (mm) (1972 - 2002) for the study area for the free-range flock***

However, milk yield of the does on free-range was also affected by seasonal variations, which were determined by the rainfall pattern (Figure 3.3). It was observed that milk yield fluctuated in a seasonal manner following the rainfall pattern; and yields would increase on the onset of rains following a dry spell. The CP content used as an indicator of forage quality, of the preferred plant species was higher during the wet season (Table 3.6) contributing to the higher milk yield.

A comparison of lactation performance across the two feeding systems showed that does under the free-range system had significantly ($P<0.05$) higher daily and lactation milk yields and longer lactations than those under confined feeding (Table 3.5). Consequently, their kids performed better ($P<0.05$) than those born of does under the confined feeding system (Table 3.5).

Table 3.5 Comparative milk and kid performance and doe daily live-weight change (LWC) for the two management systems

	Confined management	Free range management	Significance
Milk yield (MY)			
. Daily MY (g/d)	440.98±11.07^{a}	587.35±11.88^{b}	**
. Lactation length (days)	165.00±13.42^{a}	275.60±12.10^{b}	**
. Lactational MY (kg)	78.69±3.58^{a}	167.30±4.41^{b}	***
LWC (g goat^{-1} day^{-1})			
Y1 - 4 wks prior kidding to kidding	101.43±23.58^{a}	271.26±21.19^{b}	**
Y2 - Kidding to weaning	2.00±4.68^{a}	21.87±13.04^{b}	*
Y3 - Weaning to drying	19.61±4.22^{a}	34.26±3.60^{b}	*
Pre-weaning kid performance			
. Birth weight (kg)	2.56±0.14^{a}	3.00±0.15^{b}	**
. Pre-weaning ADG (g/d)	66.06±3.64^{a}	80.99±4.11^{b}	**
. Weaning weight (kg)	9.95±0.41^{a}	11.79±0.46^{b}	*
Daily milk consumption (g/d)	307.77±4.45^{a}	434.88±4.89^{b}	***
Daily surplus milk (g/d)	133.21±1.85^{a}	152.47±1.63^{b}	**

Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$.

Since the only difference between the two systems was the basal diet, this suggested that does in the free-range were able to select more nutritious feed than the Rhodes grass hay offered as the basal diet under the confined feeding system. The chemical composition of the most commonly selected pasture plants and plant parts in both wet and dry seasons is shown in Table 3.6. Although the proportionate contribution of the plants to the doe diet was not established, the compositional differences between these and the Rhodes grass suggest a higher quality basal diet for does on free-range compared to those under confined feeding. The mean CP content during both seasons [104.8 (grasses) and 170.8 g kg^{-1}DM (browse plants)] of the most commonly selected pasture species was higher than the CP content (77 g kg^{-1}DM) of Rhodes grass hay. The most commonly grazed grass species were *Aristida adoensis and A. keniensis, Cynodon dactylon, Eragrostis braunii and Themeda triandra*, while the most commonly browsed species were *Acacia gerrardii, A. seyal* and *A. xanthophloea, Fuerstia africana, Sida ovata, Lippia somalensis, Olea Africana, Rhus natalensis, Hypoestes verticilaris, Tinea aethiopica, Psidia arabica* and *Tarchonanthus camphorates*. The greater variety of feed under the free-range system could also have contributed to higher intakes. Similarly, Nianogo *et al.*, (1996) reported better performance under free-range than tethered grazing because the former allowed for a more, wider and free selection of pasture.

Table 3.6 Chemical composition (g kg^{-1}DM) of some of the most commonly grazed and browsed species by the free-range flock

Species	Dry Season							Wet Season						
	DM	CP	NDF	ADF	ADL	Ca	P	DM	CP	NDF	ADF	ADL	Ca	P
Grasses														
Aristida adoensis	166.9	80.5	805.2	451.4	86.5	1.1	0.8	122.2	108.5	818.2	456.0	55.1	0.8	1.0
Aristida keniensis	148.5	91.8	818.4	409.9	70.0	5.5	1.4	125.3	99.2	789.9	401.9	52.3	1.1	1.5
Cynodon dactylon	172.6	89.1	776.2	411.5	123.1	1.6	1.1	108.5	177.6	738.5	301.6	44.1	2.1	3.7
Cynodon plectostachyus	177.1	73.2	715.3	310.5	45.7	1.3	0.6	121.6	86.4	705.7	251.6	40.2	1.6	1.1
Cyperus rotundus	192.4	87.2	870.7	399.2	37.5	1.4	2.6	140.5	127.3	801.1	384.3	83.6	1.5	3.5
Eragrostis braunii	159.8	161.7	843.2	381.8	60.3	1.3	4.6	144.5	139.4	757.3	341.0	63.9	1.2	3.0
Pennisetum clendestinum	189.2	82.2	751.4	324.1	42.6	1.5	4.6	136.0	92.0	744.4	304.1	38.6	1.9	5.9
Themeda triandra	198.7	81.4	798.5	487.9	95.1	1.1	0.7	133.8	98.8	735.7	437.2	51.0	1.3	1.3
Mean (Grasses)	175.7	93.4	797.4	397.0	70.1	1.9	2.1	129.1	116.2	761.4	359.7	53.6	1.4	2.6
*Estimated mean ME (MJ kg^{-1}DM) grasses						◊8.62					◊8.90			
Browse plants														
Acacia gerrardii	255.4	135.3	377.7	457.8	126.9	10.8	2.0	156.1	124.2	363.5	277.3	126.2	12.0	1.4
Acacia seyal	232.5	206.3	434.5	349.1	131.0	7.0	2.1	136.5	225.3	424.5	299.1	131.0	7.2	2.3
Acacia xanthophloea	263.1	203.9	461.2	407.1	79.0	9.0	1.4	158.7	175.3	424.2	377.0	77.0	11.6	1.6
Fuerstia Africana	236.9	189.5	485.6	304.9	85.2	9.1	3.0	122.4	150.5	476.6	325.1	98.4	4.2	2.2
Hypoestes verticilans	224.7	163.8	389.2	255.6	98.0	8.1	1.6	121.8	221.5	290.7	154.9	41.6	12.6	2.4
Lippia somalensis	186.8	163.1	423.8	281.6	86.4	4.5	1.4	134.7	172.1	271.8	179.7	44.9	6.8	1.9
Olea Africana	243.8	158.3	446.7	317.3	90.1	10.5	0.7	141.7	173.4	347.6	306.3	83.2	13.4	0.92
Psidia Arabica	251.4	140.2	266.2	183.9	87.5	11.7	1.8	133.7	206.9	270.4	234.7	75.1	4.5	1.7
Rhus natalensis	195.2	132.6	284.7	201.9	93.2	13.1	1.0	152.4	143.9	206.8	176.3	86.1	5.4	1.5
Sida ovata	182.8	185.6	490.4	310.7	147.8	9.2	2.5	144.3	241.1	521.8	249.9	131.7	8.6	2.7
Tarchonanthus camphorates	219.5	139.0	270.1	174.2	119.5	5.7	1.6	151.6	136.7	259.9	221.1	106.6	3.1	1.4
Tinea aethiopica	213.3	133.5	373.1	237.5	95.9	15.5	3.1	122.8	177.2	274.9	181.4	63.2	4.0	2.1
Mean (legumes)	225.5	162.6	391.9	290.1	103.4	9.5	1.9	139.7	179.0	344.4	248.6	88.8	7.8	1.8
*Estimated mean ME (MJ kg^{-1}DM) legumes						◊9.03					◊9.48			

*Estimated mean ME (MJ kg^{-1}DM) calculated using the equation:- OMD% = 91.9 - (0.355*NDF%) + (0.387*ADF%) - (2.17*ADL%); DOM% = 0.92*OMD%) - 1.2; ME = DOM%*0.15 (Muia, 2000). ADF = Acid detergent fibre; ADL = Acid detergent lignin; DOM = Digestible organic matter; EE = Ether extract; ME = Metabolizable energy; NDF = Neutral detergent fibre; OMD = Organic matter digestibility; Ca = Calcium; CP = Crude protein; DM = Dry matter; P = Phosphorus. ◊ = Mean values of ME calculated using the respective mean composition for grasses and legumes.

Increase in milk production by the supplemented does under both management systems could be attributed to increased nutrients intake and availability for milk synthesis. The improved milk yield with supplementation on protein sources is consistent with other reports. Ondiek *et al.*, (1998) reported increased DMI and higher milk yield when dairy goats fed Rhodes grass hay were supplemented with *Leucaena* and *Gliricidia*. Paterson *et al.*, (1996), Roothaert *et al.*, (1997) and Roothaert, (1999) showed that supplementation with *Calliandra* increased milk yield and persistency in dairy cows under semi-zero management systems. Similarly, Muia, (2000) reported higher milk yield and longer lactations in dairy cows fed Napier grass supplemented with graded levels of poultry litter compared to those on Napier grass only.

The improved milk yield of the doe was reflected in better kid performance which was in harmony with the differences in lactation performance between the two systems and was significantly ($P<0.05$) higher under free-range than those of does on confined feeding (Tables 3.3, 3.4, 3.5 and 3.7; Figures 3.4 and 3.5). This was because improved milk yield of the does led to increased milk intake by the kids (Table 3.7) which was reflected as improved kid growth and higher weaning weight.

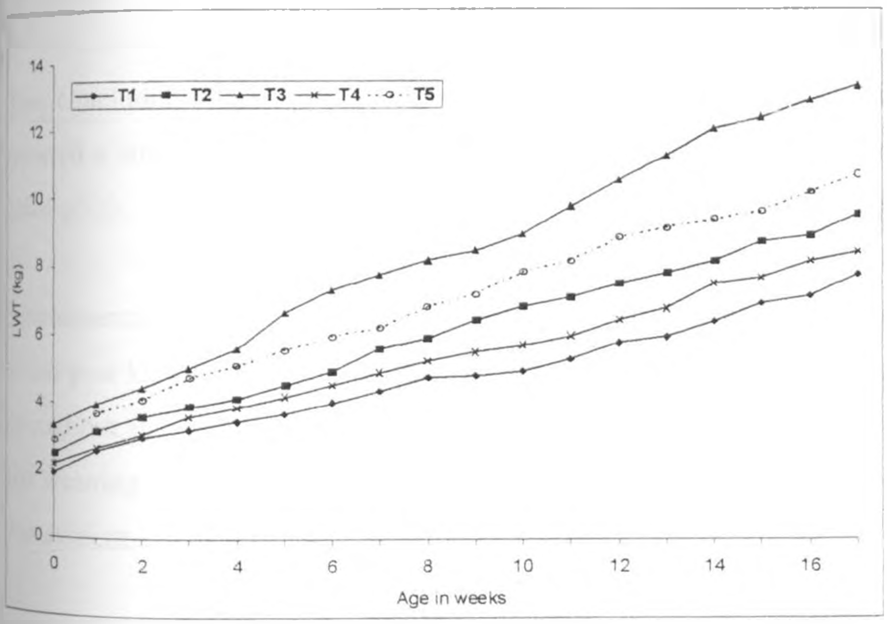

Figure 3.4 *Kids pre-weaning growth under the confined feeding management system*

During the kid-rearing phase (kidding to weaning) the kids mainly depended on their dams' milk for nutrients supply. Nianogo and Ilboudo, (1994) also observed that females with high milk output promoted faster pre-weaning growth and better survivability of their young in Sahelian goats and Mossi ewes.

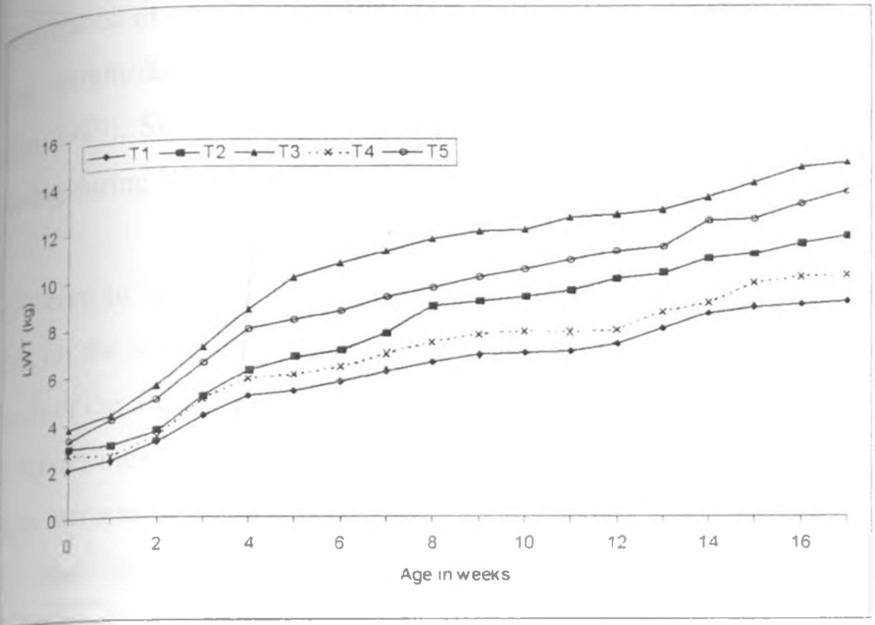

Figure 3.5 ***Kids pre-weaning growth under the free-range management system***

They concluded that kid growth was highly correlated to milk consumption. Cisse *et al.*, (1996) also reported a strong correlation between milk consumption of the kids and their growth in Senegalese Sahel goats.

Supplementation also had a significant ($P<0.05$) positive effect on weight changes of the does prior to and post kidding (Tables 3.3 and 3.4). Does on the control diet under confined feeding lost weight throughout the lactation period (Table 3.3) while those on free-range did so only between kidding and weaning (Table 3.4). Again the superiority in performance of does under the free-range system was evident

During the last trimester of pregnancy there is increased nutrients demand for foetal growth and development because it is during this period that the foetuses are undergoing rapid musculoskeletal development (Furber, 1985; Skea, 1989; Peacock, 1996). The extent to which these nutrients are supplied affects the birth weight of the young and also the subsequent lactation performance, performance of the young and thus the weaning weight (Lyatuu *et al.*, 1994; Peacock, 1996; Roothaert, 1999). Poor nutritional management during lactation may lead to weight loss due to mobilization of body reserves for milk production. It has been recorded that a doe can lose 10 - 15% body weight during the kid-rearing phase (birth to weaning) due to lactational stress (Gall, 1981; Skea, 1989). Skea, (1989) recommended improved nutritional management through supplementary feeding during lactation.

Kids born to supplemented does had significantly ($P<0.05$) higher birth weight than those born to does on the control diet. This was a reflection of the diet composition (Table 3.2) and nutrients intake of the does (Tables 3.3 and 3.4). At same level of supplementation dams on *Calliandra* kidded to heavier kids than those on Lucerne based diets. Increase in level of dam supplementation resulted in an increase in birth weight, pre-ADG and weaning weight of the kids. This can be explained by the improved nutrition, pre-kidding with supplementation and thus more nutrients being available for foetal growth and development and after kidding more milk production. Similar observations were made by Gall, (1981), who reported that birth weight was highly variable depending on environmental conditions which included variation in feeding management. Devendra and Burns, (1983) also observed that in addition to genetic factors, birth weight and kid performance were greatly influenced by environmental factors such as nutrition of the dam.

The superiority of free-range over Rhodes grass hay basal diet was also shown in the amount of milk consumed by kids and the amount of surplus milk (Table 3.7). Also, respective treatment diets under the free-range resulted in significantly ($P<0.05$) more surplus milk than confined feeding and *Calliandra* based diets than Lucerne at similar levels of supplementation (Table 3.7). The amount of surplus milk also increased with level of supplementation under both systems. These results indicated that supplementation of the dam improved both milk intake by the kids thus ensuring higher growth rates of the kids and also increased the amount of surplus milk available for human consumption (Table 3.7).

The mean birth weight (2.78 kg) obtained in this study was within the range of 2.24 - 3.50 kg reported for the same breed (Ahuya *et al.*, 1987; Ruvuna *et al.*, 1987; Ruvuna *et al.*, 1992). Similarly, the mean pre-ADG (73.53 g day^{-1}) and WWT (10.87 kg) concur with 64.42 g day^{-1} and 10.42 kg respectively, reported for the same breed (Ahuya *et al.*, 1987).

Table 3.7 Milk consumption by kids, pre-ADG and surplus milk under the two management systems

Parameter	Management system	Treatments					SED	Significance
		T1	T2	T3	T4	T5		
Daily MY (g/d)	Free-range	354.82^{a}	568.07^{b}	813.21^{c}	508.07^{d}	692.57^{e}	11.20	***
	Confined feeding	259.94^{a}	413.54^{b}	639.78^{c}	370.15^{d}	521.49^{e}	10.51	***
Daily milk consumption (g/d)	Free-range	306.92^{a}	421.27^{b}	556.70^{c}	387.67^{d}	501.83^{e}	9.25	***
	Confined feeding	226.01^{a}	285.03^{b}	407.20^{c}	259.64^{d}	360.95^{e}	8.73	***
Additional milk consumed under free-range (g/d)		80.91^{a}	136.24^{b}	149.50^{b}	128.03^{b}	140.88^{b}	11.44	*
Additional fat consumed under free-range (g/d)		4.92^{a}	8.28^{bd}	9.09^{c}	7.78^{b}	8.57^{cd}	0.61	*
Additional protein consumed under free-range (g/d)		3.75^{a}	6.32^{bd}	6.94^{c}	5.94^{b}	6.54^{cd}	0.52	*
Daily surplus milk (g/d)	Free-range	47.90^{a}	146.80^{b}	256.51^{c}	120.40^{d}	190.74^{e}	4.45	***
	Confined feeding	33.93^{a}	128.51^{b}	232.58^{c}	110.51^{d}	160.54^{e}	1.93	***
ADG (g/d)	Free-range	57.37^{a}	78.27^{b}	112.41^{c}	66.25^{d}	90.65^{e}	2.09	***
	Confined feeding	47.83^{a}	64.30^{b}	91.45^{c}	53.82^{d}	72.92^{e}	2.36	**
Additional ADG under free-range (g/d)		9.54^{a}	13.97^{b}	20.96^{c}	12.43^{ab}	17.73^{d}	1.39	**

ADG, average daily gain; SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$.

The lactation performance of does, daily LWC and kid performance were also affected by parity, type of birth and sex of kid (Tables 3.8, 3.9 and 3.10).

Does with male kids yielded significantly ($P<0.05$) more milk and had longer ($P<0.05$) lactation lengths than those with female kids (Table 3.8). This could be explained by the fact that males are reported to have a higher metabolic rate which translates to higher nutrients requirements and higher appetite than females (Inyangala *et al.*, 1990; 1992).

Table 3.8 Effect of parity, type of birth and sex of kid on daily and lactational milk yield and lactation length under the two management systems

Variable	Confined feeding			Free range		
	Daily MY (g/d)	Lactational MY (kg)	Lactation length (days)	Daily MY (g/d)	Lactational MY (kg)	Lactation length (days)
Overall Mean	440.98±11.07	78.69±3.58	165.00±13.42	587 35±11 88	167 30±4 41	275.60±12.10
Type of birth						
Single	421.74±21.47^a	75.08±6 88^a	150.48±21 27^a	581 54±12.94^a	156.33±9.02^a	208.00±16 38^a
Twins	460.22±16.17^b	82.30±4.34^b	179.52±18.27^b	593.16±15.43^b	178.27±8.31^b	343.20±19 58^b
Sex of kid						
Males	513.44±13.92^a	92.57±5 63^a	183.68±16.55^a	615.83±21.67^a	184.66±11.32^a	339.11±15.90^a
Females	368.52±13.65^b	64.81±5.58^b	146.32±19.30^b	558.87±14.13^b	149.94±11.15^b	212.09±18.71^b
Parity						
1	403.02±15.71^a	69.37±5.92^a	107.25±15.01^a	541.57±14.23^a	143.43±7.05^a	182.60±20.48^a
2	459.47±18.11^b	83.07±7.81^b	183.67±18.72^b	615.42±13.88^b	175.24±6.59^b	305.97±17.07^b
3	497.13±19.11^b	85.78±9.64^b	229.61±14.01^c	641.85±10.78^b	193.46±4.45^b	314.75±14.95^b
4	428.77±17.09^b	80.50±6.49^b	171.55±12.28^b	581.35±18.86^b	163.96±8.69^b	288.76±14.13^b
5	416.52±14.01^b	74.72±7.30^b	132.94±16.46^b	556.58±11.60^{ab}	160.40±4.33^{ab}	285.94±17.16^b

MY Milk yield; Means within a column that have different superscripts ^{a} are significantly different, ($P<0.05$).

Male kids thus exert a greater suckling stimulus on their dams leading to higher milk synthesis and yield compared to the dams with female kids. Similar findings have been reported (Zygoyiannis and Katsaounis, 1986). Consequently, due to the higher yields and higher milk consumption, male kids grew faster and had significantly ($P<0.05$) higher Pre-ADG and WWT than female kids (Table 3.10). Higher growth rate of male kids than females has been reported (Gray, 1987; Bee *et al.*, 1992; Karua and Banda, 1994). However, the greater suckling stimulus from the male kids reflected negatively on the daily LWC of their dams due to greater mobilization of body reserves for milk synthesis (Table 3.9). Hence, for the confined feeding those dams lost weight at the rate of 11.8 g day^{-1} compared to a weight gain of 15.7 g day^{-1} for those with female kids during the kid-rearing phase (Y2) (kidding-weaning) (Table 3.9).

Effect of sex of kid was also significant ($P<0.05$) for doe daily LWC prior to kidding (Y1) (Table 3.9) and birth weight of the kids (Table 3.10). Higher weight at birth for male kids has been attributed to hormonal differences in the two sexes. The male hormone (androgens) increases rate of synthesis of proteins and organic elements causing a higher metabolic rate in males. This is reflected in increased retention of nitrogen and other tissue forming materials such as Potassium, Calcium and

Phosphorus. The overall effect was that males grew faster than females. Consequently, male kids weighed significantly (P<0.05) more at birth than females. These high weights could have contributed to the greater weight increases in their dams during pregnancy. Gall, (1981), reported that birth weight of males exceeded that of females by 5 - 15%. Similar effects of sex on birth weight were reported by Ahuya *et al.*, (1987) for Kenya dual-purpose goats, Alexandre *et al.*, (1999) in Guadeloupean Creole goats and Hirooka *et al.*, (1997) for Malaysian local goats (Katjang) and their crossbreds with the German (Improved) Fawn goats in Malaysia.

Table 3.9 Effect of parity, type of birth and sex of kid on doe daily Live-weight change (LWC) g day^{-1} under the two management systems

	Confined feeding			Free range		
Vanable	Y1	Y2	Y3	Y1	Y2	Y3
Overall Mean	101.43±23.58	2.00±4.68	19.61±4.22	271.26±21.19	21.87±13.04	34.26±3.60
Type of birth						
Single	89.49±20.84^{a}	7.72±6.26^{a}	31.99±6.28^{a}	165.42±61.81^{a}	24.19±12.34^{a}	36.45±5.80^{a}
Twins	113.37±14.61^{b}	-3.73±4.98^{b}	7.23±6.43^{b}	377.11±79.88^{b}	19.55±21.12^{b}	32.07±3.36^{b}
Sex of kid						
Males	128.63±18.94^{a}	-11.72±5.37^{a}	1.26±5.86^{a}	330.99±80.85^{a}	17.07±13.69^{a}	32.11±4.08^{a}
Females	74.23±17.11^{b}	15.73±5.62^{b}	37.97±7.24^{b}	211.53±73.90^{b}	26.67±15.29^{b}	36.41±3.88^{b}
Panty						
1	63.90±17.64^{a}	5.48±8.29	28.05±4.02	64.45±96.45^{a}	23.92±17.16	34.93±3.66
2	122.86±16.23^{b}	-14.86±8.99	-0.75±7.26	399.74±85.97^{b}	21.96±13.33	27.96±4.95
3	125.03±15.31^{b}	-15.18±8.19	1.99±6.42	426.56±84.88^{b}	-5.85±32.91	24.67±7.78
4	117.10±12.42^{b}	15.78±5.17	38.89±9.18	320.95±73.27^{b}	37.87±25.77	44.89±4.07
5	78.25±16.81^{ab}	18.79±7.82	29.94±9.54	144.61±44.01^{c}	31.43±15.77	38.85±7.80

Y1 = Daily Live-weight Change (LWC) g $goat^{-1}day^{-1}$ - 4 weeks prior kidding to kidding. Y2 = LWC - Kidding to weaning (16 weeks).
Y3 = LWC - Weaning to drying. Means within a column that have different superscripts ^{a} are significantly different.

Effect of type of birth was significant (P<0.05) for milk yield. Does having twins yielded significantly (P<0.05) more milk and recorded longer lactation lengths than those with single kids (Table 3.8). This could be similarly explained by the greater suckling stimulus exerted by the twins on their dams compared to single kids. Gall, (1981) reported a positive relationship between number of kids born and subsequent milk yield. He observed that development of mammary structure during pregnancy was directly proportional to litter size. This implied that on kidding, does with twins would yield more milk because of greater development of the mammary structure.

Table 3.10 Effect of parity, type of birth and sex of kid on pre-weaning kid performance under the two management systems

	Confined feeding			Free range		
Variable	BWT (kg)	Pre-ADG (g)	WWT (kg)	BWT (kg)	Pre-ADG (g)	WWT (kg)
Overall Mean	2.56±0.14	66.06±3.64	9.95±0.41	3.00±0.15	80.99±4.11	11 79±0.46
Type of birth						
Single	2.93±0.11^{a}	71 62±4 83^{a}	10.52±0.55^{a}	3.61±0 38^{a}	89.50±3.89^{a}	12.73±0 43^{a}
Twins	2.19±0.16^{b}	60.51±6.95^{b}	9.38±0.78^{b}	2.39±0.20^{b}	72.48±6.90^{b}	10.85±0.77^{b}
Sex of kid						
Males	2.64±0.14^{a}	71 45±5.66^{a}	10.37±0.64^{a}	3.16±0.29^{a}	84.06±4.14^{a}	12.14±0.57^{a}
Females	2.48±0.12^{b}	60.67±5.65^{b}	9.53±0.61^{b}	2.84±0.31^{b}	77.92±3.06^{b}	11 44±0.38^{b}
Parity						
1	2.32±0.12^{a}	55.84±4.86^{a}	8.80±1.34^{a}	2.12±0.54^{a}	59.74±4.11^{a}	9 40±0.90^{a}
2	2.52±0.18^{b}	68.43±5.25^{b}	10.23±0.59^{b}	3.22±0.43^{b}	79.33±3.46^{b}	11.62±1.17^{b}
3	3.04±0.24^{c}	72.90±9.97^{b}	10.57±1.12^{b}	3.66±0.61^{b}	104.84±5.31^{c}	14 44±1.26^{c}
4	2.55±0.17^{b}	70.89±7.44^{b}	10.54±0.84^{b}	3.31±0.51^{b}	91.56±3.61^{bc}	12.96±0.40^{bc}
5	2.39±0.29^{ab}	62.26±7.24^{b}	9.60±0.82^{b}	2.68±0.20^{c}	69.49±3.39^{b}	10.51±1.16^{b}

BWT birth weight; Pre-ADG, pre-weaning average daily gain; WWT, weaning weight. Means within a column that have different superscripts ^{a} are significantly different.

However, the higher milk yield by twin bearing does negatively affected ($P<0.05$) doe weight changes during lactation (Table 3.9). Hence, for the confined feeding, during the kid-rearing phase (Y2), single kid bearing does gained weight at the rate of 7.7 g day^{-1} while those with twins lost weight at the rate of 3.7 g day^{-1}. The respective doe weight increases between weaning and drying (Y3) were 32.0 and 7.2 g day^{-1} (Table 3.9). In contrast, Madrid-Bury *et al.*, (1982) and Wahome, (1987), working on goats in arid areas of Venezuela and Kenya respectively, reported lower milk yields and shorter lactation lengths in does with twins. This may suggest that greater suckling stimulus from the twins in a stressful environment resulted to suckling stress in their dams hence lower yields.

Although does with twins yielded significantly ($P<0.05$) more milk, twin born kids grew at a significantly ($P<0.05$) lower rate than singles to weaning (Table 3.10). On the basis of milk intake records, the amount of milk suckled per kid in twin litters was lower than the amount suckled by single born kids and thus the lower growth rate (Table 3 10). These results suggest that although the twin bearing does, produced significantly ($P<0.05$) more milk this may have been inadequate to support high growth rates for individual litter members. However, in terms of total weight weaned per doe, those with twins performed better. These findings concur with those of Ramsey *et al.*, (1994) who noted that total weight gain of twin sets was greater than the weight gain of single lambs in Targhee ewes. And, similar to the current findings, they observed that although ewes that reared twins produced more milk during early lactation than those that reared single lambs, less milk was available to each individual twin lamb than to each single lamb. They argued that milk production seemed to be a more limiting factor for growth in twin lambs than in single lambs because milk intake by single lambs may more nearly approach *ad libitum* consumption. Therefore, in twin litters the dam's milk production was likely to be more of a limiting factor on twin growth rate.

Effect of type of birth was significant ($P<0.05$), for Y1 (Table 3.9). Does carrying twins, had significantly ($P<0.05$) higher increases in weight in the last four weeks of pregnancy than those carrying singles, which may be attributed to the number of foetuses and greater development and growth of mammary glands and structure (Gall, 1981). However, single born kids weighed significantly ($P<0.05$) higher than the individual twin born kids although total weight of neonates was higher in twin litters (Table 3.10). It has been reported that individual birth weight was negatively correlated to litter size, although total weight of neonates increased with their number (Gall, 1981; Bee *et al.*, 1992). Similarly, Alexandre *et al.*, (1999) recorded significantly ($P<0.05$) higher weight at birth by 15% for single kids than multiple births in Creole kids.

Effect of litter size was also significant ($P<0.05$) for Y2 and Y3. Does with single kids maintained a better daily LWC than those with twins. This implied that higher milk yield by does with twins reflected negatively on their daily LWC due to greater mobilization of body reserves to maintain the high milk yields.

Effect of parity was significant ($P<0.05$) for milk yield, birth weight, pre-ADG and WWT. Multiparous does yielded significantly ($P<0.05$) more milk and had longer lactations than first kidders (Table 3.8). Increase in milk yield and lactation length with parity has been reported. Kinuthia *et al.*, (1998; 1999) reported increase in milk yield and lactation length with parity in dairy goat crosses in Kenya. Similarly, Torres-Acosta *et al.*, (1995a) reported increase in milk yield and lactation length with parity in Criollo goats in Yucatan Mexico.

Multiparous does bore kids that were significantly (P<0.05) heavier at birth and also grew significantly (P<0.05) faster to weaning than those born of primiparous does (Table 3.10). This concurs with the findings of Alexandre *et al.*, (1999) who reported significantly (P<0.01) higher birth weight for kids born to multiparous does as compared to those born to primiparous does in Creole kids. These differences could be attributed to age and body size of the dam. It has been reported that mature does are larger and have greater capacity to store more fat due to their ability to consume more feed (Gall, 1981). This had a positive effect on the growth of the foetus and after kidding to growth of the kid due to higher milk production as more nutrients were available for milk synthesis. Additionally older does had already attained physiological maturity (Awemu *et al.*, 1999) and thus partitioned feed nutrients only for maintenance and growth of the foetus and after kidding for maintenance and milk synthesis, unlike younger does which were still growing and partitioned feed nutrients for own growth in addition to foetal growth and maintenance. Foetuses of primiparous dams were also limited by the small body size of the dam and limitations of uterine expansion (Charagu, 1990).

Multiparous does also gained weight at a significantly (P<0.05) higher rate before kidding (Y1) compared to primiparous does. This could similarly be attributed to better body reserves. However, effect of parity on doe weight change during lactation (Y2 and Y3) was not significant (P>0.05) (Table 3.9). Interaction of management and treatment was not significant (P>0.05) for milk yield, daily LWC and kid performance. This was an indication that animals under both management systems responded similarly to treatment.

3.4.2 *Pre-weaning mortality*

The pre-weaning kid mortality rate was 26.25%. This was within the range reported for dairy goat breeds and their crosses in the tropics. In Nigeria mortality rate to weaning for Red Sokoto kids was 38.0% (Awemu *et al.*, 1999). Mtenga *et al.*, (1994) reported a pre-weaning mortality rate of 40.6% in East African, Boer X E. African and Kamorai X E. African in Tanzania. Banda, (1994) reported a lower rate of 18.9% for E. African, Boer and E. African X Boer crosses in Malawi. Kinuthia, (1998) also reported a lower rate at 10.2% for dairy goat crosses in smallholder farms in Central Kenya.

Cooper *et al*., (1996) reported a rate of 33.5% for the indigenous Malawi goat. Hussain *et al*., (1995) reported a higher rate of 55% in Black Bengal kids under adverse environmental conditions.

The pre-weaning mortality rates closely followed the performance trend of the kids and was higher under the confined management at 31.2 against 22.9% for free range; 31.7 for female kids against 20.5% for males and 41.7 for twin litters against 13.6% for single kids. There was a direct correlation between kid survival and dam's milk yield because kids mainly depended on the doe's milk for their nutrients supply before weaning. Nianogo and Ilboudo, (1994) noted that kid growth and survival was highly correlated to milk consumption. It was observed that kids with low birth weight (<2kg) were more susceptible than those with higher birth weights (>2kg). This is because kids with low birth weights have low energy reserves and are therefore more vulnerable. Similar findings of decreased mortality with increasing birth weight have been reported (Kochapakdee *et al*., 1994; Mtenga *et al*., 1994; Alexandre *et al*., 1999; Awemu *et al*., 1999).

Mortality rate was higher for kids born of primiparous does than those born of multiparous does. This could be due to a multiplicity of factors. Primiparous does were observed to have lower milk yield than older does which would have a direct negative effect on their kids during the pre-weaning period. Additionally, most kids born to primiparous does weighed less than 2 kg at birth and were therefore more susceptible. This could have been due to the small body size and limitations of uterine expansion (Charagu, 1990). Primiparous dams have also been reported to have poorer mothering ability than older dams (Inyangala *et al*., 1990; 1992; Hirooka *et al*., 1997; Kinuthia, 1998). Awemu *et al*., (1999) also reported decreased kid mortality with increasing parity and attributed this to physiological maturity of older does as well as their higher milk yield. However, Butswat *et al*., (1995) reported an increase in mortality rate with parity due to an increased twinning rate with parity.

3.4.3 *Milk Components*

The mean percentages of milk components obtained in this study were 16.71±0.28, 6.08±0.19, 10.63±0.17, 4.64±0.05 and 5.87±0.06% for Total solids (TS), Butter fat (BF), Solids-not-fat (SNF), Total protein (TP) and Lactose (L) respectively. The respective means for Calcium (Ca) and Phosphorus (P) were 146.69±3.44 and 119.10±1.72 mg/100g (Table 3.11). This composition was consistent with those reported for various tropical dairy goat breeds and their crosses (Lyatuu *et al.*, 1994; Nianogo and Ilboudo, 1994; Stemmer *et al.*, 1995; Torres-Acosta *et al.*, 1995b; Cooper *et al.*, 1996).

Table 3.11 Milk composition of dual-purpose goats

Variable	MY (g/d)	TS %	BF %	SNF %	TP %	Lactose %	Ca (mg/100g)	P (mg/100g)
Overall Mean	514.17±14.78	16.71±0.28	6.08±0.19	10.63±0.17	4.64±0.05	5.87±0.06	146 69±3.44	119.10±1.72
Management								
1	587.35±11.88^{a}	15.72±0.42	5.30±0.23^{a}	10.42±0.23	4.52±0.06	5.91±0.08	144 36±4.87	122.82±2.43
2	440.98±11.07^{b}	17.70±0.40	6 86±0.26^{b}	10.84±0.24	4.76±0.04	5.83±0.04	149.02±4.83	115.39±2.41
Stage of Lactation								
1	651.11±6.72^{a}	16.17±0.49	5.82±0.33	10.35±0.29	4.55±0.08	5.80±0.13	135.37±5.90	110.75±2.98
2	486 26±7.75^{b}	16.81±0.52	6.05±0.32	10.76±0.24	4.59±0.07	5.81±0.10	138.73±5.96	113.79±2.97
3	405.14±8.91^{c}	17.16±0.48	6.38±0.34	10.78±0.22	4.79±0.04	5.99±0.17	165.96±5.93	132.77±2.93
Treatment								
1	307.38±33.00^{a}	18.28±0.63	7.28±0.42^{a}	11.00±0.37	4.84±0.10	5.89±0.13	150.29±7.69	119.65±3.84
2	490.81±30.21^{b}	16.90±0.69	6.24±0.44^{b}	10 66±0.32	4.60±0.11	5.99±0.19	145.76±7 64	117.55±3.87
3	726.50±30.16^{c}	15.02±0.65	4.85±0.45^{c}	10.17±0.39	4.54±0.17	6.14±0.11	146.78±7.67	112.96±3.85
4	439.11±31.02^{b}	17.11±0.60	6.44±0.48^{b}	10.67±0.34	4.62±0.18	5.61±0.14	139.63±7.66	121.26±3.80
5	607.03±30.27^{c}	16.21±0.61	5.59±0.41^{bc}	10.62±0.36	4.58±0.15	5.71±0.18	150.99±7.62	124.11±3.83

MY Milk yield; TS, Total solids; BF, Butter fat; SNF, Solids-not-fat; TP, Total protein; Ca, calcium; P, Phosphorus. Means within a column that have different superscripts ^{a} are significantly different.

Effect of treatment was only significant (P<0.05) for butterfat content. Milk from the control group had significantly (P<0.05) higher butter fat content than that from the supplemented groups. This could have been due to the higher fibre content of the control diet than the supplemented diets (Table 3.2). Diets with less fibre content have been associated with lower BF (Muia, 2000). Additionally, supplemented diets had higher content of rumen fermentable OM and rumen degradable CP (Chapter 6), hence less acetate and more propionate fermentation than the control diet (Chapter 5). Reduced acetate fermentation has been associated with low BF (Sutton *et al.*, 1987). Higher acetate propionate ratio for the control diet than the supplemented diets was recorded in the current study (Chapter 5).

When the two management systems were compared, milk from goats on confined feeding had significantly ($P<0.05$) higher BF%. This would suggest that goats under the free-range system were able to select a less fibrous feed than the Rhodes grass hay offered as the basal diet under the confined feeding system. Although effect of stage of lactation was not significant ($P>0.05$) milk components tended to increase with advancing lactation. This could have been due to a significant ($P<0.05$) decrease in daily milk yield with advance in stage of lactation (Table 3.11). Torres-Acosta *et al.*, (1995b) and Ondiek *et al.*, (1999) reported increase in BF, TS and TP with advance in lactation. Similarly, Kala and Prakash, (1990) and Prasad and Sengar, (2002) observed that milk components especially BF, SNF and TS tended to increase with advancing lactation and that milk yield declined gradually with stage of lactation.

The mean BF% (6.08%) obtained in this study was consistent with those reported elsewhere. Stemmer *et al.*, (1995) reported BF% of 5.76 - 6.51% for crosses of the local Malaysian goat (Kambing Katjang) with German Fawn. Torres-Acosta *et al.*, (1995b) recorded a lower BF% of 4.03 - 4.22% for Criollo goats in Yucatan Mexico. Cenkvari, *et al.*, (2005) recorded a range of 3.77 - 4.72% for Saanen goats. Morgan *et al.*, (2003) reported a BF% of 5.14, 4.27 and 3.65% for Greek, Portuguese and French goats respectively.

The protein content (4.64%) obtained in the current study was similar to 4.87% by Stemmer *et al.*, (1995) for Malaysian goats and 5.3% by Cooper *et al.*, (1996) for Malawian goats. The amount of calcium and phosphorus, 146.69 mg/100g and 119.10 mg/100g, respectively obtained in this study corresponded with 130 mg/100g and 107 mg/100g respectively reported by Furber, (1985) and 125 mg/100g for calcium reported by Cooper *et al.*, (1996). Morgan *et al.*, (2003) reported similar values for Ca of 130.0, 134.5 and 140.0 mg/100g for Greek, French and Portuguese goats respectively.

The milk from dual-purpose goats was higher in the major constituents compared to cow's milk. With 4.64% TP, 6.08% BF and 146.69 mg/100g Ca, 200 ml of this milk would provide 9.5 g high quality protein, 12 g fat and 300 mg Ca compared to 6 g protein, 7 g fat and 240 mg Ca from same amounts of cow milk.

3.4.4 *Economic analysis*

Using the available data generated in this study, a simple analysis was done to assess the benefits of supplementation on 500 g doe^{-1}day^{-1} of *Calliandra* and Lucerne in terms of the higher milk production and kid growth as shown in Table 3.12. Results from animals on free-range management system were used in the economic analysis because the yields and the basal diet approximated more to the yields and mixed diet on smallholder farms (Kinuthia, 1998) than the Rhodes grass hay offered under the confined trial. The assumptions were that labour costs for both supplemented and unsupplemented does were equal and that *Calliandra* and Lucerne stands were already established in the farms, thus the cost of establishment was not included in the analysis.

Table 3.12 A simple economic analysis of goat milk production

Item	*Calliandra*	Lucerne	Control
Milk yield (kg) per lactation per year (A)	264.29	212.62	81.96
Daily milk consumption (kg) per kid (B)	0.56	0.50	0.31
Total milk consumed (kg) - (kidding - weaning) - 4 months (120 days) (C)	67.20	60.00	37.20
Milk (kg) available for sale (D) = (A) - (C)	197.09	152.62	44.76
Pre-ADG (g day^{-1}) of the kids (E)	112.41	90.65	57.37
Additional kid growth (g day^{-1}) (supplemented - control) (F)	55.04	33.28	-
Additional kid weight weaned (kg) per doe (G) = (F*120)/1000	6.60	3.99	-
Income from milk sales (H) - @ kshs 40/kg = (D*40)	7883.60	6104.80	1790.40
Profit due to supplementation (I) = (H-1790.40)	6093.20*	4314.40*	-

*Current exchange rate: Kshs 70=US$1

Based on the above simple economic analysis, supplementation with *Calliandra* and Lucerne, would give an estimated extra income per doe per year of Kshs 6,093 and 4,314 from milk sales for *Calliandra* and Lucerne respectively, in addition to extra kid weight (6.60 kg - *Calliandra*; and 3.99 kg - Lucerne) weaned per doe per lactation.

Of the two legume supplements, *Calliandra* grown on-farm has a number of advantages including reduced cost of weeding because *Calliandra* would smother annual weeds. Additionally, unlike

Lucerne, which thrives well as a pure stand, *Calliandra* has been successfully intercropped with food crops reducing the cost of fertilizers for such crops due to the beneficial effects of nitrogen fixation. And it has higher biomass yields of 12.4 - 26.2 t DM/ha/yr (Palmer and Ibrahim, 1996) compared to 9 - 1.4 t DM/ha/yr (Odongo *et al.*, 1999; Wanyama *et al.*, 2000) for Lucerne.

3.5 *Conclusions*

Results from this study indicated that free-range grazing provided a better diet to the lactating does than the Rhodes grass hay offered under the confined feeding system. Under both management systems supplementation improved milk yield performance, persistency, daily LWC and kid performance. Does on the control diet lost weight during the kid-rearing phase unlike the supplemented groups an indication that supplementation with protein sources was important at maintaining positive daily LWC during lactation.

At same level of supplementation, goats on *Calliandra* performed better than those on Lucerne based diets, an indication that *Calliandra* was superior to Lucerne as a supplement for goats. It was more economically viable to supplement dual-purpose goats on *Calliandra* than Lucerne. It was therefore, concluded that *Calliandra* could effectively be utilized as a protein supplement to improve lactational performance of dual-purpose goats and performance of their kids. Based on these findings it would be recommended that future potential users especially smallholder farmers on semi-stall management systems, be encouraged to grow and supplement their dual-purpose goats with *Calliandra*.

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CHAPTER 4

Effect of supplementing weaner goats with graded levels of Calliandra calothyrsus and Lucerne (Medicago sativa) on nutrients intake and weight gain

Effect of supplementing weaner goats with graded levels of *Calliandra calothyrsus* and Lucerne (*Medicago sativa*) on nutrients intake and weight gain

4.1 Abstract

A study was conducted to investigate the effects of supplementation with graded levels of two (2) protein-rich forages (PRFs), *Calliandra calothyrsus* and Lucerne (*Medicago sativa*) on nutrients intake and growth rate of dual-purpose weaner goats under two management systems [confined feeding (CF) and free-range (FR)]. Sixty (60), four (4) month old weaner goats (30 for each management system) were randomly allocated to 5 treatment diets with graded levels of *C.calothyrsus* and Lucerne in a randomized complete block design. Composition of the 5 treatment diets as fed was as follows:- T1 (control) - Rhodes grass hay only or grazing only for CF or FR respectively, T2 and T3, 100 and 200 gd^{-1} of *C.calothyrsus* respectively; T4 and T5, 100 and 200 gd^{-1} of Lucerne respectively. Feed intake was recorded daily, while the weaners were weighed weekly throughout the experimental period (8 months). The overall mean post-weaning average daily gain (post-ADG) (gd^{-1}) and yearling live-weight (YWT) (kg) for all the weaners were 40.85 and 17.30 respectively. Weaners under FR system performed significantly ($P<0.05$) better in post-ADG and YWT than those under CF. The average post-ADG (gd^{-1}) and YWT (kg) for the two systems were 46.8±1.25 and 19.4±0.31; and 34.9±1.29 and 15.2±0.38 respectively. Increase in level of supplementation significantly ($P<0.05$) increased OMI (gd^{-1}) for both types of supplements under CF where this was assessed from 220.0, for the control to 350.9, 578.8, 316.8 and 483.6 for T2 to T5 respectively. Weaners on *Calliandra* had significantly ($P<0.05$) higher post-ADG and YWT than those on Lucerne based diets and the control. For CF, the respective values for post-ADG (gd^{-1}) for T1 to T5 were, 17.4, 30.8, 56.8, 26.1 and 40.1. The respective values for FR were, 32.2, 46.1, 61.3, 41.1 and 50.0. The values for YWT (kg) for CF were 12.0, 14.6, 20.0, 12.8 and 16.3 for T1 to T5 respectively. For FR the respective values were 15.6, 19.6, 23.0, 17.3 and 21.4. At both levels of supplementation under both management systems weaners on *Calliandra* performed significantly ($P<0.05$) better than those on Lucerne based diets in post-ADG and YWT. Results from this study indicated that supplementation with PRFs improved weaner growth rate under both systems and that FR was superior to Rhodes grass hay offered under the CF system and *Calliandra* superior to Lucerne.

Key words: *dual-purpose goats; supplementation; protein-rich forages; post-weaning growth*

4.2 *Introduction*

Goats are found in many parts of Kenya and are an important source of income to many smallholder farmers, because, due to their small size they are more easily convertible to cash than cattle (Payne, 1990). They provide higher off-take than cattle because of their shorter generation interval and higher prolificacy. Annual off-take can be as high as 60% (Payne, 1990). The goat has a high twinning rate and in favourable environments, they attain a twinning rate of over 70% by second kidding. Awemu *et al.*, (1999) reported a high twinning rate of 62% for Red Sokoto goats, and Alexandre *et al.*, (1999) a rate of 59.7% for Creole goats.

In many parts of the tropics, animal productivity including that of goats is constrained by frequent feed shortages occasioned by dry seasons and droughts. During such periods animals are mainly dependent on poor quality grasses and crop by-products with little or no supplementation, leading to low animal performance (Kariuki, 1998). Supplementation of low quality grass based diets with legumes has been shown to increase dry matter intake and animal performance (Kaitho, 1997). These responses have typically been attributed to the legume overcoming the depressing effect that the low N concentration in grass has on intake and by the legume providing rumen degradable N or rumen escape N (Minson, 1990). Feeding systems that make greater use of locally grown feed resources such as leaves of protein-rich forages (PRFs) would provide alternatives to the more expensive cereal based concentrates (Nguyen and Preston, 1997).

Calliandra calothyrsus is a leguminous shrub, high in CP content (200 - 300 g kg^{-1}DM) (Paterson *et al.*, 1996). It yields well (12.4 - 26.2 t DM/ha/yr) in a range of environments and is tolerant to acidic soils (Palmer and Ibrahim, 1996). Supplementation with *Calliandra* leaf meal has been shown to improve DMI and growth in goats (Ebong, 1996). However, data on *Calliandra* supplementation in goats in the country is scarce. Lucerne is a well-established leguminous fodder in the country and has a high CP content (160 - 210 g kg^{-1}DM) (Kariuki, 1998; Odongo *et al.*, 1999). It is mainly grown in medium and large-scale farms and fed as hay as a dairy cattle supplement especially during the dry season. Improved growth in Saanen goats supplemented with Lucerne has been recorded (Muhikambele *et al.*, 1996). However, little information is available in Kenya on the use of Lucerne in goat production.

Therefore, the objective of this study was to determine the effects of supplementing graded levels of *Calliandra calothyrsus* and Lucerne to weaner goats on growth and nutrients intake under two management systems.

4.3.0 *Materials and methods*

Experimental site, feed sources, preparation and sampling, estimation of DMI and chemical analysis of feed samples were as described in Chapter 3.

4.3.1 *Experimental diets*

Composition of the 5 experimental treatment diets (T) as fed was as follows:- T1, control; T2 and T3, 100 and 200 g goat^{-1} day^{-1} of *Calliandra calothyrsus* respectively; T4 and T5, 100 and 200 g goat^{-1} day^{-1} of Lucerne (*Medicago sativa*) respectively. T1 was Rhodes grass hay only for confined feeding, while for the free range it was grazing only. All the goats on confined feeding were offered Rhodes grass hay *ad libitum* as the basal diet. Grazing in a natural thorn bush land savannah provided the basal diet for those on free-range. As for the doe diets, these supplementation levels were selected to ensure that supplement intake was within the recommended range of 30 - 40% of the daily DM intake.

4.3.2 *Experimental animals, housing, feeding and management*

Sixty (60) weaner kids at the age of 4 months (16 weeks) and a mean live-weight of 9.95±0.41 for the confined feeding and 11.79±0.46 kg for the free-range trials were recruited for the study. They were housed in individual wooden pens measuring 1x3 m on a wooden slated floor and randomly allocated to the 5 treatment diets in a randomized complete block design (Steel and Torrie, 1996). Each treatment group comprised of six (6) goats and was balanced for sex of the goats. The feeding trial was conducted for eight (8) months up to the age of one (1) year and yearling live weight recorded. For the confined feeding trial, Rhodes grass hay was offered *ad libitum* as the basal diet for all the treatments. The daily offer for Rhodes grass hay was estimated using the previous day's intake and adding a 10% allowance (Kariuki, 1998). Each morning, the previous days residues (refusals) were removed and weighed before fresh feed and water were offered. The grass hay was fed in troughs and the supplement in plastic buckets. The grass hay and supplements were fed twice daily, half in the morning (08.00 hours) and the other half in the afternoon (14.00 hours). The pplement was always provided first and all of it was consumed. Water and mineral block (Maclik^R rick) were provided *ad libitum*.

For the free-range trial, the weaners were housed in similar facilities as those on confined feeding and the supplement was similarly fed individually (in plastic buckets) in two meals, half in the morning (08.00 hours) and the other half in the afternoon (16.00 hours). After the morning feeding (08.00 - 09.00 hours), the weaners were released for grazing. They were grazed for approximately 8 hours daily in a natural thorn bush land savannah. In the afternoon (16.00 hours) they were brought back to the night enclosure where the second half of the supplement was offered. As for the confined feeding the animals consumed the entire supplement on offer. Water and mineral block (Maclik^R brick) were provided within the night enclosure. At the beginning of the experiment the weaners (in both management systems) were sprayed with an acaricide (Triatix^R) to control ecto-parasites and dewormed with an antihelminthic (Nilzan^R) to control endo-parasites. During the experimental period they were sprayed fortnightly and dewormed after every 3 months.

4.3.3 *Data Collection*

The weaners were weighed weekly, at same time and day in the morning before feeding. This was done for eight (8) months until they were one (1) year old and yearling live weight recorded.

4.3.4 *Statistical analysis*

The average daily weight gain (ADG) (g/d) over the experimental period was calculated by egressing body weight (kg) of individual animal measured at weekly intervals with time (in days). Feed utilization efficiency (FE) for the animals on confined feeding management system, was alculated as the ratio of body weight gain in grammes (g/d) per gram of DM intake (g/d) (Kariuki, 1998). The least squares and maximum likelihood procedures of Harvey, (2000) were used to etermine effect of treatment on nutrients intake, post-weaning growth rate (post-ADG), yearling ive-weight (YWT) and FE. Also analyzed were effects of management, type of birth, sex of weaner nd parity of doe on post-ADG and YWT.

Factors fitted in the fixed statistical models included:- Treatment diet, sex, type of birth, management and parity. For the purposes of data analysis these factors were coded as follows:- Treatment diet 1 - 5 as described above. Sex 1 and 2 for male and female respectively. Type of birth 1 and 2 for singles and twins respectively (there were no triplet births). Parity 1 - 5. Management system 1 and 2 for free-range and confined feeding systems respectively.

Analysis of nutrients intake and post-weaning growth

Model I:- $Y_{ijk} = \mu + T_i + e_{ijk}$ [To determine effect of treatment on nutrients intake and FE.]

Model II:- $Y_{ijklmn} = \mu + T_i + S_j + TB_k + P_l + M_m + e_{ijklmn}$ [To determine effects of treatment, sex, type of birth, parity and management on post-weaning ADG and yearling live-weight (YWT)]

Where,

Y_{ijk} = Nutrients intake (g day^{-1}).

Y_{ijklmn} = Either, post-weaning ADG (g) or YWT (kg).

μ = The underlying constant common to all observations.

T_i = Effect due to ith treatment diet (i = 1,...,5)

S_j = Effect due to jth sex of weaner (j = 1,2).

TB_k = Effect due to kth type of birth (k = 1,2,)

P_l = Effect due to lth parity (l = 1,…,5)

M_m = Effect due to mth management system (m = 1,2)

e_{ijklmn} = The random error term, associated with each observation.

4.0 *Results and discussion*

The chemical composition of feed ingredients is presented in Table 4.1 The DM content of Rhodes grass hay, *Calliandra* and Lucerne were 924.9, 925.3 and 905.4 gkg^{-1} respectively. The CP contents were 77.4, 248.3 and 194.2 g kg^{-1}DM for hay, *Calliandra* and Lucerne respectively. The CP content of hay was higher than 43 g kg^{-1}DM reported by Woyengo, (2001), but lower than 83 g kg^{-1}DM by Biwott, (2000). However, it was within the range of 40 - 112 g kg^{-1}DM for tropical grasses (Van Soest, 1994). The fibre content of Rhodes grass hay was higher than that of the legumes.

The CP content of *Calliandra* was within the range of 200 - 300 g kg^{-1}DM reported by Paterson *et al.* (1996), while that of Lucerne was within the range of 160 - 210 g kg^{-1}DM (Kariuki, 1998; Odongo *et al.*, 1999). The ME (MJ kg^{-1}DM) values estimated from the chemical composition were higher for the legumes than that of hay (9.09 MJ kg^{-1}DM), *Calliandra* (9.89) being higher than for Lucerne (9.52). The levels of Calcium (Ca) and Phosphorus (P) were higher in Lucerne than *Calliandra* and Rhodes grass hay and in agreement with those reported elsewhere (Kaitho, 1997; Kariuki, 1998). The lower NDF in Lucerne and *Calliandra* compared to hay was consistent with the general observation of lower NDF in legumes than grasses (Minson, 1990).

Table 4.1 Chemical composition (g kg^{-1}DM) of the feed ingredients

	Rhodes grass hay	*Calliandra calothyrsus*	Lucerne
Dry matter (g kg^{-1})	924.9±2.11	925.3±6.00	905.4±7.27
Chemical Composition (g kg^{-1}DM)			
Organic matter	827.2±3.56	854.9±6.42	801.1±5.98
Crude Protein	77.4±5.20	248.3±1.89	194.2±17.60
Calcium (Ca)	3.9±0.67	9.2±0.27	10.2±0.67
Phosphorus (P)	3.3±0.87	2.2±0.36	4.1±0.20
Neutral detergent fibre	723.4±1.69	406.12±9.73	520.8±7.62
Acid detergent fibre	405.5±7.28	220.4±12.31	364.4±2.71
Acid detergent lignin	65.8±0.60	57.6±3.76	77.7±0.51
Ash	97.7±0.38	70.4±0.42	104.3±3.64
Hemicellulose	317.9±2.64	197.6±9.76	153.5±8.64
Cellulose	339.7±5.31	132.9±8.56	289.7±2.20
Ether Extract (Crude fat)	12.3±0.36	14.7±2.69	8.4±0.76
*Estimated ME (MJ kg^{-1}DM)	9.09±0.01	9.89±0.51	9.52±0.36

*Estimated ME (MJ kg^{-1}DM) calculated using the equation:- OMD% = 91.9 - (0.355*NDF%) + (0.387*ADF%) - (2.17*ADL%) - (0.39*EE%); DOM% = (0.92*OMD%) - 1.2; ME = DOM%*0.15 (Muia, 2000). ADF = Acid detergent fibre; ADL = Acid detergent lignin; DOM = Digestible organic matter; EE = Ether extract; ME = Metabolizable energy; NDF = Neutral detergent fibre; OMD = Organic matter digestibility.

e chemical composition of the treatment diets is presented in Table 4.2. This was estimated based n the ratio of hay to legume in each diet as consumed using the average composition values of each gredient. DM and OM content increased progressively with increase in the proportion of *Calliandra* ut decreased with increased levels of Lucerne. These differences reflect the lower DM and OM content f Lucerne compared to *Calliandra* and Rhodes grass hay (Table 4.1).

able 4.2 Chemical composition (g kg^{-1}DM) of the treatment diets

atment	T1	T2	T3	T4	T5	SED
y matter (g kg^{-1})	924.9^{a}	925.0^{b}	925.0^{b}	920.3^{c}	918.8^{c}	0.72
hemical Composition (g kg^{-1}DM)						
rganic matter	827.2^{a}	833.3^{b}	834.6^{b}	821.0^{c}	819.1^{c}	1.32
ude Protein	77.4^{a}	113.8^{b}	123.0^{c}	105.3^{d}	114.9^{b}	1.94
alcium (Ca)	3.9^{a}	5.1^{b}	5.3^{bc}	5.4^{bc}	5.9^{c}	0.25
hosphorus (P)	3.3	3.1	3.0	3.5	3.6	0.31
eutral detergent fibre	723.4^{a}	653.7^{bc}	638.8^{c}	675.1^{b}	660.3^{bc}	10.76
cid detergent fibre	405.5^{a}	364.9^{b}	356.1^{c}	395.7^{a}	392.7^{a}	5.58
cid detergent lignin	65.8^{a}	64.0^{b}	63.6^{c}	68.6^{d}	69.5^{e}	0.25
	97.7^{a}	91.7^{b}	90.4^{c}	99.3^{d}	99.7^{e}	0.20
emicellulose	317.9^{a}	291.5^{ab}	285.8^{ab}	278.7^{ab}	266.7^{b}	14.37
ellulose	339.7^{a}	294.3^{b}	284.5^{c}	327.8^{ad}	324.1^{d}	5.74
her Extract (Crude fat)	12.3^{a}	12.8^{b}	12.9^{b}	11.4^{ac}	11.1^{c}	0.15
Metabolizable Energy (MJ kg^{-1}DM)	9.1^{a}	10.5^{b}	10.9^{b}	10.3^{b}	10.7^{b}	0.30

ME = DOM%*0.15 (Muia, 2000), DOM% obtained from the *in-vivo* digestibility trial. DOM = Digestible organic matter. SED, Standard error f difference between means; Different superscripts ^{a} within a row indicate significant difference (P<0.05).

The ME values (MJ kg^{-1}DM) of the treatment diets, estimated from the *in-vivo* OM digestibility, was gnificantly ($P<0.05$) lower for the control diet than the supplemented diets, which were similar (P>0.05). The CP content was significantly ($P<0.05$) higher for the supplemented diets than the control. It ranged from 77.4 (T1) to 123.0 g kg^{-1}DM (T3) and increased ($P<0.05$) with proportion of the supplement in the diet for both supplements. Supplementation reduced NDF and ADF levels due to lower NDF and ADF levels for the legumes (Table 4.1). ADL differed significantly ($P<0.05$) across the iets decreasing with *Calliandra* but increasing with Lucerne supplementation. T5 had the highest levels of Calcium and Phosphorus. These compositional variations of the diets reflected the differences in composition of *Calliandra* and Lucerne (Table 4.1) and level of supplementation (Table 4.2).

4.1 Nutrients intake and post-weaning growth

The estimated nutrients intake and post-weaning growth are presented in Tables 4.3 and 4.4, and Figures 4.1 and 4.2. The overall mean post-weaning average daily gain (Post-ADG) and yearling live-weight (YWT) obtained in this study for all the weaners were 40.89 g day^{-1} and 17.30 kg respectively.

Table 4.3 Nutrients intake, post-weaning average daily gain (post-ADG) and yearling live-weight (YWT) of weaner goats under the confined feeding management system

	Treatments							
	T1	T2	T3	T4	T5	SED	NRQ	Significance
Nutrients intake								
HDMI (g day^{-1})	266.0^{a}	328.6^{b}	508.4^{c}	295.3^{d}	409.2^{e}	13.79		**
TDMI (g day^{-1})	266.0^{a}	421.1^{b}	693.5^{c}	385.8^{d}	590.3^{e}	13.79		***
TDMI (g kg^{-1}W$^{0.75}$)	40.4^{a}	63.9^{b}	105.3^{c}	58.6^{d}	89.6^{e}	2.09		***
TOMI (g day^{-1})	220.0^{a}	350.9^{b}	578.8^{c}	316.8^{d}	483.6^{e}	11.41		***
TCPI (g day^{-1})	20.6^{a}	48.4^{b}	85.3^{c}	40.4^{d}	66.8^{e}	1.07		***
◊DCPI (g day^{-1})	13.0^{a}	34.1^{b}	65.0^{c}	27.9^{d}	47.7^{e}	0.73	12-15	***
MEI (MJ day^{-1})	2.5^{a}	4.0^{b}	6.5^{c}	3.6^{d}	5.4^{e}	0.13	2.3	***
Post-weaning growth								
Post-ADG (g goat^{-1}day^{-1})	17.4^{a}	30.8^{b}	56.8^{c}	26.1^{d}	40.1^{e}	2.40		***
Yearling live weight (YWT) (kg)	12.0^{a}	14.6^{b}	20.0^{c}	12.8^{d}	16.3^{e}	0.53		***
ΔFeed utilization efficiency (FE)	0.065^{a}	0.073^{b}	0.082^{c}	0.068^{d}	0.068^{d}	0.004		*

HDMI, Hay DM intake; TDMI, Total DM intake; TOMI, Total OM intake, TCPI, Total CP intake; DCPI, Digestible CP intake; MEI, Metabolizable energy intake; NRQ, Nutrient requirements for maintenance of a 10 kg live-weight goat (NRC, 1981; Furber, 1985; Peacock, 1996); ◊DCPI estimated from the *in-vivo* digestibility trial; ΔFE= ADG gd^{-1}/DMI gd^{-1} (Kariuki, 1998). SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); *, $P<0.05$, **, $P<0.01$; ***, $P<0.001$;

For the confined feeding system, TDMI (gd^{-1} and gkg^{-1}W$^{0.75}$) increased with level of supplementation (Table 4.3) it was highest for T3 and lowest for the control. Similar trends were observed for TOMI. Metabolizable energy intake (MEI MJ day^{-1}) increased with level of supplementation and differed significantly ($P<0.05$) across the diets. The MEI for all the diets was above the minimum requirements for maintenance of a 10 kg live-weight goat estimated at 2.3 MJ day^{-1} (Peacock, 1996).

The total crude protein intake (TCPI) g day^{-1} increased with level of supplementation. For the confined feeding it increased from 20.6 g day^{-1} for the control to 48.4, 85.3, 40.4 and 66.8 for T2, T3, T4 and T5 respectively and differed significantly ($P<0.05$) between the diets (Table 4.3). TCPI was ffected by level and type of supplement. These differences reflected the CP content of the treatment ets (Table 4.2). Similarly, the DCPI (estimated from the *in-vivo* digestibility trial), increased with vel of supplementation and was above the minimum requirements for maintenance of a 10 kg live-eight goat estimated at 12 - 15 g day^{-1} (NRC, 1981; Furber, 1985; Peacock, 1996) for all the diets.

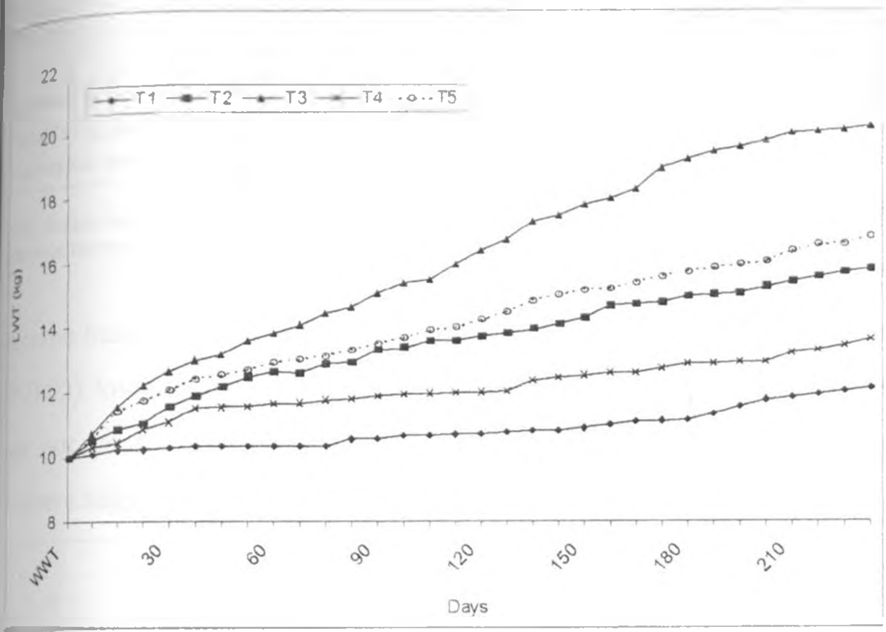

Figure 4.1 *Post-weaning growth for the weaners under the confined feeding management system*

Results on performance of weaners under the free-range management system (Table 4.4 and Figure 4.2), reflected those of weaners under the confined management system and the response to level of supplementation was similar under both systems.

The improved nutrition of the weaners with supplementation resulted in higher average daily gain and yearling live-weight (Tables 4.3 and 4.4; and Figures 4.1 and 4.2). The post-weaning growth rate and yearling live-weight were significantly (P<0.05) different across the diets and increased with level of supplementation under both management systems (Tables 4.3 and 4.4). This could be explained by the increased nutrients intake with supplementation (Tables 4.3 and 4.4). At same level of supplementation weaners on *Calliandra*, performed significantly (P<0.05) better than those on

Table 4.4 Supplement DMI, OMI and CPI, post-weaning average daily gain (post-ADG) and yearling live-weight (YWT) of weaner goats under the free-range management system

	Treatments						
	T1	T2	T3	T4	T5	SED	Significance
Supplement intake							
SDMI (g day^{-1})	0	92.5	185.1	90.5	181.1	N/A	N/A
SOMI (g day^{-1})	0	79.1	158.2	72.5	145.1	N/A	N/A
SCPI (g day^{-1})	0	23.0	45.9	17.6	35.2	N/A	N/A
Post-weaning growth							
Post-ADG (g goat^{-1}day^{-1})	32.2^{a}	46.1^{b}	61.3^{c}	41.1^{d}	50.0^{e}	2.05	***
Yearling live weight (YWT) (kg)	15.6^{a}	19.6^{b}	23.0^{c}	17.3^{d}	21.4^{e}	0.50	***

SDMI, Supplement DM intake; SOMI, Supplement OM intake; SCPI, Supplement CP intake; N/A, Not applicable; SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); ***, $P<0.001$.

Lucerne based diets under both management systems. Animals on the control diet had significantly ($P<0.05$) lower post-ADG and YWT under both systems. Under the free-range system, although it was not possible to estimate intake from pastures, the better performance of the supplemented weaners suggested improved nutrition.

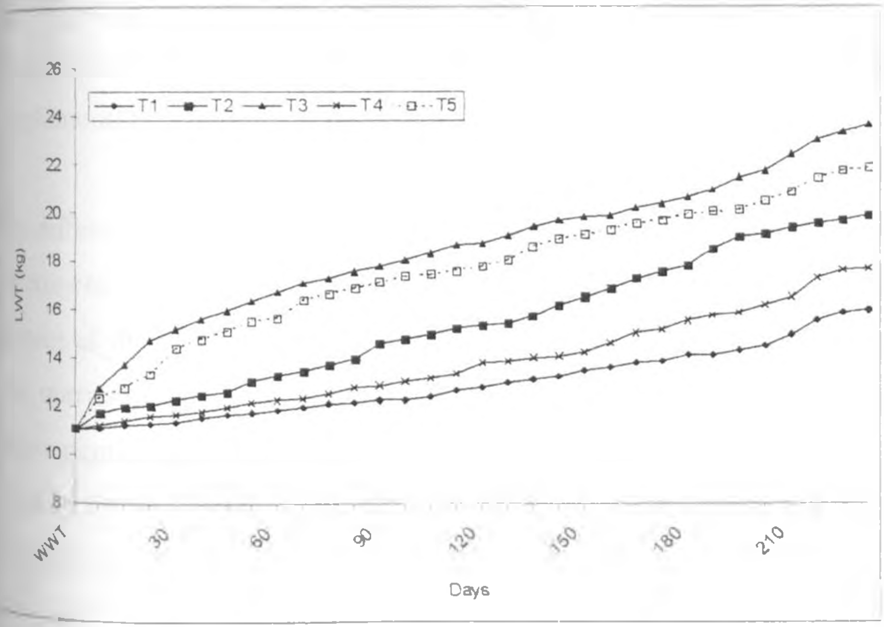

Figure 4.2 ***Post-weaning growth for the weaners under the free-range management system***

For the confined feeding, post-ADG increased with supplementation by 226 and 130% from 17.4 g day^{-1} for the control to 56.8 and 40.1 g day^{-1} at the higher level of supplementation with 200 g day^{-1} of *Calliandra* and Lucerne respectively. The respective improvements in yearling live-weight were and 36% from 12.0 kg (control) to 20.0 and 16.3 kg. Similarly, for the free-range, average daily gain increased by 90 and 55% from 32.2 (control) to 61.3 and 50.0 g day^{-1} at 200 g day^{-1} supplementation level for *Calliandra* and Lucerne respectively. The respective increases in yearling live-weight were 47 and 37% from 15.6 (control) to 23.0 and 21.4 kg.

Under the confined feeding system, supplementation improved post-ADG and YWT from the range of 10.6 to 22.2 g day^{-1} and 10.1 to 12.5 kg respectively on the control diet to within the range of 25.8 to 74.7 g day^{-1} and 12.6 to 25.6 kg for post-ADG and YWT respectively for the supplemented weaners. For the free-range flock, supplementation improved post-ADG and YWT from the range of 31.1 to 34.5 g day^{-1} and 14.3 to 16.9 kg respectively for the control group to within the range of 35.5 to 78.9 g day^{-1} and 17.0 to 29.6 kg for post-ADG and YWT respectively for the supplemented weaners.

Weaners on *Calliandra* based diets showed significantly ($P<0.05$) higher feed utilization efficiency (FE) T3 being highest, than those on Lucerne based diets, which were similar ($P>0.05$) at both levels of supplementation. Those on the control had the lowest FE (Table 4.3). This was an indication that supplementation with legumes improved FE of the diet.

The differences in performance in post-ADG and YWT with different diets, was a reflection of the differences in composition of the diets (Table 4.2). Performance was affected by DMI and nutrients content of the diets. It was observed that the supplements improved both DMI (Tables 4.3 and 4.4) and nutrients content of the diets (Table 4.2). The current study assessed the potential of supplementing Rhodes grass hay with graded levels of *Calliandra* and Lucerne to improve post-weaning performance of weaner goats. The parameters studied indicated that supplementation with legumes improved quality of the diets (Table 4.2), nutrients intake (Tables 4.3 and 4.4) and subsequently resulted in higher animal performance in terms of improved post-ADG (Tables 4.3 and 4.4).

Protein supplementation improved the rumen environment through increased ammonia concentration (Chapter 5) and available energy as a result of higher DMI thus improved microbial activity and the sultant digestibility (Osuji *et al.*, 1995; Kariuki, 1998). This was reflected as improved growth and ficiency with which the feed was utilized for the supplemented weaners compared to the control. chinda *et al.*, (1994) concluded that legumes increased the efficiency of utilization of the basal diet rough a catalytic effect on feed utilization.

This study demonstrated that supplementation of Rhodes grass hay with legumes improved DMI and the subsequent post-ADG from 17.4 g day^{-1} on hay alone with a CP content of 77.4 g kg^{-1}DM ithout legume to between 26.1 and 56.8 g day^{-1} (Table 4.3) when the grass was supplemented. These results concur with those reported by other researchers. Ebong, (1996) and Kaitho, (1997) showed that supplementing grass-based diets with legumes improved post-ADG of growing goats. bong, (1996) reported post-ADG in goats of 27.1 for the control on Elephant grass only and 67.0 g day^{-1} when they were supplemented on *Calliandra* leaf meal. Kaitho, (1997) reported a post-ADG of 32.3 g day^{-1} in weaner goats supplemented on *Luecaena pallida*, while the control on teff straw and wheat bran had lower post-ADG of 4.9 g day^{-1}.

Similarly, Palmer and Ibrahim, (1996) reported increased live-weight gain, OMI, OM and N digestibility and increased wool production in sheep supplemented on *Calliandra*. The same authors showed an increasing wool production with increasing levels of *Calliandra* intake for a diet of grass hay. In Zambia, Phiri *et al.*, (1994) observed that supplementation of local goats with *Calliandra* resulted in improved weight gain. Similarly, in Zimbabwe, Dzowela, *et al.*, (1994) reported increased DMI in local sheep and goats and improved weight gain when unimproved pasture hay was supplemented with *Calliandra*. In Kenya, Njarui *et al.*, (2000) observed that supplementation with legumes improved growth rate in Kenya dual-purpose goats on a basal diet of natural grasses.

Weaners under the free-range management system performed significantly ($P<0.05$) better with an average growth rate of 46.8±1.25 compared to 34.9±1.29 g day^{-1} for those under confined management. The respective average yearling live-weights were 19.4±0.31 and 15.2±0.38 kg. This could have been due to the differences in the basal diet offered under the two systems. While the weaners on confined feeding were offered Rhodes grass hay as the basal diet, those under the free-range grazed freely in a natural thorn bush land savannah with trees and shrubs.

These results suggested that animals under the free-range system were able to select a more nutritious diet than Rhodes grass hay. Samples of the most common grasses, trees and shrubs available to the animals in the free-range system were collected and analyzed in both the dry and wet seasons. Results presented in Chapter 3 confirmed that the basal diet of these animals was of higher nutritional value than the Rhodes grass hay. Additionally, animals on free-range could have consumed more feed due to variety and goats being browsers prefer variety. This increased intake was translated to higher post-ADG and YWT. Ademosun, (1994) reported that browses (trees and shrubs) were better sources of crude protein, minerals and vitamins than grasses.

Findings in the current study concur with those of Nianogo *et al.*, (1996), who concluded that free grazing was superior to tethered grazing in a study on performance of growing sheep. They recorded average daily weight gains of 53.02 and 27.28 g for free grazing and tethered groups respectively. Additionally, they observed that in both cases supplementation with wheat bran and cottonseed cake increased daily weight gain by 68.5%.

Effects of sex, parity and type of birth on post-weaning growth are shown in Table 4.5. Effect of sex was significant ($P<0.05$) for both post-weaning growth and yearling live-weight. Male weaners grew faster and attained higher yearling live-weight than the females. This could have been due to the higher feed intake by the males than females. For the confined feeding, it was observed that males consumed more grass hay than the females though the differences were not significant ($P>0.05$). Type of birth and parity of doe were not significant ($P>0.05$). This was expected because maternal effects have been reported to be negligible after weaning (Hirooka, 1997).

able 4.5 Effect of sex, type of birth and parity on post-weaning growth

	Confined feeding		Free range	
ariable	Post-ADG(gm)	YWT(kg)	Post-ADG(gm)	YWT(kg)
erall Mean	34.9±1.29	15.2±0.38	46.8±1.25	19.4±0.31
of kid				
Male	38.8±2.40^a	18.2±0.90^a	51.2±1.87^a	21.8±0.33^a
Female	31.1±2.88^b	12.1±0.75^b	42.4±1.33^b	17.0±0.46^b
pe of birth				
Single	37.8±1.71	17.7±0.52	51.6±0.85	21.6±0.21
Twins	31.9±3.53	12.8±1.10	42.0±2.27	17.1±0.56
rity				
1	29.2±2.20	14.7±0.76	44.6±2.76	19.0±0.68
2	36.1±3.04	15.2±0.95	46.3±0.95	19.5±0.67
3	41.7±4.78	16.0±1.49	51.8±2.60	19.7±0.64
4	34.5±2.44	14.9±0.73	45.8±2.71	19.4±0.59
5	33.2±2.34	14.8±0.25	45.4±2.40	19.3±0.23

eans within a column that have different superscripts ^{a} are significantly different.

5 *Conclusions*

Results from this study indicated that free-range grazing provided a better diet to the growing weaners than Rhodes grass hay offered under the confined feeding system. However, under both systems, supplementation of the weaners with legumes improved growth rate and as a result those weaners attained higher yearling live-weight than the control group. Improvement in average daily gain and yearling live-weight increased with level of supplementation. At same level of supplementation weaners on *Calliandra* performed better compared to those on Lucerne based diets. This was an indication that *Calliandra* was a better supplement for growth in goats than Lucerne. Based on these findings it can be recommended that smallholder farmers be encouraged to grow and supplement their dual-purpose goats on *Calliandra*.

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CHAPTER 5

Effect of supplementing Rhodes grass (Chloris gayana) hay with graded levels of Calliandra calothyrsus and Lucerne (Medicago sativa) on in-vivo digestibility, nitrogen balance and rumen fermentation patterns in dual-purpose goats

Effect of supplementing Rhodes grass (Chloris gayana) hay with graded levels of Calliandra calothyrsus and Lucerne (Medicago sativa) on in-vivo digestibility, nitrogen balance and rumen fermentation patterns in dual-purpose goats

5.1 *Abstract*

A study was conducted to determine the effects of supplementing Rhodes grass (*Chloris gayana*) hay with graded levels of *Calliandra calothyrsus* and Lucerne (*Medicago sativa*) on *in-vivo* digestibility, N balance and rumen fermentation parameters. Five (5) mature dual-purpose goats (castrates) surgically fitted with rumen cannulae were fed on a basal diet of Rhodes grass hay supplemented at two levels of *C.calothyrsus* and Lucerne in a 5 x 5 Latin square design. Composition of the five (5) treatment diets as fed was as follows:- T1, control (Rhodes grass hay only); T2 and T3, 250 and 500 gd^{-1} of *C.calothyrsus* respectively; T4 and T5, 250 and 500 gd^{-1} of Lucerne respectively. DM digestibility coefficients increased from 60.1 for the control to 68.3, 70.2, 66.4 and 69.2% for T2 to T5 respectively. The respective values for OM digestibility coefficients for T1 to T5 were 60.3, 70.1, 72.3, 68.5 and 71.2%, while the values for CP apparent digestibility coefficients were 63.1, 70.4, 76.2, 69.1 and 71.4% for T1 to T5 respectively. Supplementation improved N retention. The respective values were 4.1, 34.8, 52.3, 29.5 and 43.5% of N intake for T1 to T5 and differed significantly across the diets. Supplementation increased concentration of rumen NH_3-N from 12.4 to 13.2, 17.9, 12.6 and 16.4 mg $100ml^{-1}$; and VFA from 10.6 to 11.4, 14.9, 10.9 and 13.7 mmol $100ml^{-1}$ for T1 to T5 respectively and lowered rumen pH from 6.8 to 6.5, 6.4, 6.5, and 6.5 for T1 to T5 respectively. These results indicated that supplementation improved DM, OM, and CP *in-vivo* digestibility, N balance and significantly affected the rumen fermentation patterns. At similar levels of supplementation these effects were higher for *Calliandra* than Lucerne based diets and increased with level of supplementation for both supplements. It was concluded that supplementation with protein-rich forages (PRFs) improved *in-vivo* digestibility and N retention and that *Calliandra* was a better supplement for goats than Lucerne.

Keywords: dual-purpose goats; protein-rich forages; supplementation; in-vivo digestibility; N balance; rumen fermentation

Introduction

Over the years, goats have been reared under traditional systems, where they are either tethered or left to roam, browsing and grazing freely (Okello *et al.*, 1996). However, with the high human population growth rate in Kenya, estimated at 2.9% per annum (National Development Plan 1997 - 2001); land previously available for livestock and pasture production continues to decrease due to subdivision for human settlement (Skea, 1989; Sheikh *et al.*, 1993). The effect of this is that the traditional rearing systems have been replaced by semi-zero and zero grazing systems. Under these systems, a wide variety of often non-conventional feedstuffs such as weeds, crop residues, agro-industrial by-products and grass hay, which may be fibrous, highly lignified and of low quality have been used as feeds (Tuah *et al.*, 1994). Goats have been shown to utilize such fibrous products more efficiently than cattle and also consume a considerably wider spectrum of plant species (Rutagwenda *et al.*, 1990; Peters and Horst, 1992; Semenye and Hutchcroft, 1992). The goat will therefore make better use of the wide variety of low quality feeds available in smallholder production systems (Irungu, 1999).

Low dietary protein content has been reported to limit dry matter intake by compromising rumen microbial growth and activity thus digestibility and rumen turnover rate with a resultant sub-optimal supply of protein to the animal (Hove and Mpofu, 1996). There is therefore, need to supplement animals on a low quality diet to improve performance. Protein-rich forages (PRFs) have been used for supplementary feeding especially during the dry season because they are less susceptible to climatic fluctuations than herbaceous plants. PRFs usually have higher crude protein content (200 - 300 g kg^{-1}DM) than grasses (70 - 80 g kg^{-1}DM) (Minson, 1990; Hove and Mpofu, 1996; Odongo *et al.*, 1999). Foliage of PRFs has been used widely as a source of supplementary crude protein (Tuah *et al.*, 1994) providing both rumen fermentable N and by-pass protein. When fed to ruminants at levels below 30% of dietary DM, legumes have a catalytic effect on utilization of the basal diet, which is usually a low N pasture or a crop residue (Tchinda *et al.*, 1994). They ensure a more efficient environment for digestion of cell-wall carbohydrates by providing micronutrients such as peptides, amino acids, minerals and vitamins, which increase fungal biomass and the rate of bacterial colonization of the fibre (Tchinda *et al.*, 1994). Thus, legumes could be effective alternatives to the usually more expensive commercial protein sources as supplements to animals on deficient diets (Valk, 1990; Mureithi, 1992; Minson *et al.*, 1993; Posler *et al.*, 1993).

Supplementation of various basal diets with PRFs has been evaluated in different studies and shown to improve animal performance (Ebong, 1996; Kaitho, 1997; Kariuki, 1998; Paterson *et al.*, 1996; Roothaert, 1999; Roothaert *et al.*, 1997). In the studies reported in Chapters 3 and 4 of this thesis, the supplemented lactating does and weaner kids had a higher performance than the unsupplemented contemporaries. To explain these differences a study was carried out to determine the effects of feeding graded levels of *Calliandra calothyrsus* and Lucerne (*Medicago sativa*) to dual-purpose goats on a basal diet of Rhodes grass (*Chloris gayana*) hay on nutrients intake, *in-vivo* digestibility, N balance and rumen fermentation parameters.

5.3.0 Materials and methods

The experimental site (KARI Naivasha), feed sources, preparation and sampling; and estimation of DMI were as described in Chapter 3.

5.3.1 Experimental design

Five (5) mature dual-purpose goats (castrates) (average weight 41.9 ± 1.87 kg) surgically fitted with rumen cannulae were used in a 5 x 5 Latin square design (Steel and Torrie, 1996) involving 5 feeding periods and 5 diets (treatments). Composition of the 5 experimental treatment diets (T) as fed was as follows:- T1, Rhodes grass hay only (Control); T2 and T3 Rhodes grass hay supplemented with 250 and 500 g goat^{-1} day^{-1} of *Calliandra calothyrsus* respectively; T4 and T5 Rhodes grass hay supplemented with 250 and 500 g goat^{-1} day^{-1} of Lucerne respectively. As for the doe diets, these supplementation levels were selected to ensure that supplement intake was within the recommended range of 30 - 40% of the daily DM intake. At the beginning of the trial, the animals were dosed with an antihelminthic (Nilzan^{R}) and sprayed with an acaricide (Triatix^{R}).

5.3.2 Animal housing and feeding management

The animals were housed individually in metabolic cages with facilities for feeding, watering and separate collection for faeces and urine. Rhodes grass hay, water and mineral block (Maclik^{R} brick) were provided *ad libitum*. Every morning, the previous days residues (refusals) were removed and weighed before fresh feed and water were offered. The feed (both hay and supplement) allowance for the day was offered in two meals at 08.00 and 14.00 hours. The hay was offered in troughs and the supplement in plastic buckets. The supplement was always offered first and all was consumed. For each of the experimental periods, the animals were adapted to the diet for 10 days before feed and water intake; and faecal and urine production measurements commenced for another 5 days followed by 2 days of rumen fluid sampling.

5.3.3 *Sampling of rumen fluid*

Rumen fluid for the determination of rumen pH, NH_3-N and VFA was drawn through the surgically fitted rumen cannulae. The fluid was obtained by inserting a plastic tube (corked at one end and perforated with tiny holes on the sides) into the rumen, and using a hand vacuum apparatus about 200 ml of the fluid was drawn. The sampling was done five (5) times a day for 2 consecutive days at 2-hour intervals, viz:- at 08.00 hours (zero hour sampling - pre-morning feeding), 10.00, 12.00, 14.00 and 16.00 hours. The fluid was strained through 4 layers of cheesecloth to remove the undigested feed material. pH of the fluid was taken immediately using a portable combined glass electrode pH meter, standardized with buffers of pH 4 and pH 7 before taking the readings, after which, 100 ml of the fluid was acidified with 20% Sulphuric acid (1 ml 20% H_2SO_4 per 5 ml rumen fluid) to a pH below 3 to arrest fermentation and prevent NH_3 volatilization. This was frozen (-20°C) in tightly capped containers for subsequent NH_3-N analysis. The other 100 ml for the analysis of VFA was acidified with Metaphosphoric acid (1 ml 25% H_3PO_4 per 5 ml rumen fluid) and frozen (-20°C) for subsequent VFA analysis.

5.3.4 *Faecal and urine collection*

The total amount of faeces and urine voided over a 24-hour period were collected and weighed to make the daily output. To minimize loss of moisture, faecal material and urine were weighed and removed from the faecal and urine buckets twice daily (at 08.00 and 17.00 hours) and pooled to make the daily output. During each collection the faecal material was weighed and thoroughly mixed prior to sampling. Approximately 10% of the faecal output from each animal was stored frozen in labeled airtight sample bottles and pooled (per animal) at the end of each feeding period. After which they were air-dried and milled in a Wiley mill to pass through a 1 mm screen and stored in labeled airtight sample bottles for subsequent chemical analysis.

Urine was collected into a tightly covered plastic bucket to minimize evaporative losses. Into this bucket 20% Sulphuric acid was added (before collection commenced) at a ratio of 1:5 (acid:urine) to acidify the urine to a pH below 3 to prevent NH_3 volatilization and preserve urine-N. The amounts of urine were measured twice daily (at 08.00 and 17.00 hours) and the two collections pooled to make the total daily output per animal, from which, a 200 ml sample was collected for each animal. At the end of each feeding period, the samples from each animal were pooled and a 200 ml sample taken from the pooled urine which was then stored frozen (-20°C) for subsequent urine-N analysis.

5.3.5 Chemical analysis

5.3.5.1 Feed and faecal samples

DM content of the feed and faecal samples was determined by drying approximately 1 gm of each sample in an oven at 105°C for 12 hours. Ash content was determined by ashing the DM residue (AOAC, 1990). OM was calculated as the difference between the DM and the ash. Ca and P were determined by standard methods (AOAC, 1990), using the '2380 Atomic Absorption Spectrophotometer' and the 'CE 4400 UV Visible Double Beam Scanning Spectrophotometer' for Ca and P determination respectively. CP content was determined using the macrokjeldahl method according to AOAC, (1990). The NDF, ADF and ADL contents were determined by sequential analysis according to Van Soest, (1994). Hemicellulose and cellulose were determined by difference. Ether extract (EE) was determined by the Soxhlet Extraction method in di-ethyl ether (AOAC, 1990). Urine samples were analyzed for total N according to AOAC, (1990).

5.3.5.2 Determination of dry matter (DM) and organic matter (OM) digestibility

This was determined by total faecal collection according to the method of Osuji *et al.*, (1993). Ashing of samples of the feed offered and the faeces voided was done to calculate the OM digestibility. The digestibility coefficients of the other feed constituents were similarly calculated, according to the following equation:-

$$\text{Digestibility Coefficient \%} = \frac{100[(DW\ feed*C\ feed) - (DW\ faecal*C\ faecal)]}{DW\ feed*C\ feed}$$

Where:

DW feed = Dry weight of the feed consumed
C feed = Concentration of the nutrient in the feed consumed
DW faecal = Dry weight of the faeces voided
C faecal = Concentration of the nutrient in the faeces voided

5.3.5.3 *Determination of nitrogen balance*

N balance was estimated according to the method described by Osuji *et al.*, (1993). Pooled faecal and urine samples were analyzed for total N according to AOAC, (1990). Total N output was calculated as the sum of faecal and urinary N. N balance was calculated as the difference between N intake and Total N output in grams per animal per day.

5.3.5.4 *Rumen fermentation parameters*

pH of the rumen fluid was determined immediately after collection. For the determination of NH_3-N, the frozen rumen fluid samples were thawed, left to settle and 5 ml drawn from the clear upper layer. This was alkalinized with 10 ml 40% NaOH and steam heated using a micro-Kjeldahl steam distillation and titration apparatus (AOAC, 1990). For the determination of VFA the frozen rumen fluid samples were thawed, 5 ml of the clear solution was drawn and centrifuged at 2000 rpm. The supernatant was collected for the analysis of VFA concentration and molar proportions of individual volatile fatty acids by assaying using Gas Liquid Chromatography (GLC) according to Preston, (1995).

5.3.6 *Statistical analysis*

To determine effect of treatment on nutrients intake, *in-vivo* digestibility, N balance and rumen fermentation parameters; the Least-squares analysis procedures of Harvey, (2000) were used in the analysis. Factors fitted in the fixed statistical models of analyses were:- treatment diet (T), period of feeding (P) and animal (A), and for rumen fermentation parameters, time of sampling (S). For the purposes of data analysis these factors were coded as follows:- Treatment diet, 1 - 5; periods of feeding were defined as 1 - 5. The animals were coded as 1 - 5, and time of sampling of the rumen fluid was defined as 1 - 5, for 0, 2, 4, 6 and 8-hour samplings respectively. The following statistical models were fitted.

Analysis of nutrients intake, in-vivo digestibility and N balance

determine effect of treatment on nutrients intake, *in-vivo* digestibility and N balance, the following istical model was fitted.

$$Y_{ijk} = \mu + T_i + P_j + A_k + e_{ijk}$$

here.

Y_{ijk} = Nutrient intake, digestibility coefficient of a nutrient or N balance of k^{th} animal during j^{th} period of feeding on i^{th} treatment diet.

μ = The underlying constant common to all observations.

T_i = Effect due to i^{th} treatment diet ($i = 1,\ldots,5$)

P_j = Effect due to j^{th} period of feeding ($j = 1,\ldots,5$)

A_k = Effect due to k^{th} animal ($k = 1,\ldots,5$)

e_{ijk} = Random error effect associated with each observation.

Analysis of Rumen fermentation parameters

determine effects of treatment and time of sampling on rumen fermentation parameters, the lowing statistical model was fitted.

$$Y_{ijkl} = \mu + S_i + T_j + P_k + A_l + e_{ijkl}$$

ere,

Y_{ijkl} = Rumen fluid characteristics (i.e. rumen pH, NH_3-N or VFA) of rumen fluid drawn from l^{th} animal during k^{th} period of feeding on j^{th} treatment diet sampled at i^{th} time of sampling.

μ = The underlying constant common to all observations.

S_i = Effect due to i^{th} time of sampling ($i = 1,\ldots,5$)

T_j = Effect due to j^{th} treatment diet ($j = 1,\ldots,5$)

P_k = Effect due to k^{th} period of feeding ($k = 1,\ldots,5$)

A_l = Effect due to l^{th} animal ($l = 1,\ldots,5$)

e_{ijkl} = Random error effect associated with each observation.

4.0 *Results and discussion*

hemical composition of the forages used in constituting the treatment diets is shown in Table 5.1. M content was 921.1, 925.4 and 904.4 g kg^{-1} for Rhodes grass hay, *Calliandra* and Lucerne espectively. The respective CP contents were 77.3, 247.3 and 191.2 g kg^{-1}DM.

able 5.1 Chemical composition (g kg^{-1}DM) of Rhodes grass hay, *Calliandra calothyrsus* and Lucerne

	Rhodes grass hay	*Calliandra calothyrsus*	Lucerne
Dry matter (g kg^{-1})	921.1±4.38	925.4±6.27	904.4±7.96
Chemical Composition (g kg^{-1}DM)			
Organic matter	827.3±3.58	855.0±4.80	797.8±8.93
Crude Protein	77.3±5.13	247.3±1.98	191.2±19.02
Calcium (Ca)	3.8±0.58	9.3±0.20	9.8±1.22
Phosphorus (P)	3.4±0.96	2.2±0.18	4.1±0.04
Neutral detergent fibre	723.6±1.18	406.0±11.73	518.9±8.29
Acid detergent fibre	405.4±16.09	220.5±16.50	362.2±2.45
Acid detergent lignin	66.6±0.24	57.4±4.45	77.5±1.95
sh	93.8±1.03	70.4±1.75	106.6±3.77
emicellulose	350.0±5.00	204.5±9.50	165.3±3.05
ellulose	345.5±6.98	126.6±11.24	292.6±5.15
ther Extract (Crude fat)	12.2±0.36	15.0±4.02	10.4±2.71
Estimated ME(MJ kg^{-1} DM)	9.06±0.24	9.89±0.64	9.52±0.78

Estimated ME (MJ kg^{-1}DM) calculated using the equation:- OMD% = 91.9 - (0.355*NDF%) + (0.387*ADF%) - (2.17*ADL%) - (0.39*EE%); OM% = (0.92*OMD%) - 1.2; ME = DOM%*0.15 (Muia, 2000). ADF = Acid detergent fibre; ADL = Acid detergent lignin; DOM = Digestible rganic matter; EE = Ether extract; ME = Metabolizable energy; NDF = Neutral detergent fibre; OMD = Organic matter digestibility.

The CP content of Rhodes grass hay was within the range of 40 - 112 g kg^{-1}DM reported by Van oest (1994) for grasses. The CP contents for *Calliandra* and Lucerne were within the range of 200 - 00 g kg^{-1}DM (Paterson *et al.*, 1996) for *Calliandra* and 160 - 210 g kg^{-1}DM (Kariuki, 1998; dongo *et al.*, 1999) for Lucerne respectively. The ME (MJ kg^{-1}DM) values estimated from hemical composition, were higher for the legumes than that of hay and that of *Calliandra* higher han Lucerne (Table 5.1). The levels of Ca and P were higher in Lucerne than *Calliandra* and hay. he lower NDF concentration in Lucerne and *Calliandra* than hay was consistent with the general bservation of lower NDF concentrations in legumes than grasses (Minson, 1990).

hemical composition of the treatment diets (Table 5.2) was estimated based on the ratio of hay to gume in each diet as consumed using mean composition values of each ingredient. The mean DM and M contents ranged from 915.3 to 922.4 g kg^{-1} and 817.1 to 835.9 g kg^{-1}DM for T5 and T3 espectively. The DM content for T1, T2, and T3 was higher ($P<0.05$) than T5, while T4 was not ifferent ($P>0.05$) from the control. The OM content for T2 and T3 was higher ($P<0.05$) than T1, T4 nd T5. Increase in level of supplementation did not significantly affect OM content for either *alliandra* or Lucerne based diets. At similar levels of supplementation OM content was higher $P<0.05$) for *Calliandra* than Lucerne diets. Higher DM and OM for *Calliandra* than Lucerne diets at milar levels of supplementation was due to higher DM and OM contents for *Calliandra* than Lucerne Table 5.1).

Table 5.2 Chemical composition (g kg^{-1}DM) of the treatment diets

Treatment	T1	T2	T3	T4	T5	SED
Dry matter (g kg^{-1})	921.1^{ab}	922.1^{a}	922.4^{a}	917.0^{bc}	915.3^{c}	1.33
Chemical Composition (g kg^{-1}DM)						
Organic matter	827.3^{a}	833.6^{b}	835.9^{b}	820.0^{c}	817.1^{c}	1.30
Crude Protein	77.3^{a}	116.3^{b}	130.4^{c}	105.3^{d}	116.6^{b}	1.66
Calcium (Ca)	3.8^{a}	5.1^{b}	5.5^{c}	5.3^{b}	5.9^{c}	0.13
Phosphorus (P)	3.4	3.1	3.0	3.6	3.6	0.11
Neutral detergent fibre	723.6^{a}	650.8^{b}	624.4^{c}	673.3^{d}	653.0^{b}	2.83
Acid detergent fibre	405.4^{a}	363.0^{b}	347.7^{c}	394.8^{a}	390.5^{a}	6.76
Acid detergent lignin	66.6^{a}	64.5^{b}	63.7^{b}	69.3^{a}	70.4^{a}	3.85
Ash	93.8^{a}	88.5^{b}	86.5^{c}	97.0^{d}	98.2^{e}	0.47
Hemicellulose	350.0^{a}	316.7^{ab}	304.6^{bc}	304.8^{bc}	286.3^{c}	7 09
Cellulose	345.5^{a}	295.3^{b}	277.2^{c}	332.5^{d}	327.2^{e}	3.25
Ether Extract (Crude fat)	12.2^{ac}	12.8^{ab}	13.1^{b}	11.8^{ac}	11.6^{c}	0.39
•Metabolizable Energy (MJ kg^{-1}DM)	9.05^{a}	10.52^{b}	10.85^{b}	10.28^{b}	10.68^{b}	0.30

•ME = DOM%*0 15 (Muia, 2000), DOM % obtained from the *in-vivo* digestibility trial. DOM = Digestible organic matter.
SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$).

Metabolizable energy (ME) content estimated from the *in-vivo* OM digestibility ranged from 9.05 (T1) to 10.85 MJ kg^{-1}DM (T3). The control diet had significantly ($P<0.05$) lower ME than the supplemented diets, which were similar ($P>0.05$). The CP content was significantly ($P<0.05$) higher for the supplemented diets compared to the control increasing from 77.3 for the control diet to 116.3, 130.4 105.3 and 116.6 g kg^{-1}DM for T2, T3, T4 and T5 respectively. At similar levels of supplementation CP content was higher ($P<0.05$) for *Calliandra* than Lucerne based diets. This was due to the higher CP content for *Calliandra* (247.3 g kg^{-1}DM) than Lucerne (191.2 g kg^{-1}DM) (Table 5.1). Increase in level of supplementation increased ($P<0.05$) the CP content of the respective diets.

The NDF content was higher ($P<0.05$) for the control diet at 723.6 decreasing to 650.8, 624.4, 673.3

and 653.0 g kg^{-1}DM for T2, T3, T4 and T5 respectively. At similar levels of supplementation NDF was higher ($P<0.05$) for Lucerne than *Calliandra* based diets, while increase in level of supplementation resulted to a reduction ($P<0.05$) for both legumes. The NDF levels of the different diets were a reflection of it's content in the dietary constituents (Table 5.1). The other fibre related components of ADF, ADL, Cellulose and Hemicellulose followed a similar trend to that of NDF across the experimental diets (Table 5.2). T5 had the highest levels of both Calcium (Ca) and Phosphorus (P) at 9 and 3.6 g kg^{-1}DM respectively reflecting the higher Ca and P contents of Lucerne compared to Rhodes grass hay and *Calliandra* (Table 5.1).

4.1 *Nutrients intake*

The estimated nutrients intake is presented in Table 5.3. Hay dry matter intake (HDMI) and total dry matter intake (TDMI) g day^{-1} increased with supplementation. At both levels of supplementation goats on *Calliandra* had higher ($P<0.05$) hay and total DMI than those on Lucerne based diet. When TDMI was expressed as per unit metabolic body weight ($W^{0.75}$), the same trend was observed across the diets. Total organic matter intake (TOMI) showed a similar trend to that of TDMI across the diets. Supplementation with legumes increased TDMI by increasing the basal diet intake in addition to the supplement intake. Hay DMI increased by 69 and 46%; while TDMI increased by 146 and 121% for the high level of *Calliandra* and Lucerne supplementation respectively compared to the control diet. Metabolizable energy intake (MEI) differed significantly ($P<0.05$) across the diets and ranged from 44 for T1 to 13.77 MJ day^{-1} for goats on T3. The MEI for the control diet was below the minimum requirements for maintenance while the supplemented diets met this requirement of 6.6 MJ day^{-1} for a 40 kg goat (Peacock, 1996).

Total crude protein intake (TCPI) g day^{-1} increased with supplementation from 46.4 for the control group to 117.1, 192.8, 97.8 and 154.1 g day^{-1} for T2, T3, T4 and T5 respectively (Table 5.3). At same level of supplementation goats on *Calliandra* had higher ($P<0.05$) TCPI than those on Lucerne based diets. Increase in level of supplementation increased ($P<0.05$) TCPI in goats on both supplements. These differences reflected the dietary CP content of the experimental diets (Table 2). Similar trends across the diets were exhibited when TCPI was expressed per unit metabolic body weight ($W^{0.75}$) (Table 5.3). When TCPI was expressed as digestible CPI (DCPI), intake for the supplemented goats was above the minimum requirements of 43 g day^{-1} for maintenance of a 40 kg goat (Peacock, 1996) while that of the control group did not meet this requirement. Due to lower than maintenance MEI and DCPI by the control group, it was observed earlier (Chapter 3) that under the confined feeding system, milking goats on the control diet lost weight. This could have been due to mobilization of body reserves for milk synthesis.

Increase in nutrients intake with protein supplementation has been documented. Kaitho, (1997) recorded significant ($P<0.05$) increase in DMI and performance with supplementation in sheep and goats fed Teff straw (*Eragrostis tef*) supplemented with *Dolichos lablab*, *Leucaena leucocephala*, *Sesbania goetzei* and *Sesbania sesban*. Similarly, Ebong, (1996) reported increased DMI and growth with increase in *Calliandra* leaf meal levels in the diet of goats on a basal diet of Elephant grass. Legumes have been reported to increase efficiency of utilization of the basal diet through a catalytic effect on feed utilization, by providing micronutrients such as peptides, amino acids, minerals and vitamins, which increase fungal biomass and the rate of bacterial colonization of the fibre.

Table 5.3 Voluntary intake and digestibility of dry matter, organic matter and crude protein

	Treatments							
Nutrient intake	T1	T2	T3	T4	T5	SED	NRQ (g d^{-1})	Significance
Dry matter								
-HDMI (g day^{-1})	600.2^{a}	774.7^{b}	1014.7^{c}	706.3^{d}	873.9^{e}	16.84		***
-TDMI (g day^{-1})	600.2^{a}	1006.1^{b}	1477.4^{c}	932.4^{d}	1326.1^{e}	16.84		***
-TDMI (g $kg^{-1}W^{0.75}$)	36.4^{a}	61.1^{b}	89.7^{c}	56.6^{d}	80.5^{e}	1.75		***
-TDDMI (g day^{-1})	360.7^{a}	687.2^{b}	1037.4^{c}	619.1^{d}	917.4^{e}	16.41		***
Apparent Digestibility coefficient (%)	60.1^{a}	68.3^{b}	70.2^{c}	66.4^{d}	69.2^{e}	0.75		**
Organic matter								
-TOMI (g day^{-1})	496.5^{a}	838.7^{b}	1235.1^{c}	764.7^{d}	1083.8^{e}	14.10		***
-TDOMI (g day^{-1})	299.4^{a}	587.9^{b}	893.0^{c}	523.8^{d}	771.7^{e}	12.00		***
Apparent Digestibility coefficient (%)	60.3^{a}	70.1^{b}	72.3^{c}	68.5^{d}	71.2^{e}	0.68		**
Crude protein								
-TCPI (g day^{-1})	46.4^{a}	117.1^{b}	192.8^{c}	97.8^{d}	154.1^{e}	2.07		***
-TCPI (g $kg^{-1}W^{0.75}$)	2.8^{a}	7.1^{b}	11.7^{c}	5.9^{d}	9.4^{e}	0.16		***
-TDCPI (g day^{-1})	29.3^{a}	82.4^{b}	146.9^{c}	67.6^{d}	110.0^{e}	3.56	43.0	***
Apparent Digestibility coefficient (%)	63.1^{a}	70.4^{b}	76.2^{c}	69.1^{d}	71.4^{e}	0.73		**
H_2OI(ml $kg^{-1}W^{0.75}$)	93.2^{a}	205.8^{b}	366.7^{c}	165.6^{d}	298.9^{e}	13.11		**
H_2OI:TDMI	2.56^{a}:1	3.37^{b}:1	4.09^{c}:1	2.93^{a}:1	3.71^{c}:1	0.12		*
MEI (MJ day^{-1})	5.44^{a}	9.30^{b}	13.77^{c}	8.55^{d}	12.22^{e}	0.25	6.6	***

HDMI, Hay DM intake; TDMI, Total DM intake, TDDMI, Total digestible DM intake; TOMI, Total OM intake; TDOMI, Total digestible OM intake; TCPI, Total CP intake; TDCPI, Total digestible CP intake; H_2OI, Water intake; MEI, Metabolizable energy intake; NRQ (g d^{-1}), Nutrient requirements for maintenance of a mature goat (40 kg LWT) (Peacock, 1996); LWT, Live-weight; SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$);*, $P<0.05$; **, $P<0.01$; ***, $P<0.001$

hey ensure a more efficient environment for digestion of cell wall carbohydrates (Tchinda *et al.*, 004). Supplementation with legumes has also been reported to provide ruminally fermentable N nd thus increased rumen NH_3 concentration which promotes higher microbial activity (Kaitho, 997), with a resultant increase in rumen turnover and passage rate which leads to increased igestion and feed intake (McDonald *et al.*, 1995). In the current study, NH_3-N increased with level f supplementation (Table 5.5), which was an indication of increased N supply for microbial amino cid synthesis, hence increased digestion and feed intake (Table 5.3).

ncreased nutrients intake with level of supplementation was reported in heifers fed Napier grass upplemented with graded levels of desmodium and sweet potato vines (Kariuki, 1998). Similar indings were reported by Njoya and Awa, (1996) in ewes; Nantoume *et al.*, (1996) in rams; Hove nd Mpofu, (1996) in sheep and Toppo *et al.*, (1997) in steers. Njwe and Kona, (1996) recorded ignificant increases in DMI and CPI when Elephant grass (*Pennisetum purpureum*) was upplemented with Stylo (*Stylosanthes guianensis*) and soybean meal in West African dwarf sheep. Based on the above observations from various studies, it can be argued that supplementation with rotein sources improved nutrients intake.

Water intake increased from 93.2 for goats on the control diet to 205.8, 366.7, 165.6 and 298.9 ml kg^{-1}W$^{0.75}$ for those on T2, T3, T4 and T5 respectively and differed significantly ($P<0.05$) across the diets. At similar levels of supplementation goats on *Calliandra* had higher ($P<0.05$) water intake han those on Lucerne based diets. Increase in level of supplementation increased ($P<0.05$) water intake in goats on both supplements. It was observed that water intake increased with TDMI (Table 5.3). The H_2OI:TDMI ratio also increased from 2.6:1 for T1 to 4.1:1 (T3). Increase in water intake with increased DMI was reported by Muhikambele *et al.*, (1996) in a study with Saanen goats fed barley and Lucerne based diets. Njoya and Awa, (1996) reported increased water intake with supplementation on cottonseed meal in ewes. Increase in TDMI with supplementation also led to ncreased TCPI (Table 5.3) with a resultant increase in the amount of N excreted as urea through the urine (McDonald *et al.*, 1995). Urea excretion through the urine requires water hence the reported increase in water intake with higher dietary protein intake. A corresponding increase in urine N production (g day^{-1}) with level of supplementation was also observed in this study. Daily urine N production increased from 4.4 (control) to 7.4 (g day^{-1}) (T3) (Table 5.4). Water requirement is affected by environmental factors such as DMI, nature of feed, physiological conditions, temperature of drinking water, ambient temperature, frequency of drinking, as well as genotype (Devendra and Burns, 1983). Of these only DMI and nature of feed, especially in protein content, would be expected to have contributed to the variations in water intake among the experimental animals in this study as the animals were housed and other factors were standardized

5.4.2 *In-vivo digestibility*

In-vivo digestibility of the various nutrients is presented in Table 5.3. Supplementation significantly ($P<0.05$), improved DM, OM and CP digestibility. Improved digestibility with supplementation on protein sources has been reported (Preston and Leng, 1987; Matejovsky and Sanson 1995). The DM digestibility coefficient increased from 60.1 to 70.2% while the amount of total digestible DM intake (TDDMI) increased from 360.7 to 1037.4 g day^{-1}, for T1 and T3 respectively. The respective OM digestibility coefficients were 60.3 and 72.3% and followed a similar trend to that of dry matter digestibility (DMD). Increase in level of supplementation increased ($P<0.05$) DM and OM digestibility. The amount of DM and OM digested by goats on T3 was higher ($P<0.05$) than all the other diets. At both levels of supplementation DM and OM digestibilities were higher ($P<0.05$) for *Calliandra* than Lucerne based diets.

Similarly, Njwe and Kona (1996) observed improvements in digestibility when West African dwarf sheep on Elephant grass were supplemented with stylo (*Stylosanthes guianensis*) and soybean meal. They noted that supplementation significantly ($P<0.05$) improved DM and OM digestibility from 56.61 and 59.89% for animals on grass alone to 69.32 and 71.51%; and 72.49 and 75.05% for those supplemented with stylo and soybean meal respectively. The conclusion from these studies was that supplementation on protein sources improved digestibility as the supplement increased N supply to the rumen microbes, which improved the rate of breakdown of the digesta in the rumen.

Supplementation had a significant ($P<0.05$) effect on CP apparent digestibility and total digestible crude protein intake (TDCPI) (Table 5.3). The CP apparent digestibility coefficient ranged from 63.1 to 76.2% while the amount of TDCPI ranged from 29.3 to 146.9 g day^{-1}, for goats on T1 and T3 respectively. At same level of supplementation, CP apparent digestibility and DCPI were higher ($P<0.05$) for goats on *Calliandra* than those on Lucerne. Increase in level of supplementation increased ($P<0.05$) both CP apparent digestibility and DCPI for both groups of animals. These differences can be explained by the higher ($P<0.05$) CP content of *Calliandra* compared to Lucerne based diets at similar levels of supplementation (Table 5.2).

Supplementation with both forage legumes appears to have improved the overall rumen environment and thus microbial activity resulting in improved digestibility and digestible nutrients intake. This would explain the earlier observed improved milk and growth performance for goats on supplemented diets. Supplementation appears to have increased the whole tract (*in-vivo*) apparent digestibility mainly by increasing basal diet digestibility. This could explain the observed apparent increase in intake of hay digestible nutrients with increasing levels of supplementation. For example, using the OM *in-vivo* digestibility coefficient for hay (60.3%) obtained in this study, it was observed that hay DOMI increased by 69 and 46% from 299.4 (control) to 506.2 and 436.0 g day^{-1} for the high level of *Calliandra* and Lucerne supplementation respectively.

However, increase in digestibility with supplementation is not linear as it depends on microbial needs for CP and once this is met additional CP may not necessarily result in an increase in digestibility. Thus the improvement in DM digestibility was 13.6 and 10.5% at the low level of supplementation with *Calliandra* and Lucerne respectively. However, the additional supplement on T3 and T5 resulted in improvements of only 2.8 and 4.2%. Impact of improvements in digestibility coefficients on digestible nutrients intake was highly significant. For example the increase in TDDMI between the control and low level of supplementation for *Calliandra* and Lucerne based diets was 90 and 72% respectively, while the increase in TDDMI between the low and the high level for *Calliandra* and Lucerne based diets was 51 and 48% respectively. The respective increases for TDOMI were 96 and 75%; and 52 and 47% between the control and low level of *Calliandra* and Lucerne supplementation, and between the low and the high level for *Calliandra* and Lucerne. The respective values for TDCPI were 181 and 131%; and 78 and 63%. These results indicated that increase in intake of digestible nutrients decreased with level of supplementation, this suggests that there is an optimum level of supplementation beyond which the beneficial effects, in terms of gestible nutrients intake, diminish to a level where there are no further increases.

The lower DM, OM and CP digestibility for Lucerne compared to *Calliandra* based diets at similar els of supplementation could have been due to its higher content of fibre components including gnin (Table 5.2). Dietary fibre content has been reported to be negatively correlated to digestibility Muia, 2000; Tolera and Sundstol, 2000; Adesogan *et al.*, 2002). This is because high fibre content nd especially lignin binds N making it unavailable to the rumen microbes, the effect of which is wered digestibility. Thus, although fibre-bound N was not analyzed, it is probable that, due to its igh NDF, ADF and ADL content, some N in Lucerne was bound and unavailable.

4.3 *Nitrogen balance*

Nitrogen intake (Ni) was 7.4, 18.7, 30.8, 15.6 and 24.7 g day^{-1} for T1 to T5 respectively (Table 5.4) and differed significantly (P<0.05) across the diets. Supplementation increased (P<0.05) faecal N losses. Faecal N (Nf) originates from various sources; endogenous (breakdown and replacement of body cells and tissues, secretions, enzymes, breakdown of the gut lining and other substances secreted into the gut), microbial origin (rumen, caecal and ileal micro-organisms) in addition to indigestible feed N (Orskov and Miller, 1988; McDonald *et al.*, 1995). Metabolic faecal N increases with feed intake and could partly account for the higher (g/d) losses in goats on the supplemented diets, which also tended to have higher DMI (Table 5.3). However, in the current study, the higher feed intake with supplementation was also accompanied by increased N intake and it would be expected that proportionately, the contribution by N of metabolic origin to total faecal N would decrease. So the increase in faecal N losses (g/d) with supplementation must also reflect increased indigestible N. Thus, when faecal N was expressed as a proportion of N intake it showed proportionate decreases with level of supplementation and was highest for the control diet at 36.5% and lowest for T3 at 23.7%. Thus, with supplementation, proportionately more of the feed N was digested and absorbed from the GIT (Table 5.3). Goats on the higher level of Lucerne supplementation had higher proportionate faecal N loss compared to those on *Calliandra* at similar level of supplementation (Table 5.4).

able 5.4 Nitrogen intake, nitrogen losses and nitrogen balance

ariable	Treatment					SED	Significance
	T1	T2	T3	T4	T5		
rogen intake (Ni) (g day^{-1})	7.4^a	18.7^b	30.8^c	15.6^d	24.7^e	0 33	***
ecal Nitrogen (Nf) (g day^{-1})	2.7^a	5.7^b	7.3^c	4.8^d	7.1^e	0.31	***
ecal Nitrogen (% N intake)	36.5^a	30.5^b	23.7^c	30.8^b	28.7^d	1.23	**
ne Nitrogen (Nu) (g day^{-1})	4.4^a	6.5^b	7.4^c	6.2^b	6.9^d	0.84	*
e Nitrogen (% N intake)	59.5^a	34.8^b	24.0^c	39.7^d	28.0^e	2.19	**
tal Nitrogen losses (g day^{-1})	7.1^a	12.2^b	14.7^c	11.0^d	14.0^e	0.47	**
tal Nitrogen losses (% N intake)	95.9^a	65.2^b	47.7^c	70.5^d	56.7^e	4.16	***
tained Nitrogen (Nr) (g day^{-1})	0.3^a	6.5^b	16.1^c	4.6^d	10.7^e	1.26	***
tained Nitrogen (% N intake)	4.1^a	34.8^b	52.3^c	29.5^d	43 5^e	3.42	***
sorbed Nitrogen (Na) (g day^{-1})	4.7^a	13.0^b	23.5^c	10.2^d	17.6^e	0.32	***
sorbed Nitrogen (% N intake)	63.5^a	69.5^b	76.3^c	65.4^d	71.5^e	1.31	**

ED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); *, $P<0.05$; **, <0.01; ***, $P<0.001$.

Urinary N (Nu), losses increased from 4.4 on the control diet (T1) to 6.5, 7.4, 6.2 and 6.9 g day^{-1} for goats on T2, T3, T4 and T5 respectively and increased ($P<0.05$) with supplementation. At the low level of supplementation urine N losses in goats on *Calliandra* and Lucerne based diets were similar. But at the high level, Nu was higher ($P<0.05$) for *Calliandra* than Lucerne based diet. Part of the urine N has endogenous origin from normal day to day catabolism of body proteins but it is expected that contribution of this to total (g/d) urine N loss would decrease with increased N intake. So, the increase in urine N (g/d) for goats on supplemented diets must also reflect an increase in exogenous (feed origin) urinary N (McDonald *et al.*, 1995). When expressed as a proportion of N intake there were differences ($P<0.05$) between the diets. The control diet had the highest proportionate urine N losses (59.5%) while T3 had the lowest (24.0%). At same level of supplementation, proportionate urine N losses were higher ($P<0.05$) for Lucerne than *Calliandra* based diets and decreased ($P<0.05$) with level of supplementation.

Total N losses (Nf+Nu) differed significantly ($P<0.05$) across the diets. Losses in goats on supplemented diets (T2 to T5) ranged from 11.0 to 14 7 g day^{-1} and were higher ($P<0.05$) than 7.1 g day^{-1} by goats on the control diet. At both levels of supplementation goats on *Calliandra* had higher ($P<0.05$) losses than those on Lucerne. Increase in level of supplementation increased ($P<0.05$) losses in goats on both supplements. When expressed as a proportion of N intake all the diets were ifferent ($P<0.05$). The control group had the highest proportionate losses (95.9%) and T3 the lowest 7.7%), (Table 5.4). At same level of supplementation goats on *Calliandra* had lower ($P<0.05$) roportionate losses than those on Lucerne. Increase in level of supplementation decreased ($P<0.05$) roportionate total N losses for both supplements.

icrobial protein synthesis utilizes N from dietary protein, non-protein N and recycled N and equires energy both for the synthetic process as well as for supplying the carbon skeletons for ynthesis of microbial amino acids (McDonald *et al.*, 1995). Poppi and McLennan, (1995) observed hat an important factor in ruminant digestion and transfer of dietary protein to the lower gut is the vailability of fermentable energy. Lack of adequate energy to the rumen microbes slows down icrobial synthesis and multiplication leading to reduced incorporation of feed protein to microbial rotein. Therefore, the high proportionate urinary N losses for the control diet could have been due o low fermentable energy supply to the rumen microbes. Synchronization of the rate of rumen egradation of protein and energy fermentation is beneficial for microbial synthesis and thus the fficiency of protein and energy utilization (McDonald *et al.*, 1995). This is because when N is egraded at a faster rate than fermentation of energy sources available for utilization, excess NH_3 is bsorbed and transported via portal blood to the liver (McDonald *et al.*, 1995). Of this, some is ecycled back to the digestive tract but a large portion is lost through excretion in the urine. Thus in the current study, supplementation appears to have improved energy availability and the ynchronization of protein and energy supply which reduced NH_3 losses through the urine, by mproving incorporation of feed N into microbial N. This would explain the lower proportionate N oss for the supplemented diets.

Supplementation improved ($P<0.05$) the amount of absorbed N. The differences were significant ($P<0.05$) among the diets and ranged from 4.7 (T1) to 23.5 g day^{-1} (T3) and increased ($P<0.05$) with evel of supplementation for both legumes. At similar levels of supplementation absorbed N was higher for *Calliandra* ($P<0.05$) than Lucerne diets. When expressed as a percentage of N intake, N absorption was 63.5, 69.5, 76.3, 65.4 and 71.5% for T1 to T5 respectively, was higher ($P<0.05$) for supplemented diets and increased ($P<0.05$) with level of supplementation.

retention (Nr) differed significantly (P<0.05) across the diets and increased with level of pplementation. The range was 0.3 to 16.1 g day^{-1} for goats on T1 and T3 respectively. N retention goats on T2, T4 and T5 was 6.5, 4.6 and 10.7 g day^{-1} respectively (Table 5.4). At similar levels of upplementation N retention was higher (P<0.05) for *Calliandra* than Lucerne diets and increased P<0.05) with level of supplementation. When N retained was expressed as a proportion of N intake, ere were significant (P<0.05) differences across the diets. The control animals had the lowest roportionate N retention. The respective values were 4.1, 34.8, 52.3, 29.5 and 43.5% for T1 to T5. At similar levels of supplementation proportionate N retention was higher (P<0.05) for *Calliandra* han Lucerne based diets, and increased (P<0.05) with level of supplementation for both upplements. Increase in N retention with N intake has been reported (Muinga *et al.*, 1995; Ebong, 1996; Njwe and Kona, 1996; Muhikambele *et al.*, 1996; Hove and Mpofu, 1996; Toppo *et al.*, 1997; Lee *et al.*, 2000; Tolera and Sundstol, 2000; Nyabende, 2003). However, the high N retention values obtained in this study for mature goats were difficult to explain. It is probable, that there was compensatory muscle gain (Orskov, 1992), occasioned by a prolonged dry spell prior to the commencement of the experiment. It was especially difficult to explain the N retention values for the control group, which should have been in negative N balance due to the fact that their DCPI was below maintenance requirements (Table 5.3). These results suggest that N losses may have been underestimated. Some undocumented N losses, which could have contributed to the under estimation of N losses, could be attributed to dermal losses of N occurring in scurf, hair and sweat and other errors inherent in the conduct of nutrient balance trials (McDonald *et al.*, 1995).

5.4.4 *Rumen fermentation*

Rumen pH, VFA, and NH_3-N for all the diets ranged from 6.4 to 6.8, 10.6 to 14.9 mmol $100ml^{-1}$ and 12.4 to 17.9 mg $100ml^{-1}$ respectively (Table 5.5). Supplementation with legumes affected ($P<0.05$) rumen fermentation parameters.

Table 5.5 Rumen fermentation parameters (pH, VFA, and NH_3-N) for the treatment diets

Parameter	Treatment					SED	Significance
	T1	T2	T3	T4	T5		
pH	6.8^a	6.5^b	6.4^b	6.5^b	6.5^b	0.03	*
VFA (mmol $100ml^{-1}$)	10.6^a	11.4^b	14.9^c	10.9^d	13.7^e	0.24	***
NH3-N (ml $100ml^{-1}$)	12.4^a	13.2^a	17.9^b	12.6^a	16.4^c	0.69	***
Molar percentages of VFA							
Acetate (A)	71.1^a	69.9^b	69.3^b	70.6^b	69.7^b	0.44	**
Propionate (P)	14.6^a	15.5^b	15.8^c	15.4^b	15.6^b	0.19	**
Butyrate	9.1^a	9.2^a	9.3^a	8.7^b	8.5^c	0.08	**
Iso-butyrate	2.6^a	2.5^a	2.4^a	2.6^a	3.0^b	0.05	**
Iso-valerate	1.8^a	1.9^{ab}	2.1^b	1.8^a	2.1^b	0.03	*
Valerate	0.8^a	1.0^{ab}	1.1^b	0.9^a	1.1^b	0.02	*
A:P	4.9^a	4.5^b	4.4^b	4.6^b	4.5^b	0.07	*

SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); *, $P<0.05$; ** $P<0.01$; ***, $P<0.001$

5.4.4.1 *Rumen pH*

Animals on the control diet had a higher ($P<0.05$) rumen pH of 6.8 than those on the supplemented diets, which were all similar (Table 5.5). According to Van Soest, (1994) the optimum rumen pH range for optimal rumen microbial growth and activity is 6.2 - 7.2. The range obtained in the current study for all the diets (6.4 - 6.8) was within this range. The higher rumen pH for goats on T1 could be attributed to its higher fibre (NDF and ADF) content compared to the supplemented diets (Table 5.2). Similarly, Archimede *et al.*, (1996) recorded higher rumen pH for higher crude fibre diets. It has been reported that time spent eating and ruminating when high fibre diets are fed is more compared to that spent on low fibre diets (Feng *et al.*, 1993; McDonald *et al.*, 1995). This results in increased salivation and buffering capacity (Russell *et al.*, 1992) of the rumen fluid leading to high pH (Reddy and Reddy, 1986; Van Soest, 1994). Saliva contains buffering substances (sodium, potassium, bicarbonate and phosphate) (Orskov and Ryle, 1990). The lower pH values for the supplemented diets compared to the control could thus be attributed to the shorter time spent ruminating.

Trends of rumen pH post-feeding for the various treatment diets

For all the diets pH was highest at the zero-hour (pre-feeding) and gradually declined with time after feeding (Figure 5.1). Robinson *et al.*, (1986) and Zorilla-Rios *et al.*, (1988) also reported high pH alues before feeding followed by a general gradual decline after feeding. Decline in pH with time after feeding was due to increased VFA concentration (Figure 5.2). Conversely, high pH levels in the rumen at the zero-hour (pre-feeding); was due to low rumen activity during the night hours without feed. The rumen environment tends towards alkalinity, leading to higher pH levels before feeding Robinson *et al.*, 1986; Zorilla-Rios *et al.*, 1988).

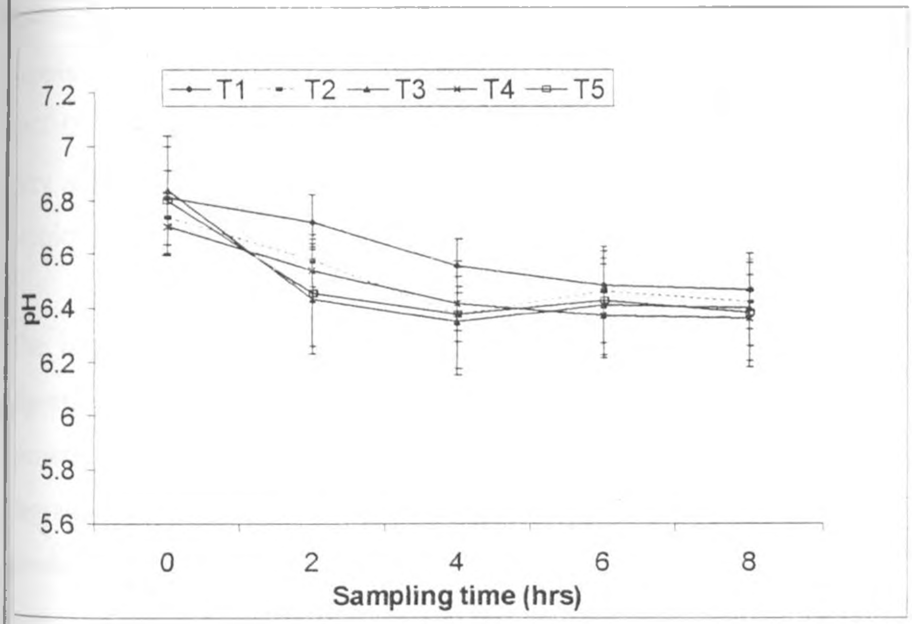


Figure 5.1 Trends in rumen pH post-feeding for the various treatment diets

The gradual decline in rumen pH after feeding can therefore, be attributed to the active fermentation of the feed by the rumen microbes. The extent of pH depression was dependent on the level of supplementation and CP content of the diet. Similarly, Gasa *et al.*, (1991) observed greater rumen pH depression when Friesian cows on grass silage were supplemented with graded levels of protein concentrates an indication of increased VFA release with level of supplementation due to a corresponding increase in rumen fermentation.

When the feed enters the rumen, it is fermented to yield mainly VFA, microbial cells and the gases methane and carbon dioxide, with a resultant drop in pH (McDonald *et al.*, 1995). Thus rumen pH rend was inversely proportional to the increase in VFA concentration. Stritzler *et al.*, (1998); adamana and Sutton, (1992); and Chiou *et al.*, (1997) all reported inverse relationship between rumen pH and VFA concentration.

4.4.2 *Rumen VFA*

The mean VFA concentration ranged from 10.6 (T1) to 14.9 mmol 100ml^{-1} (T3) and differed significantly ($P<0.05$) across the diets. According to McDonald *et al.*, (1995) the normal range of VFA concentration is 7 - 15 mmol 100ml^{-1}, thus values obtained in this study were within this range. VFA concentration was lowest for the control diet and increased ($P<0.05$) with level of Supplementation (Table 5.5). At similar levels of supplementation VFA concentration was higher ($P<0.05$) for goats on *Calliandra* than Lucerne. The average range of molar proportions of the main fatty acids were 69.3 - 71.1, 14.6 - 15.8, 8.5 - 9.3, 2.4 - 3.0, 1.8 - 2.1 and 0.8 - 1.1% for acetate, propionate, butyrate, iso-butyrate, iso-valerate and valerate respectively (Table 5.5).

The high levels of VFA obtained for the supplemented diets could be attributed to the higher digestible nutrients intake with supplementation (Table 5.3), which improved rumen microbial growth and activity. Supplementation with protein sources has also been reported to improve feed degradation in the rumen (McCarthy *et al.*, 1989), which leads to higher concentration of the products of microbial fermentation and thus the higher concentration of VFA in the rumen fluid of goats on the supplemented diets (Orskov and Ryle, 1990). Supplementation increased digestible OMI (Table 5.3), hence increased available OM for fermentation in the rumen. Oosting and Waanders, (1993); and Reddy and Reddy, (1986), concluded that VFA production depended on availability of OM in the feed and that it increased with increase in OM intake and digestibility. Van Soest, (1994) noted that rumen VFA concentration was regulated by a balance between production, absorption across the rumen wall and utilization by rumen microorganisms. Dijkstra *et al.*, (1998) also observed that the dynamics of VFA concentration, absorption and production in the rumen operated in such away that as production increased absorption also increased. However, absorption and utilization were not measured in this study.

The control diet had a significantly ($P<0.05$) higher A:P ratio of 4.9 compared to an average of 4.5 for the supplemented diets (Table 5.5). The high A.P ratio for the control can be attributed to its high fibre content, which led to high acetate levels. The lower levels of A:P ratio for the supplemented diets could be attributed to the higher degradation rate in the rumen and higher passage rate, which led to increased feed intake. The resultant effect was an increased production of propionate, hence lower A:P ratio. These values concur with the ratio of 4.8:1 obtained by (Robertson *et al*., (2004) and with the findings of Archimede *et al*., (1996); Kariuki, (1998) and Muia, (2000).

Trends in rumen VFA post-feeding for the various treatment diets

The highest rumen VFA levels for all the diets were recorded 6 hours post-morning feeding followed by a gradual decline. Lowest levels were recorded for the zero-hour samples (pre-feeding) (Figure 5.2).

Since VFA production rates vary with eating patterns, the rumen VFA and pH levels vary, such that, immediately after feeding there is an increase in VFA concentration and a corresponding drop in pH, followed by a slow recovery to the original pre-feeding state (Van Soest, 1994). Huntington and Offer, (1994) noted that rumen pH, NH_3-N and VFA showed a diurnal variation and attributed this to an inherent variability in the rumen ecosystem. VFA concentrations in the rumen also vary depending on rate of production, utilization and rumen outflow (Tamminga, 1992; Feng *et al*., 1993).

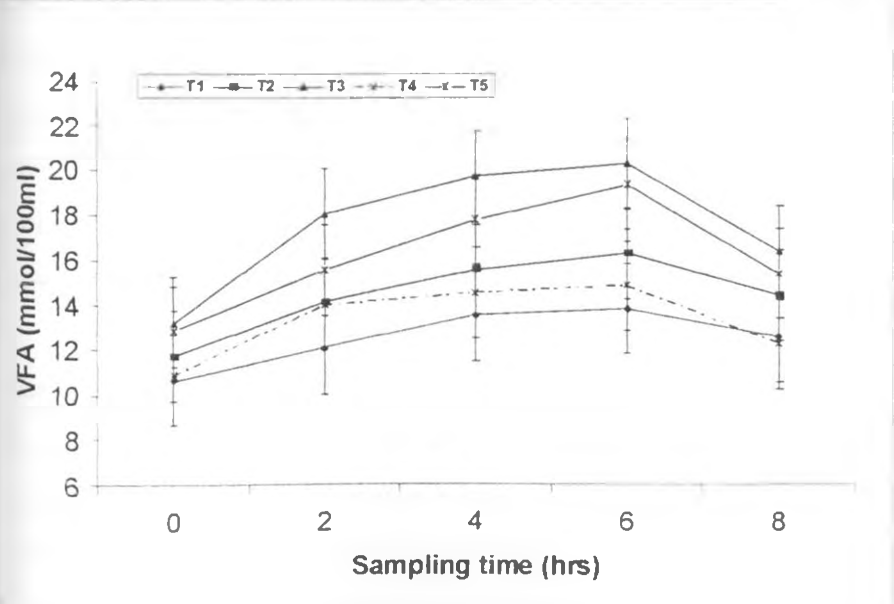


Figure 5.2 Trends in rumen VFA post-feeding for the various treatment diets

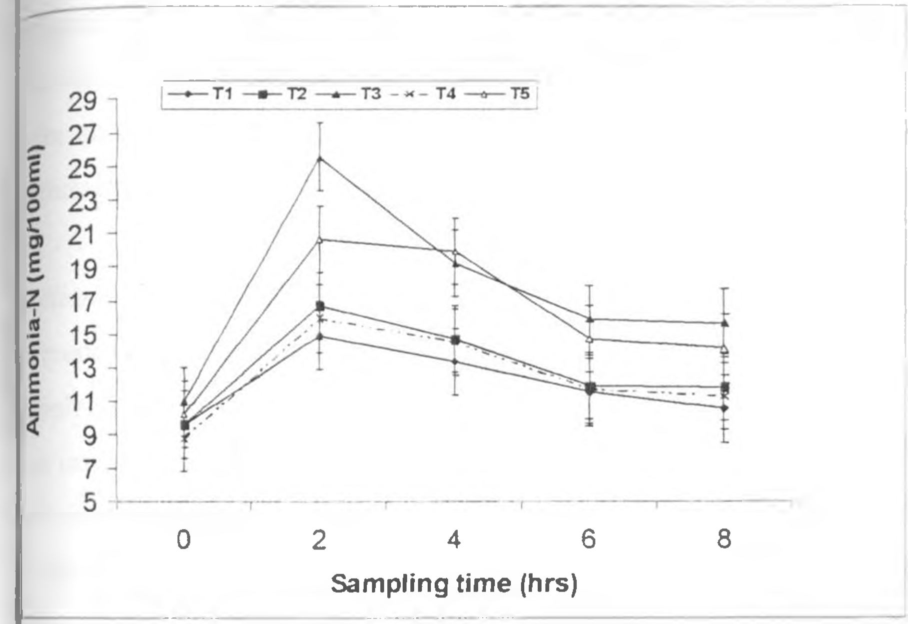
5.4.4.3 *Rumen ammonia-nitrogen (NH_3-N)*

The mean rumen NH_3-N concentration obtained in this study ranged from 12.4 - 17.9 mg 100ml^{-1} and increased with level of supplementation; was lowest for animals on T1 and highest for those on T3 (Table 5.5). According to Preston and Leng, (1987) the required minimum range of NH_3-N concentration below which microbial activity would be compromised is 5 to 25 mg 100ml^{-1}. Values obtained in this study were within this range. Increase in rumen NH_3-N concentration with supplementation was significant ($P<0.05$) at the high level but not at the low level. At the high level goats on *Calliandra* had higher ($P<0.05$) rumen NH_3-N concentration than those on Lucerne (Table 5.5).

Increase in rumen NH_3-N concentration with supplementation can be attributed to the increased content of rumen degradable CP. This ensured more N availability for microbial protein synthesis and feed digestion, and therefore faster rate of exit of feed from the rumen, which led to the observed increase in nutrients intake with supplementation (Table 5.3). Mackie and Morrison, (1995), concluded that NH_3-N was the major source of N for rumen microbial protein synthesis. Similarly, Minson, (1990) and Oosting and Waanders, (1993) reported that higher CP content in the diet led to higher concentration of rumen NH_3-N. Muinga *et al*., (1995); Abdulrazak *et al*., (1996) and Kariuki, (1998) similarly, reported increases in NH_3-N concentration with increased supplementation of Napier grass with high-protein forages. Higher CP degradability with increase in level of supplementation, observed in this study (Chapter 6) could also have contributed to the higher rumen NH_3-N concentration. Orskov, (1992) and McDonald *et al*., (1995), observed that concentration of rumen NH_3-N was mainly a factor of the protein content of the diet and its degradability. Thus high levels of dietary protein and degradation observed upon increase in level of supplementation in this study led to high NH_3-N levels in the rumen.

Trends in rumen NH_3-N post-feeding for the various treatment diets

The lowest NH_3-N concentration levels were recorded at the zero-hour (pre-morning feeding). This was followed by a sharp increase within the first 2 hours post-feeding then a gradual decline with time (Figure 5.3). Absorption of NH_3-N across the rumen wall and its utilization for microbial synthesis affects its concentration. Additionally, available energy (in form of ATP molecules) released during microbial fermentation of carbohydrates (Van Soest, 1994; McDonald *et al*., 1995) improved microbial amino acids synthesis and thus increased utilization of NH_3-N in the rumen. Thus the gradual decline in NH_3-N after 2 hours post-feeding (Figure 5.3), while concentration of VFA (Figure 5.2) was still increasing observed in this study, was an indication of increased energy availability and NH_3-N incorporation into microbial amino acids hence its gradual decline with increasing VFA levels.



igure 5.3 Trends in rumen ammonia-nitrogen post-feeding for the various treatment diets

Haaland *et al.*, (1982) concluded that high levels of supplementation with CP provided large mounts of fermentable OM which increased utilization of N by rumen microbes, thus lowering the vels of NH_3-N. Similarly, Orskov and Grubb, (1978) and Russel *et al.*, (1983) observed that tilization of NH_3-N by rumen microorganisms depended on the availability of fermentable OM. hen *et al.*, (1992) also observed that increases in rumen VFA concentration led to a reduction in pH d NH_3-N and attributed this to increased microbial activity and multiplication thus much of the H_3 in the rumen was being captured for microbial amino acids synthesis.

5.5 *Conclusions*

Supplementation of Rhodes grass hay with *Calliandra* and Lucerne improved nutrients intake, the improvement increased with level of supplementation. At each of the two levels of supplementation increase in nutrients intake was higher for *Calliandra* than Lucerne based diets. Supplementation improved *in-vivo* digestibility of DM, OM, and CP. At similar levels of supplementation, *Calliandra* based diets had higher DM, OM and CP digestibility than Lucerne based diets and increase in level of supplementation resulted to improved digestibility. Supplementation improved the efficiency (g/d and %) of N retention. Rumen NH_3-N and VFA concentrations increased with supplementation and were above the critical minimum levels for optimum rumen microbial activity for all the diets. Although supplementation lowered rumen pH the mean values remained within the critical range of 6.2 - 7.2 below which cellulysis would be compromised. Since at similar levels of supplementation *Calliandra* resulted in higher nutrients intake, *in-vivo* digestibility and N balance and better rumen fermentation characteristics, than Lucerne; it can be concluded that *Calliandra* was a better supplement for goats than Lucerne. This study has demonstrated that supplementation with legumes can improve utilization of high fibre diets in ruminants. Based on these results it can be suggested that smallholder farmers be encouraged to grow and supplement their dual-purpose goats with *Calliandra* since the shrub has characteristics that make it adoptable at small-scale production.

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CHAPTER 6

Effect of supplementation with graded levels of Calliandra calothyrsus and Lucerne (Medicago sativa) on rumen degradation characteristics in dual-purpose goats fed Rhodes grass (Chloris gayana) hay

ffect of supplementation with graded levels of *Calliandra calothyrsus* and Lucerne (*Medicago sativa*) n rumen degradation characteristics in dual-purpose goats fed Rhodes grass (*Chloris gayana*) hay.

1 Abstract

investigate the effects of supplementation of Rhodes grass (*Chloris gayana*) hay with different levels of *alliandra calothyrsus* and Lucerne (*Medicago sativa*), on rumen degradation characteristics, five (5) mature ual-purpose goats (castrates) surgically fitted with rumen cannulae were fed on Rhodes grass hay upplemented at two levels of *Calliandra calothyrsus* and Lucerne in a 5 x 5 Latin square design feeding trial. he 5 treatment diets were:- T1, control (Rhodes grass hay only); T2 and T3, 250 and 500 gd^{-1} of *C.calothyrsus* espectively; T4 and T5, 250 and 500 gd^{-1} of Lucerne respectively. Supplementation significantly ($P<0.05$) creased potential degradability (PD) and effective degradability (ED) of OM and CP in the rumen with level of upplementation. The values of PD for OM were 583.2, 649.5, 673.7, 642.3 and 666.3 g kg^{-1}OM, while the ED alues were 389.7, 443.5, 461.8, 434.1 and 456.4 g kg^{-1}OM for T1 to T5 respectively. Similarly, the values of D for CP were 629.8, 700.3, 726.0, 696.6 and 723.7 g kg^{-1}CP, while the ED values were 524.1, 584.1, 608.2, 80.2, 605.5 g kg^{-1}CP for T1 to T5 respectively. The available organic matter fermented in the rumen (DOMR) ncreased ($P<0.05$) from 193.5 for the control to 372.0, 570.4, 332.0 and 494.6 gd^{-1} for T2 to T5 respectively. y-pass protein (BP) significantly ($P<0.05$) increased from 494.5 for the control to 524.4, 540.3, 523.7 and 35.5 g kg^{-1}CP, the respective values for intestine degradable protein (IDP) were 188.7, 256.6, 286.3, 241.0 nd 262.2 g kg^{-1}CP for T1 to T5 respectively. For each of the parameters the values were higher for *Calliandra* han Lucerne based diets at both levels of supplementation and increased with level of supplementation for oth legumes. It was concluded that supplementation of Rhodes grass hay with protein-rich forages (PRFs) mproved rumen degradation characteristics and that *Calliandra* was a better supplement for goats than ucerne.

eywords: dual-purpose goats; protein-rich forages; supplementation; rumen degradation; by-pass protein

6.2 *Introduction*

In tropical and subtropical regions, pasture grasses and cereal residues which constitute the bulk of animal feeds in most production systems are frequently low in protein among other nutrients and therefore cannot support high levels of animal production (Kaitho, 1997). In the dry season the quality of the available forages is poor, especially in the arid and semi-arid zones. Most producers rely on crop residues generated from their own farms and also foliage of protein-rich forages (PRFs) and grasses from their farms or roadsides as feed for their livestock (Tuah *et al.*, 1994). Supplementation of such feeds with legumes has been shown to increase dry matter intake and improve animal performance. PRFs which, are an integral part of many agricultural production systems, have been proved to be good protein supplements for ruminants (Kaitho, 1997).

Legumes in the farming system constitute an important source of fermentable N and by-pass protein (Tchinda *et al.*, 1994). When fed to ruminants at low levels of supplementation, legumes increase the efficiency of utilization of the basal diet, which is usually a low N pasture or crop residue. Legume supplements given at levels below 30% of dietary DM have a catalytic effect on feed utilization (Tchinda *et al.*, 1994). They ensure a more efficient rumen environment for digestion of cell-wall carbohydrates, by providing micronutrients such as peptides, amino acids, minerals and vitamins, which increase fungal biomass and the rate of bacterial colonization of the fibre. The potential of the diet to meet the requirements of the animal for amino acids, glucogenic precursors and long chain fatty acids depend on the pattern of fermentation and on dietary protein, lipids and starch that escape fermentation and are digested in the intestine (Tchinda *et al.*, 1994).

In forage-based diets, protein quality of each dietary component is important in evaluating responses to supplementation. The current systems of protein evaluation partition feedstuff N into the amount degraded in the rumen (RDP) and available for microbial protein synthesis, and that, which escape rumen degradation as by-pass protein (BP) (Tamminga *et al.*, 1994). Microbial protein production is also influenced by the available digestible energy to fuel incorporation of NH_3 and degradable protein into microbial protein. However, protein available for absorption post-ruminally is influenced by the amount of feedstuff N that is resistant to ruminal degradation plus microbial protein (Brown and Pitman, 1991). Therefore, feed N, which escapes rumen degradation but is digested in the lower tract is one of the major elements in the determination of feed N value (Brown and Pitman, 1991).

The extent to which the protein in a supplement escapes the rumen is partly a function of its rate of degradation in the rumen (Preston and Leng, 1987). In the earlier chapters of this thesis supplementation with graded levels of *Calliandra calothyrsus* and Lucerne (*Medicago sativa*) in dual-purpose goats on a basal diet of Rhodes grass (*Chloris gayana*) hay was observed to improve milk production and growth performance and to affect rumen fermentation products in goats. The current study was conducted to determine rumen degradation characteristics of those diets to further explain these results.

6.3.0 Materials and methods

The experimental site (KARI Naivasha), feed sources, preparation and sampling, and estimation of DMI were as described in Chapter 3; while experimental design, animal housing and feeding nanagement were as described in Chapter 5. For each of the five (5) experimental periods, the nimals were adapted to the diet for 10 days before rumen incubation of feed samples commenced.

.3.1 Rumen degradation

umen degradation was determined using the nylon bag (Nybold, Switzerland; polymide, porosity 6%, pore size 40 μm, bag size 8 x 16 cm) technique, by incubating feed samples in the rumen rough surgically fitted rumen cannulae. Air-dried feed samples for incubation were ground in a iley mill to pass through a 2 mm screen and compounded by mixing respective ratios of y:legume intake for each treatment diet as observed during the voluntary feed intake trial (Chapter). This was thoroughly mixed in a portable feed mixer after which, three (3) g of each treatment diet as weighed into a nylon bag and sealed. The bags were fixed to a nylon string (Rutagwenda *et al.*, 90) and incubated in the rumen. The bags were introduced progressively in the rumen and cubated for 336 (quadruplicate), 120 and 96 (triplicate), and 72, 48, 24, 12, 6 and 3 (duplicate) urs in each animal as described by Ørskov *et al.*, (1980). All the bags were removed from the men at the same time. After removal they were rinsed in tap water until the water was clear, dried in the oven at 70°C for 48 hours, cooled in a desiccator and weighted to determine the extent of OM disappearance. For the control (zero hour disappearance), two (2) bags for each diet prepared as above were soaked in a water-bath maintained at 39°C for 5 minutes, washed, dried and weighed in the same manner. Degradability of the two legumes was similarly estimated by incubating samples of the legumes in the rumen.

The difference in weight of organic matter and the N content in the samples before and after incubation represented the material degraded in the rumen (AOAC, 1990). The degradation characteristics of each ration were described using the following exponential equation (Ørskov and McDonald, 1979).

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

where a, b & c are constants.

a = The zero time intercept (immediate or water soluble fraction).

b = insoluble but potentially degradable fraction at time t.

c = rate of degradation per hour; and

P = level of degradation at time t.

Potential degradability (PD) was estimated as (a + b), while Effective degradability (ED) was calculated according to the Ørskov and McDonald, (1979) equation; ED = a + bc/(k + c); where k is the estimated outflow rate (Lechner-Doll *et al.*, 1990). An outflow rate (k) of 0.045 per hour was assumed (Lechner-Doll *et al.*, 1990).

6.3.2 Chemical analysis

Rumen incubated residues were analyzed for DM (105°C for 12 hours), OM by ashing the DM residue at 600°C and Kjeldahl N (AOAC, 1990). Feed samples were analyzed as described in Chapter 5.

6.3.3 Statistical analysis

The OM and CP degradation for each diet were analyzed using the Least-squares procedures of Harvey, (2000). Factors fitted in the fixed statistical model of analyses were - treatment diet (T), period of feeding (P) and animal (A). For the purposes of data analysis these factors were coded as follows:- Treatment diet, 1 - 5; periods of feeding were defined as 1 - 5 and the animals were coded as 1 - 5.

The following statistical model was fitted.

$$Y_{ijk} = \mu + T_i + P_j + A_k + e_{ijk}$$

Where,

Y_{ijk} = Degradation of OM or CP at time t after rumen incubation in k^th^ animal during j^th^ period of feeding on i^th^ treatment diet.

μ = The underlying constant common to all observations.

T_i = Effect due to i^th^ treatment diet (i = 1,...,5)

P_j = Effect due to j^th^ period of feeding (j = 1,...,5)

A_k = Effect due to k^th^ animal (k = 1,...,5)

e_{ijk} = Random error effect associated with each observation.

4 *Results and discussion*

The DM (g kg^{-1}), OM and CP (g kg^{-1}DM) of dried forages used in constituting the rations incubated in the rumen are shown in Table 6.1. The DM and OM were; *Calliandra*, (925 and 855); Rhodes grass, (921 and 827); and Lucerne, (904 and 798). The CP content decreased from 247 to 191 and 77 g kg DM for *Calliandra*, Lucerne and Rhodes grass hay respectively.

Table 6.1 Chemical composition (g kg^{-1}DM) of dried forages used in constituting the rations incubated in the rumen of goats

	Rhodes grass hay	*Calliandra calothyrsus*	Lucerne
Dry matter (g kg^{-1})	921.1±4.38	925.4±6.27	904.4±7.96
Chemical Composition (g kg^{-1}DM)			
Organic matter	827.3±3.58	855.0±4.80	797.8±8.93
Crude Protein	77.3±5.13	247.3±1.98	191.2±19.02

The composition (g kg^{-1}DM), ratio (hay:legume) and intake (g day^{-1}) of the treatment diets incubated in the rumen of goats are shown in Table 6.2. The CP content increased with increased proportion of the supplement in the diet. The DM content increased with increase in the proportion of *Calliandra* but decreased with increased Lucerne levels. The OM content followed a similar trend. The mixing ratio (hay:legume) was estimated based on hay intake (Table 6.2) for the various treatment diets as observed during the voluntary feed intake trial (Chapter 5) and the supplementation levels (250 and 500 g day^{-1}) of *Calliandra* for T2 and T3; and Lucerne for T4 and T5.

The hay:legume ratio on DM basis for the supplemented diets ranged from 1.93:1 for T5 to 3.35:1 for T2. This ratio was higher for *Calliandra* than Lucerne diets at similar levels of supplementation. This was due to higher hay intake (Table 6.2) with *Calliandra* than Lucerne supplementation at similar levels. However, due to the higher CP content of *Calliandra* (Table 6.1), the CP content of *Calliandra* diets was higher ($P<0.05$).

The mean DM, OM and CP intake (Table 6.2) for the various treatment diets increased with level of supplementation for both supplements and differed significantly ($P<0.05$) across the diets. The bserved increase in intake was attributed to the inclusion of *Calliandra* and Lucerne in the diets. An portant requirement of a good high protein forage supplement is that it should improve the CP atus and intake of grass based diets (Richards *et al.*, 1994; Muinga *et al.*, 1995; Kariuki *et al.*, 999). This is due to an increase in the amount of N available to the rumen microbes, which nhances microbial activity and therefore the rate of digestion (Norton and Poppi, 1995).

Table 6.2 Mixing ratio (hay:legume) of rumen incubated samples; chemical composition ($g\ kg^{-1}DM$) and intake ($g\ day^{-1}$) of the experimental diets

Treatment	T1	T2	T3	T4	T5		
	Hay:Legume ratio (DM basis)						
	100:0	3.35:1	2.19:1	3.12:1	1.93:1	SED	Significance
Dry matter ($g\ kg^{-1}$)	921.1^{ab}	922.1^{a}	922.4^{a}	917.0^{bc}	915.3^{c}	1.33	
Chemical Composition ($g\ kg^{-1}DM$)							
Organic matter	827.3^{a}	833.6^{b}	835.7^{b}	820.0^{c}	817.1^{c}	1.30	
Crude Protein	77.3^{a}	116.3^{b}	130.4^{c}	105.3^{d}	116.6^{b}	1.66	
Nutrients intake ($g\ day^{-1}$)							
HDMI	600.2^{a}	774.7^{b}	1014.7^{c}	706.3^{d}	873.9^{e}	16.84	***
TDMI	600.2^{a}	1006.1^{b}	1477.4^{c}	932.4^{d}	1326.1^{e}	16.84	***
TOMI	496.5^{a}	838.7^{b}	1235.1^{c}	764.7^{d}	1083.8^{e}	14.10	***
TCPI	46.4^{a}	117.1^{b}	192.8^{c}	97.8^{d}	154.1^{e}	2.07	***
Available DOMR ($g\ day^{-1}$)	193.5^{a}	372.0^{b}	570.4^{c}	332.0^{d}	494.6^{e}	3.11	**
% increase in Available DOMR with supplementation	-	92.2^{a}	194.8^{b}	71.6^{c}	155.6^{d}	2.98	***

HDMI, Hay DM intake; TDMI, Total DM intake; TOMI, Total OM intake; TCPI, Total CP intake; DOMR, organic matter fermented in the rumen; DOMR = TOMI*ED/1000 (Kariuki, 1998); ED, effective degradability; SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); **, $P<0.01$; ***, $P<0.001$.

These results indicated that both supplements had positive effects on microbial activity and fermentation and greatly improved the available organic matter fermented in the rumen (DOMR) by up to 195 and 156% for the high level of *Calliandra* and Lucerne respectively (Table 6.2). It has been observed that DOMR influences microbial protein (MP) production (Brun-Bellut *et al.*, 1990; Tamminga *et al.*, 1994) and that the efficiency of microbial protein production is related to the amount of DOMR available in the diet (Tamminga *et al.*, 1994). It is estimated that about 150 g of MP are formed per kg DOMR (Brun-Bellut *et al.*, 1990; Tamminga *et al.*, 1994). Norton and Poppi (1995) observed that legumes have the greatest potential to improve the protein:energy ratios in tropical grass-based diets because of their inherently higher CP and digestibility. Increase in DOMR due to supplementation with legumes has previously been reported (Kaitho, 1997; Kariuki, 1998; Muia, 2000).

Table 6.3 shows the estimated OM and CP degradability characteristics of Rhodes grass hay, *Calliandra* and Lucerne. The legumes were observed to have higher OM and CP degradation characteristics in terms of proportion and rate of degradation of the soluble and potentially degradable fractions than grass hay, a reflection of their good quality.

Table 6.3 OM and CP degradation characteristics of Rhodes grass hay, *Calliandra calothyrsus* and Lucerne (g kg^{-1} of original forage OM and CP)

Degradation characteristics	Rhodes grass hay	*Calliandra* calothyrsus	Lucerne
OM Degradation characteristics (g kg^{-1}OM)			
a	229.4	370.1	348.2
b	353.8	501.9	478.5
c (hr^{-1})	0.0373	0.0487	0.0449
PD	583.2	872.0	826.7
ED	389.7	642.1	587.2
u	122.7	82.3	89.7
CP Degradation characteristics (g kg^{-1}CP)			
a	190.6	262.5	251.3
b	439.2	674.2	653.7
c (hr^{-1})	0.142	0.158	0.152
PD	629.8	936.7	905.0
ED	524.1	787.2	755.7
u	305.8	140.6	210.5
BP	494.5	624.7	614.6
RDP	505.5	375.3	385.4
IDP	188.7	484.1	404.1

a, b, and c are constants in the equation $P = a+b(1-e^{-ct})$ where P is the level of degradation at time t; a is the intercept or immediate soluble fraction; b is the insoluble but potentially degradable fraction at time t; c is the rate of degradation per hour; PD, Potential degradability; PD=a+b; ED, Effective degradability; ED=a+bc/(k+c); u, truly undegradable residue (336 hour incubation); BP, By-pass protein; BP=u+IDP; IDP, intestine degradable protein; RDP, rumen degradable protein; BP+RDP=1000.

Tamminga *et al.*, (1994) observed that in forage-based diets, protein quality of each dietary component is important in evaluating responses to supplementation. The generally greater absolute quantities of CP in legumes led to greater overall total yield of RDP from legumes than the grass hay. This is important because when used as supplements to low CP grass based diets, the legumes improve RDP of the diet, which has been suggested to be the most limiting factor for ruminants fed on tropical grasses (Kaitho, 1997). Although protein sources with low RDP improve total N flow to the small intestine (Cecava and Parker 1993; Ludden and Cecava, 1995), high RDP may be beneficial in low CP tropical forages because it would considerably increase DOMR and hence MP production. Van Eys *et al.*, (1986), attributed improved weight gain in goats fed on *Pennisetum purpureum* supplemented with *Gliricidia*, *Leucaena* or *Sesbania* to the amount and characteristics of RDP in the legumes and its effect on MP production.

Although tannin levels were not measured in this study, some studies have shown that *Calliandra* could contain tannins, which depress digestion (Ahn *et al.*, 1989; Jackson *et al.*, 1996; Hove *et al.*, 2001; Seresinhe and Iben, 2003). It has been reported that tannin levels above 4% DM could negatively influence digestibility but contents that are below this limit (below 4% DM) may play a beneficial role by preventing excessive degradation of protein in the rumen thereby increasing the proportion of BP (Topps, 1992; Fassler and Lascano, 1995; Kaitho, 1997). It is therefore, possible that *Calliandra* in this study had low tannin levels (below 4% DM) because a high proportion (77%) of the BP was digested in the small intestine. Kiura, (1992) and Kaitho *et al.*, (1998) concluded that legumes with high tannin levels (above 4% DM) had high BP but low IDP.

The lower degradability characteristics of Lucerne than *Calliandra* could have been due to its higher lignin content (Chapter 5, Table 5.1). Lignin, which forms a complex with hemicellulose, also protects cellulose from enzymatic and microbial attack (Hartfield, 1993). Similarly, the lower degradability of the grass hay than the legumes could probably be due to its high fibre content (723 and 405 g kg^{-1}DM - NDF and ADF respectively). This could be an indication that some of its CP was fibre bound (Aufrere and Guerin, 1996) and therefore indigestible (Van Soest, 1994; McDonald *et al.*, 1995). Protein bound to certain cell wall components like lignin is not degraded in the rumen and is considered indigestible in the intestine (Chalupa and Sniffen, 1996) thus lowering the amount of degradable CP. Tamminga and Van Vuuren, (1988), Reid *et al.*, (1988) and Bosch, (1991) observed that low CP content negatively affects degradation of roughages. From the results of this study, it seems that the lignin in the grass at 66.6 g kg^{-1}DM had a greater negative effect on CP degradability than the lignin in Lucerne at 77.5 g kg^{-1}DM (Chapter 5). This concur with the general observation that lignin in grasses has a greater negative effect on degradability than in legumes (Minson, 1990; Van Soest, 1994; McDonald *et al.*, 1995).

Sniffen *et al.*, (1992) observed that tropical grasses are characterized by high contents of indigestible detergent fibres and lignin, low total N content and high proportion of bound N within the indigestible vascular bundles resulting in low digestibility, low nutrients intake and consequently low animal performance. Kaitho, (1997), concluded that the N content of browses does not fully account for their nutritive value as protein supplements. Factors such as N degradability in the rumen and digestibility of the by-pass N are of paramount importance and these are subject to factors such as tannin, fibre or lignin concentrations of the browses (Kaitho, 1997). Kariuki, (1998) observed that the low CP in tropical grasses limits microbial protein synthesis and suggested that protein supplementation strategies to such grasses should first target at satisfying the rumen microbial requirements. The author suggested that protein supplements containing a combination of both ruminally degradable protein and BP could then be considered for improved animal performance. The two legume supplements in this study provided both RDP and BP The RDP provided by the legumes was higher by 138 and 89% for *Calliandra* and Lucerne respectively as compared to that provided by the grass hay and therefore their inclusion as supplements improved both RDP and BP of the supplemented diets (Table 6.4). This was reflected in improved voluntary feed intake (Chapters 3, 4 and 5) and animal performance (Chapters 3 and 4) in animals on supplemented diets.

The PD and ED of the legumes were higher than for hay. This could be attributed to their higher immediate 'a' and potentially soluble fractions 'b' than the grass hay (Table 6.3). Hagerman *et al.*, (1992) and Kaitho, (1997) observed that the differences in solubility and potential degradation are dependent on the cellular structure of the components being degraded and on inherent attributes of the NDF and CP present. Additionally, microbial protein synthesis is influenced by feedstuff N that is soluble and degradable in the rumen and the energy available to fuel incorporation of NH_3 into microbial amino acids (Preston and Leng, 1987). In this study, the legumes were observed to have higher ME than grass hay (Chapter 5). This contributed to their higher PD and ED values because more energy was available to the rumen microbes for their growth and activity hence improved degradation.

The estimated OM and CP degradability characteristics of the various treatment diets are shown in Table 6.4. These results indicated improved OM and CP degradability characteristics of the diets with level of supplementation. The estimated immediately soluble OM and CP fractions 'a' and potentially degradable OM and CP fractions 'b' increased ($P<0.05$) with level of supplementation (Table 6.4). At similar levels, *Calliandra* had higher immediately soluble OM and CP fractions and potentially degradable OM and CP fractions than Lucerne based diets. Increase in level of supplementation increased ($P<0.05$) 'a' and 'b' for both *Calliandra* and Lucerne diets. The higher OM and CP degradability characteristics of the legumes than grass hay (Table 6.3) improved the overall degradability of the supplemented diets because they provided more degradable OM and CP. Additionally, the higher CP content of the supplemented diets (Table 6.2) increased the amount of NH_3-N available to the rumen microbes thus improving microbial protein synthesis with a resultant improvement in OM degradability in the rumen. This increased feed intake (Table 6.2), which would be associated with improved animal performance by the supplemented animals observed earlier in

Table 6.4 OM and CP degradation characteristics of the treatment diets incubated in the rumen of goats (g kg^{-1} of original OM and CP of the diet)

Treatment diet	T1	T2	T3	T4	T5	SED	Significance
OM degradation characteristics (g kg^{-1}OM)							
a	229.4^{a}	261.7^{b}	273.5^{c}	258.2^{d}	269.9^{e}	3.04	**
b	353.8^{a}	387.8^{b}	400.2^{c}	384.1^{d}	396.4^{e}	2.32	***
c (hr^{-1})	0.0373^{a}	0.0397^{b}	0.0400^{b}	0.0380^{b}	0.0400^{b}	0.002	*
PD	583.2^{a}	649.5^{b}	673.7^{c}	642.3^{b}	666.3^{d}	3.57	**
ED	389.7^{a}	443.5^{b}	461.8^{c}	434.1^{d}	456.4^{e}	3.75	***
u	122.7^{a}	113.4^{b}	110.0^{c}	114.7^{d}	111.4^{e}	1.71	***
CP degradation characteristics (g kg^{-1}CP)							
a	190.6^{a}	207.1^{b}	213.1^{c}	205.3^{d}	211.3^{e}	1.24	**
b	439.2^{a}	493.2^{b}	512.9^{c}	491.3^{d}	512.4^{e}	2.11	***
c (hr^{-1})	0.142^{a}	0.146^{b}	0.151^{c}	0.145^{b}	0.150^{c}	0.002	*
PD	629.8^{a}	700.3^{b}	726.0^{c}	696.6^{d}	723.7^{e}	2.27	***
ED	524.1^{a}	584.1^{b}	608.2^{c}	580.2^{d}	605.5^{e}	3.12	***
u	305.8^{a}	267.8^{b}	254.0^{c}	282.7^{d}	273.3^{e}	1.77	***
BP	494.5^{a}	524.4^{b}	540.3^{c}	523.7^{b}	535.5^{d}	3.71	**
RDP	505.5^{a}	475.6^{b}	459.7^{c}	476.3^{b}	464.5^{d}	2.69	**
IDP	188.7^{a}	256.6^{b}	286.3^{c}	241.0^{d}	262.2^{e}	2.61	**

a, b, and c are constants in the equation $P = a+b(1-e^{-ct})$ where P is the level of degradation at time t; a is the intercept or immediate soluble fraction; b is the insoluble but potentially degradable fraction at time t; c is the rate of degradation per hour; PD, Potential degradability; PD=a+b, ED, Effective degradability; ED=a+bc/(k+c); u, truly undegradable residue (336 hour incubation); BP, By-pass protein; BP=u+IDP; IDP, intestine degradable protein; RDP, rumen degradable protein; BP+RDP=1000. SED, Standard error of difference between means; Different superscripts ^{a} within a row indicate significant difference ($P<0.05$); *, $P<0.05$; **, $P<0.01$; ***, $P<0.001$.

his study (Chapters 3 and 4). Increase in OM and CP degradability with increase in CP content in he diet has been reported (Preston and Leng, 1987; Minson, 1990; Woolfe, 1991; Van Soest, 1994; Norton and Poppi, 1995).

The improvement in degradability characteristics of the supplemented diets suggests that the rumen environment was limited in nutrients supplied by the supplements. Therefore, it is possible that basal diet degradability was different in supplemented and unsupplemented animal groups. Thus effects of supplementation with the legumes were two fold. Supplementation improved the degradability of the basal diet by providing more degradable N in the rumen, thus improving microbial protein synthesis and, due to their higher rate of degradation 'c' (Table 6.3) than the basal diet, they were degraded faster in the rumen than the basal diet. The overall effect was improved degradability of the supplemented diets compared to the control diet. Additionally, degradation increased with level of supplementation as the proportion of the less degradable Rhodes grass hay in the animal's diet decreased from 77 to 69% for T2 and T3; and 76 to 66% for T4 and T5 respectively (Table 6.2). The increased intake of the basal diet with level of supplementation also suggests further improvements in the rumen environment for microbial activity. It has been suggested that legumes ensured a more efficient rumen environment for digestion by providing micronutrients such as peptides, amino acids, minerals and vitamins (Tchinda *et al.*, 1994).

Minson, (1990); Ibrahim *et al.*, (1995) and Mgheni *et al.*, (1994) observed that grasses had lower overall degradability characteristics in terms of proportions and rates of degradation of the soluble and potentially digestible fractions than legumes. This is because grasses generally have lower CP content than legumes (Minson, 1990; Boonman, 1997). Thus in the current study supplementation of Rhodes grass hay with legumes improved the degradability characteristics of the supplemented diets. Similarly, Kaitho, (1997) noted that the value of forages as supplements depends mainly on their capacity to provide the nutrients that are deficient in the basal diet. This includes their ability to provide the essential nutrients to the rumen microbial population and/or critical nutrients to meet the host animal's requirements thus increasing the efficiency of feed utilization. Thus hay alone supplied a deficient diet, which responded to supplementation with forage legumes probably due to the improved N supply among other nutrients required for rumen microbial activity.

Supplementation also improved the ME content of the diets, which improved the MEI. This was important because energy was required by rumen microbes, for microbial protein synthesis. Additionally, it has been reported that a number of minerals such as Ca, Cl, P, Na, K, Mg, S, Fe, Zn, Co, Cu, F, I, Mo, Se and Mn are required by rumen microorganisms for their normal growth and metabolism and deficiencies could negatively affect the ability of microorganisms to digest fibre and synthesize protein (Spears, 1994). It is therefore, possible that the legume supplements provided minerals, which could have been deficient in the grass only diet with a resultant effect in improved degradability of the supplemented diets. Underwood, (1981) concluded that mineral deficiencies were likely to lead to depressed feed intake and forage utilization and subsequently poor animal performance. Preston and Leng, (1987) reported that nutrient imbalances were the main cause of low productivity of livestock in the tropics and subtropics, as these could lead to inefficient utilization of the nutrients (Leng, 1990; 1993). Preston, (1986) observed that a potential forage legume supplement for enhancing utilization of poor quality roughages and crop residues should have a high protein content to supply degradable protein and that there would be an added advantage if the legume contains other critical nutrients such as minerals, vitamins, lipids and other compounds which enhance the rumen ecosystem. PRFs have a great potential to enhance the nutritive value of low N pastures and poor quality crop residues because they contain satisfactory levels of protein and minerals (Aletor and Omodara, 1994).

Supplementation increased the rate of OM degradation 'c' in the rumen from 0.0373 (T1) to 0.0397 and 0.0400 per hour for T2 and T3 respectively and to 0.0380 and 0.0400 per hour for T4 and T5. The differences were significant ($P<0.05$) between the control and supplemented diets but similar among the supplemented diets. Similarly, degradation rate of CP increased from 0.142 to 0.146 and 0.151 for T2 and T3 respectively and to 0.145 and 0.150 for T4 and T5 (Table 6.4). The increases with level of supplementation were significant ($P<0.05$) for both supplements. Supplementation with legumes increased rate of degradation of the diets since the legumes had higher 'c' than grass hay (Table 6.3) in addition to increased amounts of degradable OM and CP available to the rumen microbes, thus improving microbial protein synthesis with a resultant increase in rate of degradation of the basal diet.

Increase in rate of degradation with supplementation on protein sources has been reported by other researchers. Osuji *et al.*, (1995), concluded that for improved animal performance a supplement should enhance fermentation of the basal diet, improve rate and extent of particle size reduction and thus increase the passage rate of the digesta out of the rumen leading to increased feed intake. In the current study, increased intake of the basal diet (Chapters 3, 4 and 5) indicated its improved fermentation with supplementation (Chapter 5). Similarly, Cerrillo and Juarez, (2004) in a study evaluating the nutritional value of shrubs, trees and cactus consumed by browsing goats, concluded that the rate of degradation, 'c' provided a good estimate of the nutritional quality of forages consumed by goats. Tamminga, (1979) and Leng and Nolan, (1984) observed that the rate at which feeds are hydrolyzed controls the rate at which they pass out of the rumen and therefore intake of the feed.

The potential degradability (PD) of OM increased with supplementation. The mean potentially degradable OM was 643.0±2.97 g kg^{-1}DM and varied from 583.2 (T1) to 673.7 g kg^{-1}DM (T3) (Table 6.4). At the low level of supplementation PD values were similar, while at the high level *Calliandra* (T3) had higher ($P<0.05$) PD than Lucerne based diet (T5). Similarly, potentially degradable CP increased with supplementation and with level of supplementation. These results indicated that supplementation with legumes increased the amount of OM and CP in the feed that was potentially degradable. *Calliandra* based diets had significantly ($P<0.05$) higher potentially degradable CP at both levels of supplementation. Tchinda *et al.*, (1994) reported increase in potential degradability when Elephant grass (*Pennisetum purpureum*) fed to sheep was supplemented with increasing levels of perennial peanut (*Arachis glabrata*). Similarly, Kariuki, (1998) reported significant increases in potential degradability of Napier grass based diets supplemented with graded levels of Desmodium and Sweet potato vines fed to Friesian steers.

The effective degradability (ED) of OM and CP in the rumen followed a similar trend to that of PD and increased ($P<0.05$) with level of supplementation (Table 6.4). This was an indication that supplementation with legumes increased the amount of OM and CP that was actually degraded in the rumen. Increase in potential and effective degradability of OM and CP of a feed with supplementation could be an indication of improved nutritional status of the feed. Cerrillo and

Juarez, (2004), indicated that high PD values may be an indication of a better nutrient availability to the rumen microorganisms. It was observed that supplemented diets with higher 'c' values also had higher PD and ED values. Thus it may be argued that supplementation improved the nutritional status of the feed with a resultant improvement in the rate of degradability, and PD and ED of those diets. Therefore, the low 'c', PD and ED values of T1 (control diet) compared to the supplemented diets could be attributed to resistance to degradation by rumen microbes due to the lower nutritional value of that diet. The higher nutritional value of the supplemented diets was also reflected in higher concentrations of VFA (Chapter 5), thus more energy was supplied to the rumen microbes, which resulted to increased degradability in the rumen.

The non-degradable OM and CP 'u' (336 hours incubation residue) decreased significantly ($P<0.05$) with supplementation, an indication that supplementation improved OM and CP degradability. Supplementation increased ($P<0.05$) by-pass protein (BP) and intestine degradable protein (IDP) (Table 6.4). BP and IDP were highest for T3 and increased ($P<0.05$) with level of supplementation for both supplements. At similar levels of supplementation, *Calliandra* based diets were higher ($P<0.05$) in these values than Lucerne. This reflected the higher BP and IDP for *Calliandra* than Lucerne (Table 6.3). Perez-Maldonado, (1994) observed that supplementation with *Calliandra* increased the amount of BP

The increased IDP with legume supplementation was an indication that increasingly more CP from the diet was digested in the small intestine by enzymes of the host animal. This improved the quantity of amino acids made available to the animal and was reflected as improved animal performance in terms of milk yield and growth observed earlier in the study. Muia, (2000) suggested that for improved milk production a supply of BP from the supplement, which is digested in the lower gut is required. Mackie and Morrison, (1995) also noted that for high production by ruminants, a high amount of BP digested in the intestine would be required and this can be provided by supplementation with a legume or a concentrate source with rumen BP qualities. Similarly, Buxton, (1996) suggested that forages with comparatively high concentration of rumen-undegradable protein (UDP) may be utilized more efficiently than those with readily degradable protein.

Van Straalen, (1995) suggested that the amount of N apparently digested in the small intestine is a good indication of the protein available to the host animal. Protein available for post-ruminal absorption is influenced by the amount of digestible forage protein that is resistant to rumen degradation plus microbial protein (Brown and Pitman, 1991; Kaitho *et al.*, 1998). Therefore, the total amount of protein available is dependent on the flow of microbial and dietary protein to the duodenum and their respective intestinal digestibilities. It is also possible that BP could be of an inferior quality than MP or even be indigestible and lost in the faeces in which case it would not be of benefit to the animal Additionally some degraded N may escape as NH_3 and therefore unavailable for utilization by the animal. However, where microbial protein synthesis on a particular diet is optimized, improved BP content would increase the protein available to the host animal and its performance. In the earlier chapters of this study it was observed that digestibility and intake (Chapter 5) and animal performance (Chapters 3 and 4) improved with supplementation. All these indicated that supplementation improved the overall supply of protein and the other nutrients necessary for enhanced microbial and host animal performance.

In the current study *Calliandra* was readily consumed and goats on *Calliandra* based diets performed better (growth and milk yield) than those on Lucerne based diets and the control. Kaitho, (1997) observed that legume supplements that are rapidly degraded in the rumen provide high levels of rumen NH_3, much of which could be wasted by excretion as urinary urea; and concluded that species which contain moderate levels of tannins will provide adequate levels of both RDP and UDP and will therefore be more effective sources of supplemental protein for ruminants. In a study on effects of chestnut tannins on digestibility and ruminal digestion in sheep and goats, Zimmer and Cordesse, (1996) observed that chestnut tannins did not affect rumen degradation of cell wall or ruminal microbial synthesis. The conclusion from these studies was that manifestation of adverse effects depends on the level of intake of the high tannin browse, and on the extent and rate of ruminal metabolism of the anti-nutritive constituents. It has also been suggested that the rumen microbes of goats are capable of metabolizing most anti-nutritive factors (Lee *et al.*, 2000; Robertson *et al.*, 2004).

6.5 *Conclusions*

Results obtained in this study indicated that supplementation of a grass based diet with legumes improved rumen degradation characteristics of OM and CP and RDP, BP and IDP thus improving the efficiency of utilization of the basal diet. These improvements increased with level of supplementation. At similar levels of supplementation goats on *Calliandra* had higher rumen degradation characteristics of OM and CP; and higher amounts of RDP, BP and IDP than those on Lucerne based diets. This was an indication that *Calliandra* could be a better supplement for goats than Lucerne.

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CHAPTER 7

General discussion

General discussion

7.1 *Introduction*

The traditional system of management and production for small ruminants in the tropics over the years has been free grazing, where the animals graze and browse freely (Okello *et al.*, 1996). However, in the recent past, due to increasing human population, land holdings are declining as a result of increased subdivision for human settlement especially in the medium and high agricultural potential areas in Kenya (Muia, 2000). The priority in these areas is to put more land under crop production to cater for food for human consumption (Muia, 2000). Less land is therefore available for fodder production, and as a result, small ruminants are often underfed especially during the dry season when only poor quality forages and crop residues are available (Kaitho, 1997).

Due to the need to maximize use of available land, free grazing is slowly being phased out in favour of stall-feeding where the animals are housed and fed on a wide variety of feeds through a cut-and-carry system. Irungu, (1999) observed that one of the main characteristics of smallholder animal production systems is reliance on diverse types of feeds. During the dry season, feed sources are scarce and the available grasses highly fibrous and lignified (Kaitho, 1997; Kariuki, 1998; Muia, 2000). Such feeds are high in cell wall components (cellulose, hemicellulose and lignin) and low in minerals and crude protein content and digestible cell components (starch, water soluble carbohydrates) (Muia, 2000). To meet the animal's N and energy requirements these feeds must be supplemented with high protein and energy sources. However, commercial concentrates, which are high in these nutrients are often expensive and usually out of reach of the smallholder farmers. Alternative and affordable high protein supplements in the form of protein-rich forages (PRFs) have been identified (Njwe and Kona, 1996).

One way by which protein supplementation improves performance of animals consuming low quality forages is through stimulation of voluntary feed intake and by increasing efficiency of utilization of the nutrients. PRFs increase intake by increasing rate of degradation and rate of exit of the digesta from the rumen through enhanced population and activity of cellulolytic microbes thus more microbes are available to colonize and degrade the basal diet (Kaitho, 1997).

In the current study, Rhodes grass (*Chloris gayana*) hay was supplemented with graded levels of *Calliandra calothyrsus* and Lucerne (*Medicago sativa*). In the first phase of the study, graded levels of the two (2) legumes were offered as supplements to dual-purpose does and weaners, under two (2) management systems (confined feeding and free-range). The does were offered the supplements from four (4) weeks of expected kidding date, and throughout the lactation period till drying. Effects of the supplements on feed intake, doe daily live-weight change (before and after kidding), birth weight of the kids, lactation performance and pre-weaning kids growth were monitored. After weaning at 16 weeks, the weaners were also supplemented with the two (2) legumes to study the effects on post-weaning growth and yearling live-weight. In the second phase, effects of graded levels of these supplements on *in-vivo* digestibility, N balance, rumen fermentation characteristics and rumen degradability in goats on Rhodes grass (*Chloris gayana)* hay basal diet were investigated.

7.2 Performance of dual-purpose goats on PRFs supplementation under two management systems

Results of the lactation performance study (Chapter 3) indicated that supplementation of Rhodes grass hay with legumes improved the doe daily live-weight change (LWC) prior to and after kidding, birth weight and growth rate of the kids, milk yield and lactation persistency. At similar levels of supplementation does on *Calliandra* performed better ($P<0.05$) than those on Lucerne based diets. The daily LWC of the does improved with level of supplementation for both supplements. Under the confined feeding system, the control animals lost weight, while the supplemented groups maintained a positive daily LWC throughout the lactation period. Supplementation of the does during the third trimester improved birth weight of the kids, the improvements increased with level of supplementation of the doe. Supplementation during the third trimester is crucial as rapid musculoskeletal development of the foetus takes place during this period (Furber, 1985; Skea, 1989; Peacock, 1996). The mean birth weight (2.78 kg) obtained in this study was comparable to the range of 2.24 to 3.50 kg reported for the same breed (Ahuya *et al.*, 1987; Ruvuna *et al.*, 1987; Ruvuna *et al.*, 1992), while the mean lactational milk yield (123.00 kg) corresponded with the range of 78.40 to 120.00 kg obtained by Ruvuna *et al.*, (1987) for the same breed.

The mean pre-ADG and weaning weight obtained in this study were 73.53 g day^{-1} and 10.87 kg respectively, and were comparable to 64.42 g day^{-1} and 10.42 kg reported for the same breed (Ahuya *et al.*, 1987). Daily milk yield and lactation persistency improved with level of supplementation resulting in higher milk intake by the kids, hence high growth rate (ADG and WWT) and low pre-weaning kid mortality. The better performance of the supplemented does was due to increased nutrients intake with supplementation, which made more nutrients available for milk synthesis. Results of this study indicated a strong positive relationship between level of supplementation, lactation performance of the dam and live-weight gain of the kid. Similar findings have been reported (Nianogo and Ilboudo, 1994; Cisse *et al.*, 1996).

The poor performance of the does fed the control diet (Rhodes grass hay only) compared to those on the supplemented diets could be attributed to the low CP and high fibre (NDF and ADF) contents of the control diet, which led to low digestibility compared to the supplemented diets (Chapter 5). Dietary fibre content has been reported to be negatively correlated to digestibility (Muia, 2000; Tolera and Sundstol, 2000; Adesogan *et al.*, 2002). This was reflected in low milk yield, poor body condition and shorter lactation lengths for those does translating to lower milk supply to their kids, which was reflected in reduced growth rate and higher pre-weaning kid mortality than those born to does on supplemented diets (Chapter 3).

At similar levels of supplementation does on free-range management system performed better ($P<0.05$) than those on confined feeding. This could have been due to the differences in the basal diet offered under the two systems. While does on confined feeding were offered Rhodes grass hay only as the basal diet, those on free-range grazed freely in a natural thorn bush land savannah with trees and shrubs. Chemical analysis (Chapter 3) of the most preferred species under the free-range system indicated that the goats were able to select feed of a better nutrient composition and therefore higher quality than Rhodes grass hay. Trees and shrubs have been reported to be better sources of CP, minerals and vitamins than grasses (Ademosun, 1994; Kaitho, 1997). Though it was not possible to measure the amount of feed consumed under the free-range system, it is also possible that those goats consumed more feed than the confined group due to free choice and selection. For similar reasons, weaners on free-range performed better ($P<0.05$) than those on confined feeding by up to 8 and 25%, and 15 and 31% improvement in post-ADG and yearling live-weight at the high level of *Calliandra* and Lucerne supplementation respectively However, performance on free-range would vary with environment and the natural vegetation of the area. Performance of animals in grass plains dominated by grass species would be expected to be different from those in a thorn bush land savannah with trees and shrubs where this feeding trial was conducted.

The mean post-ADG (40.85 g day^{-1}) and YWT (17.30 kg) obtained in this study, were similar to the mean of 47.42 g day^{-1} and 21.80 kg respectively, reported for the same breed (Ahuya *et al.*, 1987; Ruvuna *et al.*, 1987). Supplementation of weaner goats with PRFs (Chapter 4) improved feed intake with a resultant improvement in post-ADG and YWT with level of supplementation. For the free-range, post-ADG improved from 32.2 for the control to 61.3 and 50.0 g day^{-1} equivalent to 90 and 55% improvement in performance, for the high level of *Calliandra* and Lucerne supplementation respectively. The corresponding improvements for the confined feeding were from 17.4 for the control to 56.8 and 40.1 g day^{-1} equivalent to 226 and 130% improvement in performance, for the high level of *Calliandra* and Lucerne supplementation respectively (Chapter 4). Based on the percentage increases in post-ADG it was observed that the improvements were higher for the confined feeding than under the free-range system an indication that the impact of supplementation was greater on the poorer basal diet. These results indicated that supplementation of weaner goats on a low quality basal diet with PRFs could be practiced to improve post-weaning growth rate (post-ADG) with the advantage of early attainment of mature body weight. This allows breeding at an early age thus increasing the productive life of the animal and/or early attainment of slaughter weight for meat animals.

The improvements in post-ADG with supplementation on legumes obtained in the current study were comparable to the findings by other researchers on similar supplementation trials. Ebong, (1996) and Kaitho, (1997) demonstrated that supplementation of grass-based diets with legumes improved ADG of growing goats. Ebong, (1996) reported post-ADG in goats of 27.1 for the control on Elephant grass only and 67.0 g day^{-1} after supplementation on *Calliandra* leaf meal. Similarly, Kaitho, (1997) recorded a post-ADG of 32.3 g day^{-1} in weaner goats supplemented on *Luecaena pallida*, while the control on teff straw and wheat bran had post-ADG of only 4.9 g day^{-1}.

The observed improvement in milk yield and growth rate could be attributed to improved nutrients intake with supplementation. It was observed that both hay and total DMI increased with level of supplementation (Chapters 3, 4 and 5). For the does under confined feeding, TDMI increased from

674.3 (control) to 1317.1 and 1254.2 g day^{-1} for the high level of *Calliandra* and Lucerne supplementation respectively. Similarly, TCPI increased from 52.2 (control) to 180.8 and 149.8 g day^{-1} for the high level of *Calliandra* and Lucerne supplementation respectively. Supplementation appears to have improved the rumen environment enhancing microbial activity with a resultant effect in improved digestibility and intake of digestible nutrients (Chapter 5), hence improved performance (Chapters 3 and 4). It was observed that DM, OM and CP digestibility coefficients increased from 60.1, 60.3 and 63.1% for the control diet to 70.2, 72.3 and 76.2%; and 69.2, 71.2 and 71.4% for the high level of *Calliandra* and Lucerne supplementation respectively (Chapter 5). Inclusion of the legumes also increased ($P<0.05$) DDMI, DOMI and DCPI (g day^{-1}) (Chapter 5).

The legumes were observed to have higher ME than Rhodes grass (Chapters 3, 4 and 5), which indicated their potential as diet supplements and their inclusion significantly ($P<0.05$) increased the ME content of the supplemented diets (Chapters 3, 4 and 5). The ME content of the doe diets increased from 9.05 (control) to 10.85 and 10.68 MJ kg^{-1}DM for the high level of *Calliandra* and Lucerne supplementation respectively, consequently, MEI increased from 6.12 (control) to 12.34 and 11.59 MJ day^{-1} for those diets. The MEI for the control was below the minimum requirements for maintenance while the supplemented diets met this requirement of 6.6 MJ day^{-1} for a 40 kg goat (Peacock, 1996). Does on the control diet were also observed to have lower DCPI (g day^{-1}) than the recommended 43.0 g day^{-1} for maintenance (Peacock, 1996). Consequently, for the confined feeding system, the control animals lost weight at the rate of 9.8 g day^{-1} during the kid-rearing phase due to mobilization of body reserves for milk synthesis. The supplemented groups maintained a positive daily LWC throughout the lactation period with a weight gain of 8.4 and 7.0 g day^{-1} for the high level of *Calliandra* and Lucerne supplementation respectively during the kid - rearing phase (kidding - weaning).

Increase in energy intake with protein supplementation is crucial as energy is required by rumen microbes during microbial protein synthesis (Van Soest, 1994; McDonald *et al.*, 1995). This energy is released when OM is fermented in the rumen to yield mainly VFA, which are major energy sources for ruminants (Mackie and Morrison, 1995). The higher DOMI with supplementation (Chapter 5) would result in improved energy supply while the higher DCPI increased the amounts of NH_3-N available for microbial protein synthesis. Thus supplementation increased the amount of N incorporated into microbial amino acids and higher amounts of microbial protein was released to the lower gut for utilization by the host animal leading to improved animal performance (Chapters 3 and 4). Increased nutrients intake and improved performance due to supplementation on protein sources has been reported (Paterson *et al.*, 1996; Kaitho, 1997; Roothaert *et al.*, 1997; Kariuki, 1998; Roothaert, 1999; Muia, 2000).

It was observed that variation in rumen fermentation parameters (rumen pH, VFA and NH_3-N) followed a diurnal variation. This was attributed to an inherent variability in the rumen ecosystem (Huntington and Offer, 1994) and the feeding pattern. Immediately after feeding, there was an increase in VFA and NH_3-N concentrations and a corresponding drop in rumen pH explained by an increase in substrate available for degradation by rumen microbes followed by a slow recovery to the pre-feeding state. Decrease in NH_3-N concentration while VFA concentration was still increasing was attributed to increased incorporation of NH_3-N into microbial amino acids synthesis. The NH_3-N and VFA concentration in the rumen reflects a balance between production, absorption across the rumen wall and utilization by rumen microorganisms for microbial amino acids synthesis.

The legumes had higher rates of CP and OM degradation (Chapter 6) than Rhodes grass hay. This implied that inclusion of the legumes in the diet would improve nutrients utilization through improved degradability of the supplemented diets, due to reduced feed resistance to digestion hence a shorter feed residence period in the rumen leading, to increased feed intake and improved animal performance. This was an indication that Rhodes grass hay only diet was not adequate in protein and energy, among other nutrients and hence the improved performance (milk yield and growth rate) after supplementation (Chapters 3 and 4). Mature tropical grasses fed as sole diets lead to low animal performance due to poor quality (Kaitho, 1997; Kariuki, 1998; Muia, 2000). Therefore, to enhance production supplementary feeds that contain rumen degradable protein (RDP) should be fed to ensure that rumen NH_3-N concentration would support high microbial growth and activity (Hoover, 1986). In the current study supplementation with legumes increased both the CP content of the diet (Chapters 3, 4 and 5) and rumen degradable protein (RDP) (Chapter 6) with level of supplementation. Increase in RDP resulted in increased rumen NH_3-N concentration (Chapter 5), which enhanced rumen microbial growth and multiplication thus improved digestibility and feed intake (Chapter 5). This was reflected as improved milk yield (Chapter 3) and growth (Chapters 3 and 4). Similarly, Nocek and Grant, (1987) reported increased RDP with increase in CP content of the diet. Van Eys *et al.*, (1986) associated increased weight gain observed in goats supplemented with *Gliricidia*, *Leucaena* or *Sesbania* with the quantity and characteristics of RDP in the legumes and its effects on microbial protein production

Supplementation with legumes in the current study increased RDP, by-pass protein (BP) and intestine degradable protein (IDP) (Chapter 6), implying that the legumes provided additional nutrients in the rumen required by the micro-organisms for enhanced degradation of the basal diet, and also provided some BP digested in the lower gut. The amount of BP increased from 494.5 (for the control) to 540.3 g kg^{-1}DM, a 9.3% increase, for the high level of *Calliandra* supplementation and to 535.5 g kg^{-1}DM, an increase of 8.3%, for the high level of Lucerne supplementation. Similarly, the amount of IDP increased from 188.7 to 286.3 g kg^{-1}DM, a 51.7% increase and to 262.2 g kg^{-1}DM, a 39.0% increase for the high level of *Calliandra* and Lucerne supplementation respectively. Increase in BP with supplementation led to improved performance as part of BP was digested in the lower gut as IDP increasing the amount of protein available to the animal, hence improved performance (Barry *et al.*, 1986; Mangan, 1988).

7.3 *Calliandra calothyrsus versus Lucerne (Medicago sativa) as a legume supplement for goats*

Based on results of this study, it was evident that Rhodes grass hay only diet was an inadequate diet because animal performance improved with supplementation. This was an indication that the legume supplements provided additional nutrients such as N, energy and probably minerals and vitamins that were deficient in the grass hay. In addition to their perennial nature PRFs have high herbage yields and could be harvested and fed to livestock at any time of the year to increase efficiency of utilization of the basal diet.

At similar levels of supplementation, animals on *Calliandra* performed better ($P<0.05$) in terms of milk yield and growth rate than those on Lucerne based diets (Chapters 3 and 4), an indication that *Calliandra* was a better supplement than Lucerne for goats. This could have been due to the fact that *Calliandra* had higher CP content than Lucerne (247 vs 191 g kg^{-1}DM). Additionally, *Calliandra* is normally fed as leaves only (Ella *et al.*, 1989), while Lucerne hay is chopped and fed as a whole plant (both stems and leaves). Leaf protein has been reported to be less lignified and fibrous hence more digestible than stem protein (Mannetje, 1983; Van Soest, 1994). On chemical analysis, *Calliandra* was noted to be lower in fibre (NDF and ADF) and lignin contents than Lucerne hence more digestible (Van Soest, 1994; McDonald, 1995) since fibre content has been reported to be negatively correlated to digestibility (Muia, 2000; Tolera and Sundstol, 2000; Adesogan *et al.*, 2002). *Calliandra* based diets had higher *in-vivo* digestibility, better rumen fermentation characteristics and N balance (Chapter 5) than Lucerne based diets at similar levels of supplementation. Superiority of *Calliandra* over Lucerne based diets could also be attributed to it's higher rumen degradability characteristics than Lucerne (Chapter 6), which led to higher degradability of *Calliandra* based diets than Lucerne at similar levels of supplementation. All these factors contributed to higher nutrients intake thus better animal performance on *Calliandra* based diets than Lucerne diets at similar levels of supplementation suggesting its superiority over Lucerne as a supplement for lactating and growing goats.

The two PRFs varied in their CP content at an average of 24.8 for *Calliandra* and 19.3% for Lucerne although the estimated ME content was similar. This implied that at any level of supplementation, the animals on *Calliandra* would have a higher CP intake. This would have contributed to the better animal performance on *Calliandra*. In spite of this, the superiority of *Calliandra* is still evident in such nutritive value determinants as the lower fibre components and lignin (Chapter 3, 4 and 5) as well as the more favourable degradation characteristics (Chapter 6). Thus, per unit dry matter intake, the supplementation benefits would be higher on *Calliandra* than Lucerne. Additionally, *Calliandra* has higher yields of forage biomass at 12.4 - 26.2 t DM/ha/yr (Palmer and Ibrahim, 1996; Paterson *et al.*, 1996), compared to Lucerne at 0.9 - 1.4 t DM/ha/yr (Odongo *et al.*, 1999; Wanyama *et al.*, 2000). This contributes further to the superiority of *Calliandra* as a supplementary feed for goats at the farm level.

7.4 *Conclusions*

1. This study has demonstrated that supplementation of Rhodes grass hay with legumes improved animal performance (milk yield and growth). The improvements increased with level of supplementation.
2. Supplementation with legumes improved *in-vivo* digestibility, rumen degradability, rumen fermentation characteristics and N utilization efficiency. These improvements increased with level of supplementation.
3. At similar levels of supplementation animals on *Calliandra* performed better than those on Lucerne based diets. It was therefore, concluded that *Calliandra* was a better supplement for goats than Lucerne.
4. At similar levels of supplementation goats under the free-range management system performed significantly better than those on confined feeding.
5. A simple economic analysis indicated that supplementation with *Calliandra* was more economically viable than Lucerne.

7.5 *Recommendations*

Based on the findings of this study, it would be recommended that:-

1. Farmers especially smallholder farmers with limited land resource be encouraged to establish *Calliandra* and use it as a supplementary feed for goats.
2. Technology adoption and awareness studies should be conducted on farm to educate farmers on establishment, management, harvesting, pre-feeding treatment, feeding procedures, storage and preservation of *Calliandra* and other potential species of PRFs.
3. For optimum utilization of PRFs, it is essential that details of agronomic characteristics, palatability and nutritional value of the potential species are determined.
4. There is a need for socio-economic studies to evaluate the potential of multipurpose trees in mixed farming systems and their role as sources of fodder.

7.6 *References*

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