FEEDING TWO NERICA RICE STRAW VARIETIES TO SHEEP: EFFECTS OF SUPPLEMENTATION WITH LEGUMINOUS FOLIAGES ON DIGESTIBILITY, NUTRIENT UTILIZATION AND GROWTH PERFORMANCE.

BY

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DECLARATION

I hereby declare that this submission is my own work towards the PhD and that, to the best of my knowledge it contains no material published by another person, nor material which has been accepted for the award of any other degree of the University, except where due acknowledgment has been made in the text.

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ABSTRACT

Five experiments were carried out to evaluate the nutritive value of shade-dried *Samanea saman* and *Stylosanthes hamata* foliages as supplements for rams fed Nerica 1 and Nerica 2 rice straws as basal diets on the growth performance of these rams.

Four rumen fistulated Djallonké rams weighing averagely 22.5 kg, were used in a randomized complete block design (RCBD), within a 2x2 factorial arrangement of treatments (2 legumes and two levels each of the supplements), in Experiment 1 to determine the digestibility of DM, OM, N and NDF of the different treatments. The treatments were T_{SA360} (360 g *S. saman* foliage), T_{SA480} (480 g *S. saman* foliage), T_{ST360} (360 g *S. hamata* foliage) and T_{ST480} (480 g *S. hamata* foliage). The digestibility of the nutrients ranged from 60.9 to 88.4 %. The digestibility coefficients were significantly ($P<0.05$) higher for T_{ST360} for DM, N and NDF. Nitrogen balance was positive for all the four levels of offer but significantly ($P<0.05$) lower for T_{SA360}. Nitrogen efficiency was very high and differed significantly ($P<0.05$) between the treatments and ranged from (99.7 to 99.86). The rumen pH values for the higher levels of offer of the two foliages were significantly ($P<0.05$) different T_{SA480} and T_{ST480} (6.35 and 6.31) when compared to the lower levels ie (6.23 and 6.20) for T_{SA360} and T_{ST360} at 0 h post feeding. At 4 and 6 h post feeding the rumen pH values were significantly ($P<0.05$)

different for *S. saman* and *S. hamata* foliages as well as their two levels of offer. The rumen NH_3-N level peaked at 4 h post feeding for all the four levels of offer but was significantly (P<0.01) higher for T_{SA480} (9.6 mg/100 ml) and significantly (P<0.01) lower for T_{ST480} (7.8 mg/100 ml). The blood urea nitrogen (BUN) level was significantly (P<0.01) higher for the two offer levels of *S. saman* compared to the *S. hamata* offer levels. The purine derivative excretion was significantly (P<0.05) higher (23.33 mmol/d) for sheep on the higher level of offer of *S. saman* foliage compared to the others.

Rumen degradation of DM for *S. saman*, *S. hamata*, Nerica 1 and Nerica 2 rice straws were evaluated using RCBD within a 2 x 2 factorial arrangement of treatments (2 legumes and two levels each of the supplements giving 4 rumen environments) in experiment 2. The degradability of the DM of all the 4 feed samples increased with time. The potential disappearance (P) and the potentially degradable but insoluble fraction (b) was significantly (P<0.01) low for all the 4 feed samples (*S. saman*, *S. hamata*, Nerica 1 and Nerica 2 rice straws) under T_{ST480}. The rate of degradation (c) was significantly (P<0.05) higher for T_{ST480} ie (0.005, 0.037, 0.024 and 0.035 %/h) for *S. saman*, *S. hamata*, Nerica 1 and Nerica 2 respectively but significantly (P<0.05) lower for T_{ST360} (0.002, 0.032, 0.022 and 0.032) for *S. saman*, *S. hamata*, Nerica 1 and Nerica 2 respectively. The rate constants for *S. saman was* significant (P<0.01) lower than the others. The washing loss was significantly (P<0.01) higher (22.6 %), for *S. hamata* and significantly (P<0.01) lower (4.4 %), for Nerica 2. *S. saman* had the

highest potential disappearance (91.15 %) followed by (85.2 %) for *S. hamata* and (71.35 and 60.44 %) for Nerica 1 and Nerica 2 repectively.

In Experiment 3 four fistulated Djallonké rams were used in a 4 x 4 (4 animals and 4 mordanted feed samples) Latin Square Design to evaluate the passage kinetics of *S. saman, S. hamata*, and Nerica 1 and Nerica 2 rice straws. The transit time (TT) was significantly ($P<0.05$) higher for Nerica 1 and significantly ($P<0.05$) lower for *S. saman*. The fractional passage rate (k_1/h) in the fore gut was significantly ($P<0.01$) higher for Nerica 1 (0.025/h) and similar for *S. saman* and Nerica 2 (0.019/h). The fractional passage rate (k_2/h) in the hind gut was significantly ($P<0.05$) higher for Nerica 1 (0.033/h) and similar for *S. saman* and *S. hamata* (0.029/h).The MRT was significantly ($P<0.01$) different for all the four feeds. Nerica 2 had a significantly ($P<0.01$) higher value of (125.80 h) and *S. saman* had a significantly ($P<0.01$) lower value of (110.81 h).

The growth performance of 48 rams of an average weight of 13. 99 kg and 18 months of age was evaluated in Experiment 4 using a CRD in a 2 x 3 factorial arrangement of treatments (two rice straw varieties and three levels of offer of the foliage, *S. hamata* [240, 360 and 480 g]). There were six (6) treatments and these were randomly assigned, with eight (8) replicates per treatment. The average daily gain (ADG) and gain on metabolic weight basis were significantly ($P<0.05$) lower for the rams on T_{240} and significantly ($P<0.05$) higher but similar for the rams on T_{360} and T_{480} for Nerica 1 rice straw variety. The average daily gain (ADG) and gain on

metabolic weight basis were significantly (P<0.05) lower for the rams on T_{240} and significantly (P<0.05) higher for the rams on T_{360} for Nerica 2 rice straw variety. The straw intake was significantly (P<0.05) lower for the highest level of offer of *S. hamata* for both straw varieties. The intake of *S. hamata* increased significantly (P<0.05) as the offer level increased. The total intake on LW and metabolic weight basis followed the same trend as the legume intake for both rice straw varieties.

Forty eight (48) rams of an average weight of 13. 03 kg and 17 months of age, were used in a growth performance assessment in Experiment 5, using a CRD in a 2 x 3 factorial arrangement of treatments (two rice straw varieties and three levels of offer of the legume foliage, *S. saman* [240, 360 and 480 g]). The final weight and the ADG were significantly different between the 3 treatments. The increase in weight and the daily gain increased significantly (P<0.01) with increasing levels of *S. saman* foliage. Intake of straw was similar between the 6 treatments for the 2 rice straw varieties Nerica 1 and Nerica 2. Intake of *S. saman* and total intake on metabolic weight basis were significantly (P<0.05) different between the treatments.

It is concluded that 480 g/d of *S. saman* supplemented with Nerica 1 and Nerica 2 was beneficial in young Djallonké rams as it resulted in positive nitrogen balance and a high efficiency of rumen microbial protein synthesis to improve their daily

gains. *S. hamata* when fed at 360 g per day to young Djallonké rams elicited the best performance.

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ABBREVIATIONS

AIA	Acid Insoluble Ash
ADF	Acid Detergent Fibre
AOAC	Association of Official Analytical Chemists
BP	By-pass protein
BSS	*Bacillus stearothermophius*
CGIAR	Consultative Group on International Agricultural Research
CP	Crude Protein
CRI	Crop Research Institute
DDMI	Digestible dry matter intake
DE	Digestible energy
DM	Dry Matter
DMD	Dry Matter Digestibility
DMI	Dry Matter Intake
ECB	Economic Cooperation Bureau
FAO	Food and Agriculture Organization
FAOStat	Food and Agriculture Organization Statistics
FAR	Fibrous Agricultural Residues
FFTC	Food and Fertilizer Technology Centre

IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis for Agricultural Commodities and Trade
IRRI	International Rice Research Institute
IVDMD	*in-vitro* dry matter digestibility
KNUST	Kwame Nkrumah University of Science and Technology
LPD	Livestock Production Directorate
LW	Live weight
MOFA	Ministry of Food and Agriculture
MPT	Multipurpose tree
MRT	Mean Retention Time
N	Nitrogen
NAS	National Academy of Sciences
NBOMD	Nylon Bag Organic Matter Digestibility
NERICA	New rice for Africa
NDF	Neutral Detergent Fibre
NDS	Neutral Detergent Soluble
NPN	Non Protein Nitrogen
NRDP	National Rice Development Project
OM	Organic Matter
P	Phosphorous
PPR	*Peste des petite ruminants*
S	Sulphur

SARI	Savanna Agricultural Research Institute
SRID	Statistical Research and Information Directorate
SSA	Sub Saharan Africa
TCRV	Tissue Culture Rinderpest Vaccine
TT	Transit Time
UNCTAD	United Nations Council on Total Agricultural Development
USA	United States of America
VFA	Volatile Fatty Acid
WAD	West Africa Dwarf
WARDA	West African Rice Development Association

CHAPTER ONE

INTRODUCTION

Ruminant livestock are kept worldwide for their numerous economic and social contributions to humanity. Recently, more attention has been paid to small ruminants in developing countries as their advantages are becoming more understood than ever before, particularly for their ability to produce meat and milk, even in hostile environments (Aganga and Fabi, 2007). Furthermore, the resistance of small ruminants to the many diseases of cattle and the ease of marketing their products makes them the animal of choice for many resource-poor farmers and peri urban livestock farmers (Gatenby, 2002; Ameyaw-Djan, 2009).

Livestock farming is an integral part of the agricultural systems in West Africa. The peasant farmers derive a larger proportion of their incomes from the livestock section of their mixed farming systems (Delgado *et al.,* 1999). Urban dwellers likewise raise small ruminants to supplement their income as there is a niche market for them (Oppong-Anane, 2006; Twum, 2009). Livestock often serve as a 'bank account' and animals could be bought or sold as money accumulates or runs out. In addition, bullocks are used to plough fields reducing the community's dependence on tractors (Van Berkel, 2008). The demand for meat and milk is projected to more than double over the next two decades in developing countries, due to population growth,

increased urbanization and higher incomes (Delgado *et al.*, 1999; Ngwa *et al.*, 2002). These projected increases require high productivity in animal breeds and better quality feeds (Osuji *et al.*, 1995).

In Ghana, livestock are kept for social, subsistence and commercial purposes. The production of livestock and their productivity is, however, far below the population's requirement for animal protein. This under-production and low productivity is attributed mainly to inadequate year-round availability of feed and water, coupled with poor management (Abbey *et al.*, 2001). There is thus the need to improve on the productivity of ruminant livestock. This can only be achieved through an effective and proper management of the renewable natural resources that are not used by non-ruminants and humans (Ngwa *et al.*, 2002).

Ghana's livestock population indicates that there were 1.39 million cattle, 3.21 million sheep, 3.63 million goats, over 29.5 million poultry, including guinea fowls and 0.305 million pigs in 2005 (Debrah, 2008; SRID, 2006). Fifty-eight percent of the 8.26 million Ghanaians identified as poor are in the agricultural sector, most of which rear livestock, especially small ruminants. In times of insufficient crop production, livestock, mainly small ruminants and poultry, become the main source of food and income (Ameyaw-Djan, 2009). Increased domestic livestock production will reduce the foreign

exchange spent on livestock imports, which are currently at 70 % of the national supply. In this regard, investment in the sub – sector among smallholder farmers will not only enhance food security, increase household incomes of the poor and peri-urban dwellers that produce for the niche market, but will also increase its contribution to the GDP (MOFA-LPD, 2004; Oppong-Anane, 2006; Ameyaw-Djan, 2009).

In many developing countries including Ghana, the major feed resources for ruminant livestock are unimproved natural pastures with low nutritive value. The requirement for feed is aggravated by lack of alternative sources during the dry season when the protein content of the forage grasses is low, while fibre content is high and digestibility of nutrients is therefore also low (Castillo-Caamal *et al*., 2003; Mpairwe *et al*., 1998). The use of forage grasses and crop residues in various conserved forms has been identified to play an important role in the nutrition of ruminant livestock and ensure year round availability of feed. It is also the cheapest way of reducing the rising cost of feeding ruminants in the tropics (Loosli *et al*., 1994; Attoh-Kotoku, 2003). It appears from a biological standpoint that, the limitations of many types of forage and cereal crop residues in animal feeding could be overcome if the problems related to technological and economic viability of their use are tackled. The reasons for under-utilisation of agricultural residues include, from the nutritional point of view, the low feeding value of the residues. This

is due to their deficiencies in crude protein, soluble carbohydrates, minerals and vitamins coupled with high fibre, lignin and/or silica contents. Therefore, such feed resources when fed to ruminant livestock have very low voluntary consumption, digestibility, passage through the GIT and productivity (Parra, 1978; Nuru, 1995). In addition there is poor integration between crop, animal and agro-industrial concerns, which makes it difficult in many tropical countries to incorporate these feed resources into animal production on a large scale (Escobar and Parra, 1984). Also, an increase in animal populations in areas where management has improved, has led to overgrazing. This is further worsened by expansion in arable agriculture and urban spread into traditional grazing lands, thus reducing ruminant livestock forage resources (Nuru, 1995).

The cultivation of cereal crops generates grain as well as crop residues, which could be used for feeding livestock. The recent increase in the production of rice as a staple food in many African countries, coupled with the introduction of improved new varieties like the Nericas', have the potential of producing large quantities of rice straw, which could be harnesed as feed for small ruminants. The government of Ghana, being concerned with the impact of rice imports on rural livelihoods and food security (MOFA, 2002; CGIAR, 2006), has seen the need to promote local rice production. This has led to the development of promising lowland and

upland NERICA varieties (ECB, 2006). Total rice demand by the country is 600,000 mt; and if the assumption is that there is a 1:1 straw/grain ratio (Udo and El-Harith, 1985), then when this target is achieved there is going to be generated 600,000 mt of rice straw, which could be harnessed for small ruminant feeding. Paddy straw, which is the vegetative residue after grain harvest (Vadiveloo *et al*., 2009) is an important energy feed for ruminant animals; but like all crop residues it is associated with low nitrogen, soluble carbohydrates, minerals and vitamins content. Rice straw is also associated with poor palatability and low organic matter digestibility, which obviously fails to meet the maintenance needs when fed to ruminant animals (Widyastuti *et al*. 1987; Nuru, 1995). The use of straws from improved rice varieties such as the Nericas' could help improve ruminant livestock production, if their straws are equally higher in utilization.

One way in which, the low nutritive value of rice straws could be improved is through supplementation with leaves from multipurpose trees (MPTs) and leguminous plants. The MPTs and leguminous plants abound in Ghana, which has a diverse range of vegetation with different types of flora. Some of the promising MPTs and leguminous plants identified for livestock feeding are *Samanea saman* and *Stylosanthes hamata* (FFTC, 2005; Oppong-Anane, 2006; Omole *et al*., 2007). Fodder from leguminous plants and MPTs contain higher quality proteins, vitamins and minerals, as well as have higher

digestibility than grasses when fed to ruminant livestock (Crowder and Chheda, 1982). The observed improved body condition of animals (meat, dairy or draft) when fed with such leguminous fodders, is a major response to a better balanced nutrition and this improvement also boosts work performance and reproductive efficiency (El Hassan *et al*., 2000; Attoh-Kotoku, 2003).

The amount of microbial protein made available to the animal per unit feed consumed is very important in ruminant nutrition. The method of measurement is based on the amount of purine derivatives in urine. It is a very simple and non-invasive method that requires the total collection of urine (Chen and Gomez, 1995). There is a lack of knowledge on the rates of passage of nutrients out of the rumen, in comparison with published information on degradation rates in the rumen (Attoh-Kotoku, 2003; Dijkstra *et al*., 2007). Digestibility for any feedstuff is not a constant, and depends on the rates of digestion and passage that a specific feed is exposed to in the gut (Mulligan *et al*., 2001). Interaction between high fibre diets and concentrates in mixed diets in the rumen contribute to changes in the rates of digestion and passage (Galyean and Owen, 1988). A recent review of the literature has called for more research into factors affecting the fractional rumen outflow rate of ruminant feeds (Offer and Dixon, 2000). The nutritional characteristics of straws from two of the newly improved rice varieties (Nerica 1 and Nerica

2) and foliages from two multipurpose tree legumes, *Samanea saman* and *Stylosanthes hamata*, need to be assessed for animal feeding. There is the need to thoroughly investigate the intake, digestibility, purine derivative contribution and passage rates of the straws as well as the foliages.

1.1 PROBLEM STATEMENT

Livestock farming being an integral part of the agricultural systems of Ghana is still plagued with lack of qualitative and quantitative nutrition during the dry season. *Samanea saman* is identified as a multipurpose tree legume that has appreciable levels of crude protein that could be used as a dry season feed supplement for livestock fed a basal diet of the straws of Nerica 1 and Nerica 2, two new rice varieties.

1.2 JUSTIFICATION

A recent *in vitro* digestibility study of *Samanea saman* foliage showed a marked reduction in methane gas production. This suggests *Samanea saman* foliage has a nutritional value beyond its nutrients content, i.e. as a rumen manipulating agent. A more detailed study of the legume could lead to the discovery of forage that would improve dry season nutrition for ruminant livestock; as well, it might be capable of reducing the contribution of green house gases released by ruminants into the environment.

1.3 OBJECTIVES OF STUDY

1.3.1 *General objectives*

The general objectives of this study were to evaluate:

1. The nutritive value of two improved rice straw varieties (Nerica 1 and Nerica 2) and *Samanea saman* and *Stylosanthes hamata* foliages.
2. The growth performance of young rams fed the straws of Nerica 1 and Nerica 2 and supplemented with either *Samanea saman* or *Stylosanthes hamata* foliage.

1.3.2 *Specific objectives*

The specific objectives were to determine:

1. The chemical composition, the digestibilities of the nutrients DM, OM, N and NDF, degradation characteristics and the production of microbial protein under four different rumen environments (two levels of offer each of *Samanea saman* and *Stylosanthes hamata* foliages as supplement) to the straws of Nerica 1 and Nerica 2.
2. The kinetics of passage of *Samanea saman* foliage, *Stylosanthes hamata* foliage, Nerica 1 and Nerica 2 rice straws.
3. The voluntary feed intake of young rams fed Nerica 1 and Nerica 2 rice straws as basal diet supplemented with either *Samanea saman* or *Stylosanthes hamata* foliage.

CHAPTER TWO

LITERATURE REVIEW

2.1 SHEEP POPULATION IN THE WORLD

The total world population of sheep as at 2006 was 1024 million (Table 2.1). Together, Asia and Africa account for as much as 64 % of the world's sheep population (Zygoyiannis, 2006). The reasons for these concentrations are in two categories. The first is environmental and biological: such as ambient temperature, humidity, daylight length, nutrition, water availability, disease and heredity. The second is human: such as social and religious issues, economic factors, market facilities, credit availability, trend toward high yielding breeds and land tenure (Zygoyiannis, 2006). It is generally recognised that sheep have a potential to make a significant contribution to food security, poverty reduction and improved livelihoods of smallholder producers in Africa and globally (Winrock International, 1992; Perry *et al*., 2003).

Table 2.1 World sheep population

	Sheep (x 10^6)	World proportion (%)
Asia	416	40.6
Africa	244	23.8
Oceania	138	13.5
Europe	139	13.6
North America	7	0.7
South America	70	6.8
Central America and Caribbean	10	1.0
Worldwide	1024	100.0

Source: Zygoyiannis (2006)

Between 1999 and 2004 sheep growth rates in Africa were among the highest in the world with an average of 2.3 % per year. In the same period, the urban population increased by 3.89 % per year (World Bank, 2009). As expected, the total number of sheep in Africa is increasing; the continent has approximately 254 million sheep (FAOSTAT, 2009). The projection is that there would be a change in per capita meat consumption of over 40 % in developing countries by 2030 (IAASTD, 2007).

2.1.1 *Sheep population in Ghana*

Small ruminants are abundant in the south and predominate in the north of Ghana. Sheep numbers have increased gradually over the years from the estimated figure of 2.4 million in 1996 (LPIU, 1997), 3.21 million in 2005 (SRID, 2006) to 3.642 million in 2009 (VSD, 2010 – see Table 2.2).

Table 2.2 Sheep numbers in Ghana for the period 2006 – 2009

	2006	2007	2008	2009
Sheep (x 10^6)	3.314	3.420	3.529	3.642

Source: VSD (2010)

2.1.2 *Prospects for Sheep Production in Ghana*

Local meat production in Ghana has not been able to meet the total meat demand. The goals for the livestock industry are to increase the supply of

meat, animal and dairy products from the current aggregate level of 30 % to 80 %. The increase in the supply of animal and animal products would subsequently contribute to the reduction of the incidence of poverty among food farmers (who are also livestock keepers) from 59 % to 30 % by the year 2015 (UNCTAD/WTO, 2006). It is projected that there is going to be a higher consumption of livestock products globally compared to other agricultural products like cereals (IAASTD, 2007). This is because there is an expanding urban market as urbanization is generally associated with higher average household incomes and changing lifestyles such as more food consumed outside homes (Delgado *et al*., 1999); this is fuelling demand for food, including livestock products. Sheep off-take supplies only 30 % of the animal protein requirements of Ghanaians (UNCTAD/WTO, 2006). While agriculture as a whole contributes 54 % of Ghana's GDP, the livestock sector contributes in direct products only about 7 % of GDP (SRID, 2001) excluding manure and draught power provided to the crop sector. It is obvious that the animal industry has a lot of room for improvement. Livestock are a key resource in Ghana's agriculture (IAC, 2004) contributing significantly to the livelihoods of smallholder farmers and to consumers in general, through the provision of animal products, income, nutrients and traction. Sheep production is also a key capital asset for poor families, making an indirect contribution to rural poverty reduction. In addition, it offers rapid growth opportunities, as the necessary internal market exists (Perry *et al*., 2002).

2.1.3 *The Importance of Sheep Production*

Sheep are processors of resources that are unsuitable for human food, such as fibre from forages and crop residues, into products (milk, meat, skin and leather) for human consumption and clothing (Powell and Williams, 1995). Sheep also produce manure that can be used as fertiliser for crop production or as fuel for cooking or heating in some systems. It is easier to increase the population of small ruminants such as sheep than cattle as the reproductive turn over of sheep is higher. A ewe can lamb when conditions are favourable every eight months and the generation interval is less than two years (Gatenby, 2002). Also the capital investment for sheep farming is relatively low and average land holdings are usually small making them more suitable to smallholder family operations. Sheep, being small, are easy to control. Keeping sheep and eating mutton are activities, which are virtually free from cultural and religious barriers (Attoh-Kotoku, 2003; Animut *et al.*, 2005).

Sheep meat (mutton and lamb) are relished all over the world. Sheep are economical of labour because they stay together while grazing; thus one shepherd can herd a sizeable flock (of about 50) in an open grazing system (Gatenby, 2002). Sheep production has the potential to make a significant contribution to food security and poverty reduction and improve the livelihood of smallholder producers (Winrock International, 1992; Perry *et al.*, 2003). Sheep in Africa make substantial contribution to the well-being of the

people by the supply of meat, milk, skins, wool/hair, draught power, manure and cash (de Leew and Rey, 1995; Zygoyiannis, 2006). Sheep are multipurpose animals and their primary function is meat production, although in some countries sheep milk has become of greater importance. The economic importance of sheep production in both rural urban and peri - urban areas in Africa is well documented (Mosha, 1991; Maxwell, 1994; Baah, 1994; Ameyaw-Djan, 2009). Documented statistics in literature demonstrate the important role sheep production plays in the life of various classes of the human population. The sheep sector provides employment and income to the unemployed and low income urban and rural families. It also serves as supplementary income to the employed as well as the poorly paid. Another role that the sector plays is that it contributes to food security for urban and rural households, which cannot purchase all of their food requirements. It serves as food security in times of drought when small ruminants can be sold to purchase grain (Sumberg and Cassaday, 1986). Sheep serve as a source of animal protein to the rural poor who cannot afford the cost of, but would be able to slaughter a sheep, sell part and use the rest for the family. The taste of mutton and goat meat are apparently preferred by consumers to the other dietary varieties (Delgado and Staatz, 1980). Ruminants are able to convert inedible feed (grass) to highly nutritious human food. They can be reared in very hash and difficult terrains where crop production would be impossible. The cost of small ruminants is such that the rural poor can afford to start a

livestock farm in his or her backyard that is low initial capital is required and the maintenance cost is also low. Small ruminant farming can thus be said to contribute substantially to the animal protein needs, as well as economic benefits, which accrue when sold, with a resultant improvement in the living standards of small holder families (Smith and Olaloku, 1998). Sheep are able to use marginal land and crop residues to produce milk and meat in readily usable quantities and can be easily cared for by most members of the family. Sheep are prolific and are able to increase their flock sizes within a short period after catastrophies (Winrock International, 1992). Consumers are also motivated by cultural and religious considerations. Sheep are preferred by Moslems for ceremonial purposes and are used to celebrate Tabaski and other Islamic holidays. There is a sharp increase in demand during these celebrations for live solid white rams, which are a premium.

To a small farmer the security value of owning small ruminants may be as important as their tangible production. Small ruminants are a low-risk investment, which keeps its value. In a drought, sheep and goats can be eaten whereas when a farmer has cash there is no guarantee that he could buy food; and after the drought, small ruminants have the capacity to quickly regenerate again. Pastures and other forages provide most of the feed for livestock, especially for ruminants (four stomached animals such as cattle, sheep, goats etc.) throughout the world. Fortunately, the uniqueness of

the ruminants stomach permits it to consume forages and through bacterial synthesis, to convert such inedible (to humans) roughages into high quality protein like meat and milk. Hence, sheep manufacture human food from non – edible forage crops; they also serve as the primary means of storing such forage from one season to the next (Ensminger, 1991). Abaye *et al*. (1993) have demonstrated that the diet of grazing sheep contains a greater concentration of digestible nutrients than does the diet of cattle. In the study, pastures in which sheep grazed alone were generally higher in neutral detergent fibre (NDF), acid detergent fibre (ADF), cellulose and hemicellulose and lower in crude protein (CP) and *in vitro* dry matter digestibility (IVDMD) compared to forages in pastures where cattle grazed alone. This evidence clearly indicates that sheep select more nutritious fractions of plants than do cattle. Arnold and Birrell (1977) also reported that sheep are greater selectors than cattle.

2.1.4 *Breeds of Sheep in Ghana*

The major sheep breed, the indigenous West African Dwarf (WAD) or Djallonké breed is distributed nation-wide in Ghana. The breed is acknowledged for its hardiness, trypanotolerance, prolificacy and suitability for year round breeding. Although it is a small animal, with an adult weight of 25 – 30 kg in males and 20 – 25 kg in females with a height of 50 cm, it does not exhibit traits associated with dwarfism (Oppong-Anane, 2006). The

Plate 2.1 A horned Djallonké ram

Plate 2.2 A polled Djallonké ewe

most common colour of the Djallonké sheep is white, although many animals have black or brown patches. Rams have horns, a mane and a throat ruff. Ewes are usually polled. The Djallonké has a thin and medium-length tail.

The larger and long-legged Sahelian sheep and crosses between the Djallonké and the Sahelian sheep, are found mostly in the north of the country and in peri-urban areas (Gatenby, 2002; Oppong-Anane, 2006). Attempts to improve the indigenous breeds by crossing them with exotic breeds have been unsuccessful due to the inability to sustain initial efforts and lack of coordination. The Nungua Blackhead sheep developed in Ghana and the Permer sheep (a cross between the Persian and the Merino in Nigeria) are examples (Ademosun, 1991). Indigenous breeds are able to survive and produce under very hash and unstable (unpredictable) environmental conditions (Awgichew Kassahun, 2000) despite their low productivity. Crossbreeding should be preceded by rigorous selection among the adapted breeds for desirable characteristics and good productivity (Ademosun, 1991).

2.1.5 *Management Systems for Small Ruminants*

The systems identified for managing sheep and other small ruminants in Ghana include the extensive, intensive, semi-intensive, commercial smallholder and commercial. Some of these systems run into each other.

Extensive System

Most small ruminants in Ghana are kept under the traditional extensive system. This is the main production system based generally on extensive free

grazing or free range, with access to household and kitchen wastes when available among smallholder farmers (Gatenby, 1985; Ademosun, 1991; Oppong-Anane, 2006). This system is easy to manage but it is not ideal as mortality rates especially among the young, losses from outright stealing, predators and accidents are very high. There may be under estimation of pre-weaning mortality under the extensive system. There are losses which are not noticed when births occur during grazing in the bush, in addition to abortions and still births (Ademosun, 1991). Productivity is very low since there is no control over the pasture and it takes a long time to detect ill health in sheep. Breeding cannot be fully controlled as some of the animals on heat go undetected and would not be serviced. Animals are generally uncared for since the main activity of the smallholder farmer is growing of food crops. During the main cropping season, the owners are obliged to confine and provide sheep with food and water in order to protect their crops (Charray *et al*., 1992).

Intensive System

In the intensive system, there is elaborate housing; and there are two main types. One type involves the intensive use of cultivated pastures and crop residues. In this system, there is an effort to cultivate forages. The cultivated land is divided into paddocks and the animals are grazed from paddock to paddock. The paddocks usually have watering points and shelter, which are

most often shade trees. The Ministry of Food and Agriculture Sheep Breeding Farm at Bonyon in the Ejura-Sekyeredumase District of the Ashanti Region practises this system (Attoh-Kotoku, 2003).

In the other type of the intensive system, the animals are zero –grazed. In this system, which is also called stall-feeding or 'cut and carry', the forage is cut and fed to the sheep in their stalls. Stall-feeding is traditional in some intensely-cultivated areas. This system is well developed in Muslim West Africa (Gatenby, 1985). In Ghana, this system is practised in the cities by the Zongo communities for fattening rams for the Moslem festival, Eid-ul-Adha (Attoh-Kotoku, 2003). This system requires elaborate housing, with or without slated floors. The system allows for the use of agro-industrial by-products and hay. It is however, capital and labour intensive. There is also the tendency of stall-fed sheep to be under fed. Animals are also susceptible to injuries when slated floors are used. There is however, a higher return on the investment as productivity is very high, when well managed. Manure also accumulates, which can be used for fertilising crops (Attoh-Kotoku, 2003).

Commercial smallholder (Backyard small ruminant rearing)

In the commercial smallholder system of management, which is practised mostly by urban and some rural households, animals are confined at the

backyard and fed with cut herbage (cutting is done mostly by the younger members of the family). Prepared feed is sometimes purchased for the animals, as well as kitchen waste. They are not allowed to scavenge as they can be hit by an automobile, or they can destroy a neighbour's backyard crop garden. In this system, family labour is solicited, and does not put heavy financial burden on the household (Baah, 1994; Twum, 2009). Ill-health is identified early and prompt treatment given. Inbreeding is controlled by castrating the young rams and bucks. Simple pens are usually provided for sheep within or attached to the owner's house. The pens are constructed from locally available materials such as timber offcuts, bamboo, tree branches and mud, and roofed with palm branches, split bamboo or metal sheets (Oppong-Anane, 2006; Twum, 2009). This backyard system supplies fattened rams for the expanding urban market, and especially during festivals.

Commercial large scale farms

The large farms under this system, which are privately owned, utilise little or no family input except at management level. Even where family labour is utilised it is well remunerated (Smith and Olaloku, 1998). The required inputs in the form of improved genotypes, adequate nutrition and effective health management are supplied; and with good pricing policy, this system becomes potentially economical. This system is also practised by para-statal

institutions in Ghana. They are found in the hinterlands in many parts of the country where large tracts of land are available for growing fodder, which is the main feed source and also natural pastures, which are often improved with forage legumes e.g. MOFA research and breeding farms are at various parts of the country. Examples of such farms are Nkwanta in the Volta Region, Ejura in the Ashanti Region, Kintampo in the Brong Ahafo Region and Pong-Tamale in the Northern Region. The commercial system therefore, represents a comparatively safe, automatically incremental and readily realizable investment (Oppong-Anane, 2006). Sometimes performance is not optimum and economic returns are not achieved due to institutional and policy related constraints (Smith and Olaloku, 1998).

Semi-intensive

The semi–intensive system, which is also practised, is a compromise between the extensive and the intensive systems. The system is characterised by limited stall feeding and grazing. The sheep are housed at night and released in the morning and left for the most part of the day to scavenge for most of their required feed and supplemented in the evening with kitchen wastes, which consists mostly of peels of cassava and plantain, and sometimes cassava leaves from the crop farms.

Tethering (Village system)

This is another type of sheep production where the farmer takes his sheep to the farm and tethers them in an area of good quality fodder away from the crops. Their positions are changed two or three times daily so that they can eat enough forage (Gatenby, 1985). In the compound farming areas of the Northern, Upper East and West Regions this system is practised during the cropping seasons between July and October. Also found in neighbourhoods, across Ghana with animals tied to trees, large stones, old vehicle tyres etc.

Intergrated crop-livestock system

There is also an integrated system of crop and livestock production. Generally the system is associated with the humid and sub-humid tropics where crop production is intensive. Here, sheep are reared under tree crop plantations, mainly oil palm, citrus and coconut. Introduced leguminous forage species such as *Pueraria phaseoloides* constitutes the main diet for the sheep. However, a wide range of volunteer forbs and grasses such as *Aspilia africana, Asystasis gangetica, Panicum maximum* and *P. luxum,* contribute significantly to the forage biomass (Oppong-Anane, 2006). When sheep are integrated with tree crops, there is improved fertility of the land due to the return of manure and urine to the land and that leads to increased crop yield. There is control of herbage growth due to the different levels of grazing. The system is practised at the Okumaning oil palm plantation in the Eastern

Region of Ghana (Attoh-Kotoku, 2003). Among all the production systems, the intensive system has become more popular with smallholder ruminant farmers in both the urban and rural areas. This may be due in part to pressures on land use for residential purposes as population increases. Also by-laws prohibiting the roaming of ruminants in towns and cities make it obligatory for most backyard farmers to confine their animals and feed them. During the cropping season, particularly where compound farming is practised, in the savannah zones, small ruminants are confined in pens and fed to prevent them from destroying crops (Attoh-Kotoku, 2003). Backyards gardening in the cities and crop farms being walking distances from townships have made it inevitable to keep and feed livestock in confinement. The most promising small ruminant production system in both urban and peri-urban areas is zero grazing. This allows for maximum utilisation of grass, crop residues and agro-industrial by-products for maximum productivity (Oppong-Anane, 2006).

2.1.6 *Factors affecting production and growth performance of sheep*

In sheep production, the major components of interest include nutrition, reproduction and production efficiency (birth rates, mortality, age at first birth and growth rates) and management (Ngategize, 1990). The growth of the domestic ruminant livestock industry is plagued with several constraints, notably poor breeding stock, disease, poor nutrition, poor marketing, lack of

capital and lack of a grassland policy (Oppong-Anane, 2006). A number of production constraints have however been identified. These are natural disasters (drought and floods), credit, extension services and research. Other constraints are feed, need for restraint, time, capital and disease (Ameyaw-Djan, 2009). Smallholder producers have little control over these problems and their major concerns are those related mainly to nutrition, disease and management. In the area of animal diseases, helminth infestation is a problem with all ruminant livestock countrywide (Oppong-Anane, 2006). This is associated with low management standards and is a primary cause of ill-health and unthriftiness in all classes of ruminants, with high mortality in the young and low productivity in the adult (Oppong-Anane, 2006). *Peste des petite ruminants* (PPR) is one of the most serious viral diseases among small ruminants. It occurs as an epidemic with usually high morbidity and mortality rates. Young animals are more susceptible than adults, with goats being more susceptible than sheep. Tissue culture rinderpest vaccine (TCRV) is effective in the control of PPR. Ectoparasitism by ticks and mange mites is a major cause of poor productivity (Bourdin, 1983; Oppong-Anane, 2006).

Biological and economic factors also affect livestock productivity, where feed supply is a limiting factor (Al Jassim *et al*., 1996) growth rates of small ruminants have been low per annum, (about 1.2 %). World Bank funded livestock projects have generally produced very low returns on investment

compared to crop production (ILCA, 1987) as the focus is on improved breeds and numbers. Attempts at improving the inherent genetic capacity of any livestock population without improving the nutrition and management practices would limit production (Timon, 1993). There is higher productivity when the right type of animal is raised in an area where it is well adapted (Madalena, 1993). Seasonality of feed is another constraint as animals lose weight during the dry season when both the quantity and quality of available forage are limited (Velez *et al.*, 1993; Castillo-Caamal *et al.*, 2003; Oppong-Anane, 2006). Pre-weaning mortality of up to 40 % has been recorded with kids and lambs in Nigeria (Ademosun *et al.*, 1988). The major sources of available feed for ruminants during this season are low quality crop residues (in terms of metabolisable energy, digestible protein and minerals) and grazing lands, which are scarce (Gatenby, 2002). Even during the rainy season when feed is abundant, tropical forages and pastures are not able to meet the nutritional requirements of sheep due to the rapid build up of cell wall materials and decline in crude protein (CP) content with maturity; this reduces their nutritional value (Ademosun *et al.*, 1988; Matenga *et al.*, 2003; Shiawoya and Adeyemi, 2003).

Heat load could also affect sheep production. A marked interaction of heat generation in consumption, digestion, metabolism of ruminants and environmental heat load has major implications for ruminant production in

the tropics (Leng, 1990). The laws of thermodynamics suggest that inefficient utilization of feed by ruminants for tissue deposition must result in increased heat generation. Such heat generation could have major implications for ruminant production in the humid tropics (Leng, 1990). The often low intakes of poor quality forages by cattle in hot climates may be due to accumulation of heat in the body from both an inefficient rumen microbial ecosystem and an inefficient utilization of acetate in metabolism of the animal. This would be exacerbated by a high environmental heat load (Leng, 1990). Cattle in the tropics, as compared to those in cool countries, may require lower nutrients concentration for maintenance as they do not have to combat cold stress. If the nutrient spared oxidation is used for tissue synthesis, animals in warm climates can be more efficient users of forages than animals in cold climates. Ruminants use acetate or fat as energy sources when cold and such animals have a lower requirement for amino acids relative to energy (P/E ratio) than animals under hot conditions. Thus the requirements for amino acids are higher relative to energy substrate in cattle in the tropics than in animals on the same feed in cool environments: the total amount of nutrients required is lower in animals in the tropics relative to temperate areas (Mastika and Cumming, 1994). Notwithstanding these constraints, there is the potential to increase the off-take of ruminant livestock and produce good quality meat and milk to satisfy a greater part of the nation's animal protein requirements (Oppong-Anane, 2006).

Livestock production in the tropics can be increased through increasing the productivity of the animal. A major factor in this direction will be the improvement of animal nutrition by way of feed supplies, especially in the case of ruminant animals. Improved animal disease and parasite control, breeding and management practices may also be important in enhancing productivity but a major emphasis must be placed on providing better nutrition. The improvement of ruminant livestock nutrition in the tropics can either be through increasing the productivity of already utilised resources or through the introduction and development of new or little used resources. The main feeding systems for ruminants within intensively cropped areas are based on combinations of the following:

1. Crop residues and stubbles.
2. Grazing and cutting of fodder along road sides and field margins.
3. Agro-Industrial by-products such as rice bran, brewers spent grain, pito mash, maize bran, cashew pulp, groundnut skin etc., most of which are not often made use of adequately as feed supplements (MoFA, 1998; Oppong-Anane, 2006). Sheep production from within arable cropping systems can be greatly improved through the production of forage within the rotational cropping system and the better utilisation of crop residues, by-products and wastes, in combination with supplements. This can also be done through the integration of sown pastures with tropical plantation crops. Supplementary feeds should be given during the dry season in order

for the animals not to lose weight. These supplementary feeds include agro-industrial by-products (groundnut skins, coconut and palm kernel cakes), by-products of grain extraction (maize, rice, sorghum and millet), household wastes such as peels of cassava, cocoyam, yam and plantain and industrial by-products (brewers spent grains) (Ademosun *et al*., 1988).

The low productivity of ruminants fed poor quality forages in tropical developing countries is mainly a result of the low energy density of the feed and an inefficient utilization of the feed because of deficiencies of critical nutrients in the diet. The deficient nutrients may be those critical to the growth of rumen microbes which ferment the feed; or they may be those required to balance the protein to energy ratio. Supplementation of animals to supply these nutrients often results in levels of production that would be highly acceptable under temperate country practices. Correction of a nutrient imbalance by supplying nutrients deficient for microbial growth and feeding a bypass protein often increases a depressed intake of poor quality forages (i.e., from 50–60 $g/kg^{0.75}/d$) to normal, (i.e., between 80–100 $g/kg^{0.75}/d$). Research on small ruminants nationally, may be to increase their productivity in numbers and their meat production so as to reduce foreign exchange spending. Donor agencies may aim to improve the standard of living of the poorest sectors of the rural areas by supplying them with small ruminant breeding stocks (Gatenby, 2002).

In Ghana, the incidence of poverty is particularly evident among the sector engaged in agriculture and extreme poverty is especially evident among crop farmers. However, with the advent of the Millennium Development Goals (MDGs), poverty has dropped from 68 % (1991/92) to 46 % (2005/06) of the population that is engaged in some form of subsistence agriculture, and about 18 % live below the poverty line. Thus any intervention to improve their livelihood is in the right direction. Ghana is actually on course to halt hunger by 2015 (GHDR, 2007).

2.2 RICE

Rice has become the most popular staple in Sub-Saharan Africa (Sohl, 2005) with a human population growth of 4 % per annum. There is rising incomes and a shift in consumer preferences for rice, especially in urban areas (Balasubramanian *et al*., 2007). The relative growth in demand for rice is faster in this region than anywhere else in the world (WARDA, 2005). The trend in per capita rice consumption in West Africa has increased from 14 kg in the 1970s to 22kg in the 1980s and has reached about 35 kg in 2005 per person per year. This per capita increase in consumption is expected to continue as more rice becomes available and population increases. Rice consumption increases as annual income increases. It is worthy to note that 73.4 % of poor households in Ghana consume rice at least three times a week

and 75 % of the urban poor use imported rice in their meals and only 25 % use local rice (Kormawa *et al.*, 2005).

WARDA has undertaken various research and development activities to provide policy support to national programs in WARDA member countries and to draw policy-makers attention to the fact that rice is a strategic staple crop for attaining food security and poverty reduction goals (CGIAR, 2007b).

2.2.1 *Rice production in Ghana*

Ghana imports 4 % out of the total imports of rice into Africa. This trend is projected to increase though Ghana has sufficient suitable agro-ecologies and water bodies for increasing domestic rice production. Promotion of domestic rice production and development of regional markets by the Government is the panacea to reduce the imports. Available data (Awuni, 2006) show that the current total land area under rice cultivation in Ghana is 125,000 ha. The average national paddy yield is 2 tons/ha, giving an average total paddy output of 250,000 metric tonnes (mt) per annum. Rice production in Ghana is under four different ecologies: The first is the rain-fed upland system, which covers 18,750 ha and produces 18,750 mt of paddy rice and constitutes 6 % of total rice output. The average yield per hectare is 1.0 mt. The second being the midland/hydromorphic system covers 75,000 ha and yields 187,500mt of paddy and constitutes 61 % of total national output. The average yield is 1.5

mt/ha. The third, the rain-fed lowland ecology covers an area of 18, 750 ha and a production of 37,500 mt of paddy constituting 12% of the total rice output with an average yield of 2.0 mt/ha. Lastly the irrigated ecology covers an area of about 13,600 ha with 10,200 ha under rice cultivation. This gives about 45,900 mt of paddy, which constitutes 21 % of the total national output with an average yield of about 4.5 mt/ha compared to 6.5 mt/ha in the USA (Awuni, 2006).

Table 2.3 Domestic rice production, imports and consumption (1998-2005)

Date	Domestic milled rice production, mt	Rice Imports, mt	Total domestic consumption, mt	National Deficits %
1998	**89,000**	**249,289**	**338,289**	**73.7**
1999	**140,000**	**226,236**	**366,236**	**61.8**
2000	**130,000**	**170,290**	**300,290**	**56.7**
2001	**218,000**	**304,770**	**522,770**	**58.3**
2002	**137,000**	**346,750**	**483,750**	**71.7**
2003	**173,000**	**415,150**	**588,150**	**70.6**
2004	**160,000**	**379,631**	**539,631**	**70.4**
2005	**150,000**	**445,574**	**595,574**	**74.8**

Source: FAOStat (2009)

Table 2.3 shows domestic rice production and imports over the period 1998 – 2005 as well as total domestic rice consumption over the same period. The

figures on imports show actual rice discharged by vessels at Tema Port for consumption in Ghana and not on transit to neighbouring countries. A lot of rice also comes by land from Cote D'Ivoir which is not accounted for. The table (Table 2.3) also shows the huge national deficit for rice. As indicated earlier, there is the potential to produce rice locally to meet the demand (Awuni, 2006). From Table 2.3, it is estimated that 150,000 tons of rice was produced in 2005. This translates to 150,000 tons of rice straw (Udo and El-Harith, 1985) being available for feeding livestock. A resource, which could help even the seasonal shortage of feeds for ruminant animals when well researched and exploited.

2.2.2 *The NERICAs*

There have been a lot of interventions by Government to improve on local rice production through the use of improved varieties to reduce the country's % imports. Livestock production can tag on to rice breeding to select dual purpose varieties for food and livestock feeding. The NERICAs (new rice for Africa) are a cross between *Oryza glaberrima* (African origin) and *Oryza sativa* (Asian origin) combining the drought and weed resistance, high stress tolerance and high yields, but without irrigation, so as to match African environments. The NERICAs have early maturity, which allows growing a second crop, growing in areas with relatively short rainy seasons and saving labour on weeding compared to other rice varieties (Kijima,

2008). Nerica combines the ruggedness of local African rice species with the high productivity of the Asian rice. This newly developed rice (NERICA) has happened at a time when demand for rice is growing faster in West Africa than anywhere else in the world. Rice imports have increased eight-fold over the past three decades to more than 3 million tonnes a year, at a cost of almost US$1 billion (www.i-sis.org.uk/isisnews/sis15,php)(Mae-wan Ho, 2004). Impact assessment studies conducted in Benin also indicated that the adoption of NERICA rice varieties increased yields, raised farmers' incomes, all of them leading to increased schooling, demand for more medical care and better diets at the household level (Adegbola *et al*., 2006). Similarly in Uganda, where until recently, rice was relatively little-grown, it is now a cash crop due to the introduction of the NERICA varieties (Kijima et al., 2006; WARDA, 2006).

Under the Nerica Rice Development Project (NRDP) in Ghana, a total of 20 mt of foundation seeds were harvested in 2007 for Nerica 1 and 2. About 570 ha of valley bottom sites were developed for the production of 5,670 tonnes of paddy rice under the Inland Valley Rice Development Project (Narteh *et al*., 2007; Debra, 2008). All these initiatives would make available considerable amounts of rice straw, which could be used to feed livestock when well preserved and not destroyed by fire (normal method of straw

disposal) which could lead to pollution of the environment and water bodies in Ghana.

2.3 CROP RESIDUES

Crop residues are alternate feed resources that are available locally from crop production, which can be utilised to improve nutrition of livestock. Crop residues are the materials that are left after the main crop has been harvested. Cassava leaves and cereal crop residues are excellent roughage for ruminant livestock production (Wora-Anu *et al*., 2000).

Crop residues are, however characterised by their high fibre content (>700 g of cell wall material/kg (DM)), low metabolisable energy (<7.5 MJ/kg DM), low levels of crude protein (CP) (20.60 g of CP/kg DM), minerals and low to moderate digestibility (<30-45 % organic matter digestibility). Most residues are also deficient in fermentable carbohydrates, reflected by the relatively low organic matter digestibility (Wanapat, 1999). However, the residues and by-products derived from the tops and haulms of crops such as groundnut, sweet potato vines, cassava leaves, cowpea and pigeon pea straws and industrial processing (bran from cereal milling and brewing: rice, maize, millet and sorghum bran and brewers' spent grains) are high fibre-high protein feeds (Wanapat *et al*., 2000). They are generally less fibrous (>400<700 g of cell wall material/kg DM) but have relatively high amounts

of CP (>60 g/kg DM). Leaves from browse plants and tree legumes such as *Stylosanthes* and *Gliricidia*, which have crude protein levels around 250 g/kg DM can also be considered in this category.

The low fibre-low protein feeds are those obtained from renewable energy crops such as sugarcane by-products and root crops (Yuangklang *et al*., 2005). The low fibre-low protein feeds are generally rich in energy and low in protein. Examples are molasses, oil palm slurry and waste material arising from the fruit processing industry (citrus pulp, pineapple waste and tomato pomace) and cassava root crop processing (Ngamsaeng, 2005). The common characteristics of such feeds are low digestibility, low protein content and a low mineral content. The quantities available tend to be location specific. In most regions dependent on these feed resources, the quantity and quality are likely to be variable and limiting.

2.3.1 ***Importance of crop residues***

Crop and animal production generates a range of fibrous materials, which have traditionally been called "residues", perhaps due to the fact that they are not utilized and have therefore not been regarded as "resources". These materials have been classified according to their origin as: crop residues, fibrous agro – industrial residues, urban residues and animal wastes. Fibrous Agricultural Residues (FAR) have aroused considerable interest as possible

sources of animal feed, energy and fertilizer. Such uses are not mutually exclusive. A logical sequence would be to use them first as animal feed, and then use the manure as a source of energy (biogas) and finally, the biomass from the digester could be applied as fertilizer to the crop land (Escobar and Parra, 1984).

Interest in the use of FAR arises from their wide availability and from the possibility of using them to help solve the problems of seasonal feed shortages for livestock (Escobar and Parra, 1984; Osafo *et al.*, 2008). Crop residues, which frequently become available during the dry season of the year, may be used to reduce stocking rate by allowing the animals to graze them. Crop residues can contribute to solving the problem of feed shortages at critical times of the year. Crop residues are currently utilised at lower efficiency though they have been the main forage source for ruminants in the tropics for years (Khajarern and Khajarern, 1980). Grazing of crop residues is the simplest and cheapest form of feeding ruminants, but the method has its limitations as the stubbles, which are left after harvesting to be grazed, rapidly lose their nutritional value as the season advances (Parra, 1978) and large wastage from trampling under foot by animals.

Developing countries, especially those in tropical regions cannot follow the conventional approach of intensifying animal production with grain,

concentrate, hay and silage, as is common in the developed temperate countries. Feeding of crop residues is hindered by alternative uses such as sources of fuel (e.g. sorghum and millet stalks), for thatching and by the problem of collection (MoFA, 1998). Fibrous agricultural residues (FAR) will become increasingly important in tropical countries and suitable strategies for their use will have to be developed due to competition with alternate users, as stated above. These strategies will have to do with processing and supplementing the residues and development of ruminant production systems, which will allow the residues to be used efficiently. Appropriate feeding strategies are required because of the many nutritional interactions, which exist within different residues and the conventional supplements, which are available in the tropics.

There are important experiences in the use of residues in ruminant feeding in different countries of the world. These range from the highly integrated crop – animal systems in the smaller Central American and Caribbean countries to the most extensive type of use of crop residues (corn, sorghum and wheat stover) in Mexican and Venezuelan ranching systems. There is also the summer feeding of alkali-treated bagasse to beef and dairy cattle in Cuba and the use of fibrous agro – industrial residues (corn cob, cotton seed hulls) and crop residues (corn stover) in feed–lot operations in Peru (Khajarern and Khajarern,1980).

In South East Asia, only the fibrous residue from rice namely rice straw, has been widely utilised in livestock feeding systems, although at an efficiency far below its optimum potential. Much more attention has been paid, in the last decade, to improving its feeding value in order to increase livestock productivity at small farm level (Khajarern and Khajarern, 1980). The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed by the International Food Policy Research Institute (IFPRI) to project the future demand for certain commodities, estimated that the per capita demand for cereal crops will increase in SSA by some 4.9 % per year between 1997 and 2020, with the main increase in wheat and rice (Rosegrant *et al.,* 2001). The increase will be due partly to greater demand for animal feed.

2.3.2 *Methods for improving crop residues*

There are different ways of improving on the forage resource for a viable small ruminant livestock production. Use of exogenous fibre-degrading enzymes may be a potential means of improving the nutritive value of rice straw, as enzyme costs might decrease in future (Beauchemin *et al.*, 2004).

Breeding as a tool to improve nutritive value of the vegetative portion of cereal crops is another method; this is already being done for the grain portion so the possibility for the whole crop could not be far-fetched. This

work would dwell on the use of supplements to improve the feeding value of crop residues especially during the dry season. These two are being dwelt upon as they are technologies that would be easy for farmer adoption.

The target of plant breeders is geared towards improving on grain quality and quantity, without considering the other parts of the crop; but there is the need to assess straw quality as well. Rice breeders have so far concentrated their efforts on crop productivity per unit area, per unit time and in improving grain quality. Straw quantity and quality have been secondary considerations, except as they directly affect crop yield such as in resistance to insects, diseases and lodging (Khush and Kumar, 1987) or early vegetative growth to control weeds as in the Nericas. Plant breeders are becoming increasingly aware of the need for whole plant utilisation and hence the need to improve the utility of crop residues (Rexen and Munck, 1984).

A more logical approach to improvement of the feeding value of rice straw would be through genetic improvement of straw quality, which would in the long run be cheaper. In all these, grain yield and quality should not be compromised. The straws (from their experimental farms) of two cultivars of rice developed by Crop Research Institute (CRI) at Fumesua near Kumasi have very low silica content (2.17; 2.94 %) for IDSA-85 and WAB-209-5-HB. Thus if a conscious effort is made by our crop breeders to improve on straw

quality, there would be straws with minimal levels of silica, which would not compromise on the structural integrity of the crop (Abdul-Wahid, 2002).

Supplementation might permit more efficient utilisation of crop residues, which are inadequate in energy, protein, minerals and vitamins to support optimum animal productivity (Reed *et al*., 1990). The supplements act to correct deficiencies of soluble nitrogen and minerals such as phosphorus and sulphur, and also as sources of protein or energy, which escape rumen fermentation. Forage legumes and tree leaves are rich in nitrogen and this offers the opportunity for their utilisation as supplements (Baumer, 1992).

Supplementation with energy and protein sources is a prerequisite to increasing the efficiency of utilisation. Energy sources such as molasses, cassava chips and by – products from starch processing are appropriate for this purpose. Leguminous forages can supply protein to the level that can support optimum dry matter intake. Untreated chopped rice straw (25 or 35 %) was fed with 25, 33 or 45 % of molasses along with sweet potato chip – soybean meal – urea mixture and 0.46 – 0.82 kg body weight gain/day was obtained, in growing heifers (O'Donovan and Chen, 1972). The importance of maintaining a balance between carbohydrate sources such as molasses with rice straw and dietary nitrogen has been emphasized by Howard *et al*. (2007) if the maximum utilisation of the rice straw, is to be obtained.

Similar responses were observed in cattle and water buffaloes receiving rice straw rations with 2 kg/hd/d concentrates supplement containing poultry manure up to 25 % (Suriyajantratong *et al.,* 1983). Other high protein forages have also been demonstrated to be suitable supplements in rice straw rations. These include kenaf (*Hibiscus* spp.) leaves, pigeon pea (*Cajanus cajan*) straw and *Stylosanthes* (Tawinprawat *et al.,* 1971: Attoh–Kotoku, 2003). Cassava (Intramongkol *et al.,* 1978) and gliricidia leaves (Vearasilp, 1981) have also been used. Browse species, which can provide higher levels of protein and soluble carbohydrates, such as *Gliricidia sepium* and *Leucaena leucocephala* have been successfully used for small ruminant production systems in alley farms (Sumberg, 1985) and in intensive systems (Ademosun *et al*., 1988).

2.3.3 *Feeding value of rice straw*

The nutritive value of rice straw as mentioned earlier (page, 5) depends on a number of factors such as type of cultivar, soil type and time of harvest. Currently, there is dearth of information on the quantity and quality of straw from local cultivars of rice. The nutritive value of rice straw for ruminant livestock is relatively low due to its high cell wall content, low crude protein content, poor palatability and low organic matter digestibility. In addition to its high cell wall content, the ruminal degradability of rice straw is limited by its epidermal surface, which contains a high concentration of silica

(Widyastuti *et al*., 1987). Silica has been hypothesized to act as a physical barrier, which in preventing bacterial attachment (McAllister *et al*., 1994) impedes the digestion of plant cell wall carbohydrates (Widyastuti *et al*., 1987). It has long been established that rice straw has low crude protein (3 – 5%) calcium (0.25 – 0.55 %) and phosphorus (0.02 – 0.16 %) but is high in crude fibre (26 – 34 %) and silica (12 – 16 %) and lower in lignin than other straws (Jackson, 1977; Ørskov and McLeod, 1990 and Attoh – Kotoku, 2003).

Farmers grow different cultivars of rice and the straws obtained could be fed to ruminant animals. Different rice straws vary in their digestibility and intake (Cheva-Isarakul and Cheva-Isarakul, 1984; Singh, 1991 and Doyle and Oosting, 1994). Such variations may be attributed to the genetic make up of the plant (Capper *et al.,* 1986; Capper, 1988) and also different management practices during the growth of the crop (Kernan *et al.,* 1984; Thomson *et al.,* 1993) or during harvest. Singh (1993) reported that straw obtained from 21 rice varieties grown under the same agronomic conditions had nylon bag organic matter digestibility (NBOMD) varying from 44 to 55%. Herbert and Thomson (1992) emphasised that the variation in feeding value of straw is due to morphological characteristics such as proportion of leaf and stem, which is controlled by the genetic make–up of the plant. Pearce (1986) also emphasized the possibilities of improving the nutritive value of rice straw without pre-treatment, by supplementation with tree legumes.

2.3.4 *Rice straw as a potential feed source in ruminant feeding*

Several attempts have been made to improve the nutritive value of rice straw by various treatments. Considerable effort has been expended to improve the feeding value of rice straw by using pre-treatments to upgrade its digestibility (Bae *et al*., 1997), but commercial application of these pre-treatments is limited due to cost and potential environmental hazards.

However, urea treatment and supplementation had been found to be technically feasible at the farm level. The urea treatment however, has not been adopted particularly by the marginal and small scale farmers for lack of funds for purchasing inputs, engagement with crop production and low number of animals (Saadullah and Siriwardene, 1993; Singh *et al*., 1993). The second reason, i.e. risk aversion with respect to livestock production, often results in a reluctance to adopt new technologies; priority is thus given to crop production in terms of labour use and cash investment (Ogle and Bui Huy Nhu Phuc, 1997). Thirdly, the ever-developed methods *per se* seem not technically and socio-economically suited to the local conditions under which small scale poor farmers are dominant.

The utilisation of rice straw, which is a crop residue as a significant proportion of the ration of ruminant livestock would only be successful if the limitations of low crude protein (Ørskov and McLeod, 1990) and poor digestibility could be overcome. An acceptable feeding system for improving

rice straw utilisation should be simple, cheap and freely available to fit into the farmer's normal routine to be sustainable (Sundstol, 1984).

Feeding rice straw to ruminant livestock could be of great benefit, ranging from decline in threat to public health and environmental pollution through burning to reduced animal production costs arising from reduced feed cost (Givens, 1996).

Improved utilisation of rice straw and other crop residues would be a strategic solution to encourage farmers to increase both the numbers and productivity of their ruminants, as well as meeting the traditional demand for crop production and the increasing demand for livestock products. In addition to the strategies enumerated above, there should be studies on the quality and quantity of crop residues needed as ruminant feed to provide information for plant breeders to develop crop cultivars, which can produce large amounts of high quality residues without compromising grain yield and quality. This was demonstrated when rice was grown hydroponically with decreasing concentrations of silica. This lowered the silica content and improved the dry matter (DM) and organic matter (OM) digestibility of the straw (Balasta *et al.*, 1989).

2.4 FODDER LEGUMES

Fodder from leguminous plants and MPTs contain higher amounts of proteins, vitamins and minerals as well as having higher digestibility than grasses when fed to ruminant livestock (Crowder and Chheda, 1982). Unlike grass, leguminous plants and tree fodders maintain their protein content and digestibilities throughout the year (Reynolds *et al*., 1988). Research carried out at ILCA (1988) had shown that legumes and MPTs enhance high productivity and performance in ruminant livestock. Voluntary intake and dry matter (DM) digestibility are generally higher for legumes than grasses except at the earlier stages of growth of grass when they may be similar (Nuru, 1995). Tropical legumes, apart from higher crude protein (CP) content, also maintain higher sulphur and calcium concentrations in plant tops than grasses (Whiteman, 1980).

Forage legumes are a dependable source of protein feed for animals. The seeds and leaves are rich in nitrogen. Forage legumes are adequately supplied with protein for livestock feeding, even when harvested at an advanced stage of maturity (Iyeghe-Erakpotobor *et al*., 2008). The high nitrogen content of leguminous species contributes to improving the nutritional quality of the diet of ruminants whether grazed or cut and fed (Njwe and Kona, 1994). Animal productivity is normally greater from grass-legume mixtures than pure grass stands (Mannetje and Jones, 1992' Walker,

1987). Tree legumes provide a wide range of products: ie fodder from leaves, twigs and pods, as well as shade, live fences, timber and firewood. Fallen pods from the raintree are highly palatable to livestock (Kathaperumal *et al*. 1988). Leaves of fodder trees, however, have constituents like tannins, saponins and non protein amino acids, which affect fodder utilisation and may be toxic to rumen microbes (Lowry *et al*., 1996). Leaves from fodder trees not withstanding the above are used as they are high in crude protein, minerals and vitamins (Baloyi *et al*., 1997) and are available during the dry season. Sun drying reduces the levels of some of these plant secondary metabolites.

2.4.1 *Nutritive value of fodder legumes*

The productivity from native fodder trees is significant in terms of browse (Everist, 1986; Burrows *et al*. 1988). The ability of a feedstuff to provide the nutrients that are required by the animal for maintenance, growth and reproduction and its dry matter intake determine its nutritive value (Teferedegne, 2000). The quality of tree legumes cannot be easily predicted by their chemical composition as the availability of the nutrients from the forage to the animal is variable. Analyses based on detergent extraction are more useful, as plant dry matter is separated into a completely digestible fraction (neutral-detergent soluble [NDS]), which represents the cell contents and a partially digestible fraction (neutral-detergent fibre [NDF]), which

represents plant cell wall (Van Soest, 1994). The digestibility of the plant material in the rumen is related to the proportion of cell wall that is lignified. Tree forages that have a low NDF content (200 – 350 g/kg) are usually highly digestible (Norton, 1994). The foliage of tree legumes usually have high crude protein content (150 – 300 g/kg) compared to that of crop residues (30 – 100 g/kg) (Teferedegne, 2000). Changes in the relative palatability of legumes with season will often help in maintaining an adequate proportion throughout the year. During the wet season ruminant livestock tend to selectively graze the more competitive grass component in preference to legumes such as *Stylosanthes hamata*, *Macroptilium atropurpureum*, among others. This makes available adequate proportion of legumes, which are preferred for the dry season. This is important not because of the high quality of the legume or the excellent dry season productivity of some of them, but rather their utilisation by the ruminant livestock enhances the intake and utilisation of low quality crop residues, which are available during the dry season (Keoghan, 1980). The drought tolerant *Stylosanthes hamata* has shown greatest persistence when grazed over a long period compared to other legumes (Keoghan, 1980).

Interest has increased in the use of tropical plants that may have a nutritional value beyond their nutrient content and thus are able to manipulate the rumen environment. This is on the backdrop of increasing awareness over

antibiotic residues in animal products and the threat of bacterial antibiotic resistance in the wider environment and the call for the banning of antibiotics as growth promoters (House of Lords, 1998).

Stylosanthes, a genus of the subtribe *Stylosanthinae*, subfamily, *Papilionoidae* (alt. *Faboideae*) and family *Fabaceae* (alt. *Leguminosae*), occurs naturally in the tropical, subtropical and temperate regions of the Americas, Africa, and Southeast Asia (Mannetje and Jones, 1992). *Stylosanthes* is self-fertile and predominantly self-pollinating. The species differ from most tropical pasture legumes in other genera because of their non-climbing growth habit. Their growing points are often close to the ground and this is an advantage under grazing conditions where it can tolerate heavy grazing (Chaisang *et al*., 2004). *Stylosanthes* is the genus that has received most attention in the search for ideal tropical pasture legumes. The genus, *Stylosanthes*, which originated mainly in South America, was tested in West Africa as early as the 1940s in an attempt to improve livestock nutrition and soil fertility.

Stylosanthes hamata (verano stylo) is a widely used pasture legume for raising cattle, sheep and goats (Kexian Yi, 2000). *Stylosanthes* is good for cut and carry as green feed, as well as for hay if cut before the dry season. Up to 90 kg/ha forage has been obtained under experimental conditions in West Africa and Northern Australia (Pengelly *et al*., 2004). *Stylosanthes* is used to

feed cattle, sheep, goats, pigs and poultry. The crude protein level of *Stylosanthes* ranges from 17 – 24 % in the green leaf material and 6 – 12 % in the stem. In-vitro dry matter digestibility (IVDMD) for whole tops is of the order of 60 – 65 %, comprising 66 – 72 % for green leaf and 33 - 57 % for stems. Phosphorous (P) level of the forage depends on the soil P status and age of re-growth but it can be as low as 0.08 – 0.3 % (0.16 – 0.37 % of DM in green leaf and 0.06 – 0.34 % in the stem). Nutritive value declines rapidly with the onset of the dry season leaf drop (Chaisang *et al.*, 2004). The success of this genus can be attributed to its tolerance to the fungal disease anthracnose, its adaptation to infertile soils, resistance to drought, ability to fix N without special *Rhizobium* inoculum and high seed yield (Edye and Maass, 1997).

The legume is extremely palatable. Cutting or grazing can start at flowering and subsequently after every four weeks. A yield of between 7 and 10 t/ha per annum have been recorded under a range of cutting frequencies in cut and carry systems in Thailand. Live weight gain (LWG) in cattle is usually in the range of 140 – 160 and up to 200 kg/head/yr under normal growing and grazing (good stocking rate) conditions. The LWG can be as low as 100 kg/head/yr on low fertility soils (Pengelly *et al.*, 2004).

Samanea saman classified as *Albizia saman* (Jacq.) F. Muell. (Leguminosae, Subfamily Mimosoideae) is a fast growing tree, which grows to a very large size. It is most common as a pasture shade or an ornamental tree but has other numerous uses. It was formerly classified as *Samanea saman*, *Pithecellobium saman* and *Enterolobium saman*. Other common names used include saman, monkey pod, raintree, cow tamarind, algarrabo and guango. It is native to Northern South America but now naturalized throughout the tropics. It is a rare canopy evergreen tree (20 -30 m) more usually associated with the dry tropical forests typical of Costa Rica (Staples and Elevitch, 2006). It is also found in Ghana; thus the rain tree is apparently widely travelled. It is used as a shade tree, especially in parks, pastures and on road sides (Allen and Allen, 1981; Ayensu, 1981).

Samanea saman yields forage and timber. A five year old tree can produce 550 kg of green forage per season (Staples and Elevitch, 2006). The tree also produces copious pods with a sweet pulp, attractive to animals. The pods can be ground and converted to fodder. The tree has been documented as fodder (NAS, 1979). This is mainly in relation to a high production of nutritious pods which fall off the tree in November and would be a valuable energy supplement for grazing animals. The nutritious pods contain 12-18 % crude protein (CP) and are 40 % digestible. Relished by livestock, pods are an important dry season fodder (F/FRED, 1994; Flores, 2002). The leaves are

also nutritious. *Samanea saman* (monkey pod tree) is a perennial and is available all year round. The leaves contain 22-27 % crude protein and are grown and used in some Asian countries as a green fodder supplement for goats, sheep and cattle (Akkasaeng, 1997). The species is also deciduous in August to September and has quite large leaflets. Feeding trials have been carried out (Lowry, 1995) and when fed to sheep, was found to have very low digestibility; but this was compensated for by a high intake, which was believed to be due to rapid fragmentation (Kennedy and Lowry, 1996). *Samanea saman* easily survives dry seasons of 2 – 4 months (Hensleigh and Holaway, 1988). Although it has been recognised as a leguminous tree species with potential in agroforestry (Nair *et al*., 1984) and also use of the foliage and pods for livestock feeding (Gutteridge and Shelton, 1994) there has been only limited specific research on it to substantiate this potential in the tropics (Durr, 2001). Much of the earlier information about *S. saman* is contained in disparate sources and this has made critical assessment of the potential of the species difficult (Roshetko, 1995).

Samanea saman leaves in a recent research showed the lowest methanogenic potential when some MPT leaves were screened (Soliva *et al*., 2008). Although, in developing countries, the abatement of ruminal methanogenesis is not of such a high priority, it is still highly relevant because of economic reasons. In the tropics, the livestock population is fed

mainly low quality diets and only 0.10 – 0.12 % of the gross energy ingested is lost through methane, which is one of the end products of fermentation (McCrabb and Hunter, 1999) and one of the substances being connected with global warming. *Gliricidia sepium* (gliricidia) and *Samanea saman* (acasia) were studied as alternative leaf meals and the acasia ration had the highest CP content followed by the concentrate and the gliricidia (Atega *et al*., 2003). Defaunation is the selective removal of protozoa from the rumen microbial ecosystem by a cell membrane cholesterol−saponin interaction, which causes cell rupture. Because protozoa in the rumen cause protein turnover by predating on bacteria, defaunation increases the nitrogen utilization of the ruminant and may lead to an increase in growth, milk, or wool production. The growth-promoting effect was evident in the high roughage diet, suggesting that the application of saponins or saponin-containing plant materials may be beneficial for the subsistence farmers in developing countries (Wina *et al*., 2005). Plant species which contain some tannins provide both degradable and undegraded rumen nitrogen (N) and are more effective sources of supplemental N for ruminants. Tannins also have anthelmintic properties or the capacity to reduce parasite loads. Condensed tannins and binding of nutrients directly inhibit nutrient availability for larval growth or decrease gastro-intestinal parasites through inhibition of oxidative phosphorylation (Scalbert, 1991; Kahn and Diaz-Hernandez, 2000).

2.5 ANATOMY & PHYSIOLOGY OF DIGESTION IN RUMINANTS

Ruminant animals are a group of animals with complex stomachs, especially designed to facilitate easier breakdown of fibre. The ruminant has three additional digestive organs at the anterior end of the digestive tract. These are the rumen, reticulum and the omasum, which allow the microbial population to extract and the host to absorb energy from the fibrous plant materials not otherwise available to mammalian enzymes (Dehority, 2003). In the young suckling lamb/calf, the rumen and reticulum are not developed. At this physiological stage, the pre ruminant animal is basically a monogastric. The rumen develops between 6 – 8 weeks of age depending on the nutrition (France and Siddons, 1993). The major difference between the ruminant and the non-ruminant is that of a pre-gastric fermentative microbial digestion in the reticulo-rumen, where food stays for a longer time in the digestive tract.

2.5.1 *The ruminant stomach*

The ruminant stomach comprises four compartments namely, the rumen, reticulum, omasum and abomasum. The digestive system of ruminants gives them the necessary space for processing large quantities of bulky forages for nutrients. It also provides a highly desirable environment for the enormous population of microorganisms that invade and colonise these digestive systems. The number of rumen bacteria varies according to the nature of the

diet; feeding regimen; time of sampling after feeding; availability of green feed and the presence or absence of ciliate protozoa. The microorganisms serve two main functions: (1) they make it possible for ruminants to utilise roughage i.e. the fibre therein. The microbes break down the cellulose and pentosans into usable organic acids, mainly acetic, propionic and butyric commonly called volatile fatty acids (VFAs). These are largely absorbed through the rumen wall and provide the animal with 60 – 80 % of its energy needs (France and Siddons, 1993) microbial protein leaving the rumen can account for as much as 60 – 85 % if not all of the protein entering the small intestines (Ørskov, 1982). Microbial fermentation is of great practical importance in the nutrition of ruminants. It is the fundamental reason why they can be maintained chiefly on roughages.

(2) In exchange for their rumen housing privileges, the microbes synthesize nutrients for their hosts in a true symbiotic type of relationship; rumen microbes synthesize all the B- complex vitamins and all the essential amino acids (France and Siddons, 1993). The factors responsible for the microbial fermentation are the capacity of the compartment to hold the food, the buffering action of saliva, the anaerobic environment, passage of the ingesta and the continuous removal of the soluble products of fermentation. All these conditions favour the habitation of microorganisms such as bacteria,

protozoa, fungi and some viruses, which reduce the ingested food to useful products (France and Siddons, 1993).

The rumen is essentially a fermentation chamber where food enters and is attacked by microorganisms through the enzymes they secrete; they produce fermentation products, which are absorbed through the ruminal walls, for the animal's needs. The chyme leaving the rumen (a mixture of feed residues, some fermentation products and microorganisms) pass through the omasum, into the abomasum and then into the small intestines. There is a continuous flow of secretion through the salivary glands into the rumen and a continuous outflow of digesta to the omasum. Freshly eaten feed mixes with the previous ration in the rumen. The important role played by the rumen microorganisms is to degrade the complex carbohydrates like cellulose and hemicellulose to volatile fatty acids (VFAs). Thus unlike hindgut fermenters, the products of microbial fermentation mainly, VFAs and microbial protein, are available for absorption in the small intestine (Dehority, 2003).

2.5.2 *Microorganisms*

Nearly all the typical microorganisms of the rumen are specific to that habitat. They colonise the rumen through direct contact between animals on one hand and eating of feed contaminated with saliva from another animal,

on the other hand. A roughage diet is more suitable for the establishment of microbes in the pre-ruminant animal. The process takes time and even when well-established, can disappear in a few days due to a number of factors. Starvation is known to reduce the protozoa in the rumen (France and Siddons, 1993). There are various types of microorganisms, which have specific functions in the rumen. Some are listed below:

Cellulose digesters: - There are many species of bacteria, which are responsible for cellulose digestion; *Bacteroides succinogens, Butyrivibrio fibrisolvens.*

Starch digesters: - A number of cellulolytic bacteria are also amylolytic. Examples are *Clostridium lochheadii, Bacteroides succinogens* and most strains of *Butyrivibrio fibrisolvens*. Other species, which are non–cellulolytic but amylolytic are *Streptoccocus bovis, Bacteroides amylophilus, Bacteroides ruminacola* and *Selemonas ruminantium*.

Hemicellulose digesters: - Xylan is attacked by various species of Eubacterium. eg. *Bacteroides amylogenes, Bacteroides ruminacola, Butyrivibrio fibrisolvens* and *Ruminiccocus flavefaciens*.

Sugar fermenting bacteria: - In young ruminants, a number of Lactobacillus species are found.

Methanogenic bacteria: - Are less in number and produce methane, an example is *Methanobacterium ruminantium* and methanogenic *Archaea*.

Proteolytic bacteria: - Rumen fermentation is primarily saccharo classtic rather than proteoclasstic (Hungate, 1985) since forages are rich in carbohydrates. Proteinases have been found in a number of saccharoclasstic species beside the proteolytics.

2.5.3 *Tannins and rumen microorganisms*

Rumen microbes are not capable of degrading condensed tannins (Makkar *et al*., 1995b). Research conducted on *L. corniculatus* showed that condensed tannin levels of up to 4 % in the diet have beneficial effects. These effects are mediated through protein-tannin complexations at rumen pH (6 – 7) and then the dissociation of the complex postruminally; enhancing availability of feed protein for productive purposes (McSweeny *et al*., 2001). Increase in the efficiency of microbial protein synthesis and decrease in the protein degradability of feed proteins in the rumen are beneficial for ruminants as they increase the supply of non-ammonia N to the lower intestine for production purposes, resulting in higher milk and meat production. In addition, these effects lead to protein sparing in the ruminant leading to reductions in methane production and N excretion to the environment, thereby reducing emissions of environmental pollutants besides producing more meat and milk. Feeding strategies need to be designed to exploit these beneficial effects (Makkar, 2003). The higher animal performance observed when the diet contains low levels of tannins has generally been attributed to

the protection of the feed protein from degradation in the rumen leading to the flux of essential amino acids (Eaa) to the small intestines and increase in the absorption of Eaa into the blood (Waghorn and Shelton, 1997). Studies by Makkar (1995a, 1997b) showed that these beneficial effects of tannins *in vivo* could also be due to higher efficiency of microbial protein synthesis in the rumen. Another factor, which influences the microbial N supply to the small/lower intestines could be a greater proportion of DM, which may be digested *in vivo* as a consequence of a slower rate of digestion or DM passage in the rumen, despite the reduced microbial population or their activity (Makkar *et al*., 1988).

2.5.4 ***Rumen environment***

The assumption that the rumen environment for cellulolysis is optimal i.e. adequate nitrogen (N), sulphur (S), minerals, soluble carbohydrates and optimal pH conditions means that intake would be limited by the plant factors, which would affect fill and subsequent removal. In practice it may not always be possible to achieve optimal rumen conditions but it is found to be most convenient to express the value of a feed under optimal conditions. The feeds may also contain antinutritive factors, which may not only inhibit degradation of the feeds themselves but also affect degradation of accompanying feeds. Antinutritive factors can both inhibit rumen microbes or affect the host animal.

2.5.5 *Plant factors influencing intake*

The identification of the above range of factors (Sec. 2.5.4) supposes that the animals will actually eat the diet. However, throughout evolution, plants have developed survival strategies either as a way of storing nutrients or as a means of defending their structure and reproductive elements from voracious herbivores or in some instances also making use of the animals to spread their seeds (Harborne, 1989). Tannins are chemicals or secondary compounds found in fodder legumes not directly involved in the process of plant growth but act as deterrents to insect and fungal attack or to being eaten by animals. During some growth stages the animals are discouraged from eating the plants while during other stages the consumption of such plants is encouraged. Some herbivores have also developed survival strategies, e.g. the ability to select certain parts of the plants or to develop microbial populations capable of minimizing antinutritive factors such as the microbial destruction of mimosine (Jones 1981) and some tannin from tanniferous plants (Brooker *et al*., 2000). Antinutritive factors are often associated with leguminous herbage shrubs or trees rather than the gramineae (Khazaal and Ørskov, 1993). Many tree leaves contain various levels of antinutritional factors that have an affinity for carbohydrates, amino acids and minerals rendering them unavailable for rumen microflora and the animal (Makkar, 2003). The principal negative effect of tannins is on protein utilization (Silanikove *et al*., 2001) thus the inclusion of a limited quantity of

tannin containing tree leaves in animal feed is recommended to improve rumen function and productivity (Osakwe *et al*., 2004).

2.5.6 *Characteristics of roughages that influence degradation*

Even under optimal rumen conditions, crop residues are not completely degraded as some of the cell wall components are not fermentable. This, in a way, affects intake, depending on the rumen retention time. Some of the characteristics of roughages that influence rumen fill and removal of digesta are discussed below. These include: solubility (A), the insoluble but fermentable fraction (B), the rate constant (C), the rate at which long particles are reduced to small particles (D), the rate of removal of small particles (E) and the rumen volume (F). It will be immediately apparent that A + B are the potential determinants of digestibility and by definition: 100-(A + B) will be the totally indigestible fraction (Ørskov, 1995).

Solubility (A)

The best hay is made during dry weather because with rain a proportion of soluble material contained inside plant cells will be washed off and both intake and digestibility would decrease (Ørskov, 1995). The soluble material consisting largely of soluble carbohydrates and protein occupies little space in the rumen and is also rapidly fermented in the rumen (Ørskov, 1995). The soluble content can be determined in several ways. The simplest is to wash

the roughages with water for a given period and measure the loss of dry matter (Ørskov, 1995). It can also be determined as that which is soluble in neutral detergent solution i.e. 100 - NDF. It is also possible to measure the soluble organic matter, which may be desirable in samples with high content of soluble ash. In the laboratory, the loss of dry matter or organic matter from samples contained in nylon bags that have been exposed to the washing procedure, but not incubated in the rumen, is often used (Ørskov, 1995).

Insoluble but potentially fermentable fraction (B)

This factor is determined by extrapolating the exponential curve describing degradation of insoluble material to its asymptote. This potential or asymptote is seldom achieved in practice due to rumen retention time and the degradation rate. It is clear that the fraction which is totally indigestible, 100 - asymptote, will require space in the gut until it is eliminated in the faeces.

The rate at which the insoluble fraction B is digested (C)

It is clear that the importance to the animals of the B fraction is determined not only by its size but also by its potential rate of fermentation, as this will determine the amount of the B fraction that will be released within the time

span limited by the rumen retention time. It follows that the B fraction and the C value should not be considered in isolation from each other.

The rate at which large particles are reduced to small particles (D)

Large particles are normally broken down into small particles by chewing/mastication, rumination and disintegration by the microbial biomass in the animal. This rate is a very elusive parameter and yet it is undoubtedly important for some feeds. If the rate at which the large particles are reduced to particles small enough to enter the liquid phase and be exposed to outflow is greater than the rate at which small particles flow out then it will not be a constraint to feed intake (Ørskov, 1995). In the laboratory this rate is obtained by measuring outflow or rumen retention time of mordanted long or small hay particles. This is of course not totally realistic as the mordanted particles are completely undegradable and therefore not exposed to microbial disintegration. Some feeds, such as palm pressed fibre or sisal pulp, contain very tough fibre, which is reduced to small particles at a rate much slower than the outflow of small particles (Zinn and Ware, 2007).

Outflow of small particles (E)

Small feed particles are as a result of extensive rumination and microbial degradation/fermentation in the rumen (Welch, 1982). Small feed particles are closely associated with the rumen fluid pool and the rumen fluid turn

over rate. This parameter depends in part on rumen motility and differs substantially between roughages. There are very large differences in the outflow of small particles from ground fibrous roughages and of protein supplements. Ørskov *et al*. (1988) showed that in circumstances in which the outflow of protein supplements was 0.06, the outflow of roughage was only 0.03. These differences reflect the length of time it takes for particles to traverse the solid mass of rumen contents and become suspended in the liquid phase from which outflow occurs. Outflow, therefore depends on the shape and specific gravity of the small particles and on the hairiness, which makes then cling, and adhere to large particles in the solid phase (Zinn and Ware, 2007). The specific gravity is an elusive parameter as fermentation gases can be entrapped inside Nerica straw cell walls and makes them less buoyant. There is still a great deal to learn about the factors affecting outflow of small particles of Nerica rice straw. The question, which should be addressed, is whether the variation between fibrous roughages is sufficiently large to warrant a specific value to improve prediction of feed intake. There is no doubt variability exists in specific gravity between roughages and type of roughages and between small particles from seeds and roughages.

Rumen volume (F)

The primary concern with respect to fibre digestion is the effect that energy intake consequently have on animal performance. The rumen has an upper

limit on its physical capacity (Zinn and Ware, 2007). The rumen volume is extremely important but it is not a plant factor as such. The volume of the rumen, determines how much fermenting material can be accommodated at any one time. Ruminants that are most selective usually have the smallest rumen volume (Hoffman, 1989). It is a factor, which has been neglected in selection procedures for animals. Indeed in some countries it has probably been selected against as a high killing out percentage, i.e. carcass weight as a percentage of live weight has been taken to be advantageous. Rumen volume is undoubtedly genetic in origin (Ørskov *et al.* 1988). Animals selected on the basis of high or low outflow rate consistently showed differences in flow rates regardless of level and type of feed offered. Cattle in Bangladesh also have a much higher gut volume (33%) (Mould *et al.*, 1982) than normally reported for Friesian cattle, probably due to the higher fibreous content of tropical forages compared to temperate ones.

2.6 THE IMPORTANCE OF DIGESTIVE KINETICS IN RUMINANTS

Components of the diet, which enters the rumen can only leave by one of two mechanisms; either through fermentative digestion and absorption, (which is about 61 – 85 % of organic matter) or through passage (Galyean and Owen, 1988). These two processes compete with each other. Digestion refers to the extent of degradation. The extent of ruminal fibre digestion is a function of the rate of digestion (k_d) and rate of passage (k_p).

Digestion = $\frac{k_d}{k_d + k_p}$

A primary factor that influences the rate of ruminal fibre digestion is the accessibility of substrate to the fibrolytic process, especialy the physical and chemical interactions of cellulose, hemicellulose and lignin. The rates of passage and digestion will affect feed digestibility, feed intake and end products of fermentation. The concern for the knowledge on the rate of passage and digestion, with respect to the Nericas and the other test feeds is the consequent effect on intake and subsequently animal performance.

2.6.1 ***Mechanism of passage of particles from the rumen.***

The fibre mat and the reticulo-omasal orifice are impediments to particle passage from the rumen. Passage from the rumen is also controlled by the functional specific gravity of the feed particle, the particle size, shape, rumen volume and motility (Zinn and Ware, 2007). The particle size has to be reduced to be able to pass through the mat and the reticulo-omasal orifice (Welch, 1986 and Schettini *et al*., 1999). Particle size reduction is effected by rumination and microbial digestion. Flat and cuboid particles pass through more readily than cylindrical and long particles (Welch, 1986). Passage rates of animals with smaller rumens will be greater than those with larger rumens. Small ruminants must thus be very selective grazers or concentrate selectors to survive. Disappearance rate (feeding rate) is a combined effect of

the rates of passage and digestion and it is the dry matter consumed divided by the dry matter content of the rumen (Schettini *et al.*, 1999).

The rate of passage or turnover rate, which for liquid digesta is dilution rate, is the proportion of undigested residues from a given meal that passes a given point in the gut in a set period of time. In considering passage rate, the DM intake, body weight of animal, % forage in diet and the eNDF content of the diet have to be taken cognisance of. Lechner-Doll *et al.* (1991) described the importance of particle density in the rumen and its effect on rumen retention time, which in turn could affect intake. Retention time or turnover time is the average time the digesta particles remain in the rumen and it is the reciprocal of the passage rate. Digestion rate is the proportion of the digestible fraction of a feedstuff, or nutrient within that feedstuff that is digested in a set time period; it is the difference between the disappearance and passage rate. The rate of passage is usually determined using markers (Schettini *et al.*, 1999).

2.6.2 ***Markers in passage studies***

Digesta markers should be non-absorbable; meaning the amount of marker placed in the gut should equal the amount recovered. The marker should not affect or be affected by the gut or the microbial population. Markers must be physically similar and intimately associated with the material being

measured. Determination must be specific, sensitive and easy to analyze. There are two types of markers. Internal markers are components within feeds themselves, which can be used as digesta markers, eg. lignin, silica, indigestible NDF to mention a few. External markers on the other hand, are not components of the diet but are external additives that are used as the digesta markers. They could be dyes, plastic particles, chemical compounds or rare earth elements. Inorganic markers such as chromium mordanted NDF and Cr/Co-EDTA are commonly used for measurement of solid and liquid passage rates respectively, through the gastrointestinal tract of ruminants. Limitations of using these and other inorganic markers have been outlined in several reviews (Owen and Hanson, 1992; Faichney, 1993). An alternate approach to measuring rate of passage is the microbiological technique using spores of bacteria. This technique was utilised by de Contrepois and Gouet (1969) to measure the transit of microparticles in the digestive tract of ruminants using the spores of *Bacillus subtilis*. They concluded that this method was simple and rapid. They also suggested that judgement on the method should await comparison with other methods that were not undertaken in their experiment. Marteau *et al*. (1990) used spores of the bacterium, *Bacillus stearothermophius* (BSS) to measure orocaecal transit time in humans. Mathers and Carter, (1993) compared BSS with water soluble Cr – EDTA to estimate gut transit time in rats and found the times to be strongly correlated. In this study, chromium-mordanted fibre using the

method outlined by Uden *et al*. (1980) was applied. The technique of chromium mordanting was used as it allows chromium to permanently bind to the forages under investigation and so does not leach into the rumen environment allowing for total recovery. The method also makes it possible for direct measurement of rumen turnover rates of small particles from feacal Cr excretion patterns.

2.7 SUMMARY OF THE LITERATURE REVIEW

The economic importance of sheep production in both rural urban and peri - urban areas in Africa is well documented (Mosha, 1991; Maxwell, 1994; Baah, 1994; Ameyaw-Djan, 2009). Sheep production in the tropics can be increased through increasing the productivity of the animal. A major factor in this direction will be the improvement of animal nutrition by way of feed supplies, especially in the case of ruminant animals. The improvement of ruminant livestock nutrition in the tropics can either be through increasing the productivity of already utilised resources or through the introduction and development of new or little used resources. Crop residues arising from cereal crops such as straws and stovers from rice, millet, sorghum and maize and sugarcane bagasse are high fibre-low protein feeds and so lack adequate levels of nitrogen, energy and minerals (Wora-anu *et al*., 2000). Most residues are also deficient in fermentable carbohydrates, reflected by the relatively low organic matter digestibility (Wanapat, 1999).

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) estimated that the per capita demand for cereal crops will increase in Sub-Saharan Africa (SSA) by some 4.9 % per year between 1997 and 2020, with the main increase being in wheat and rice (Rosegrant *et al.,* 2001). The increase will be due partly to greater demand for animal feed. Rice has become the most rapidly growing food source in SSA (Sohl, 2005) and the trend in per capita rice consumption in West Africa has increased from 14 kg in the 1970s to 22kg in the 1980s and has reached about 35 kg/yr in 2005 per person per year and this trend is expected to continue as population increases.

Various kinds of livestock are supported by rice-based systems. Cattle, sheep and goats graze on rice straw as their main food source in rice-producing areas. In turn, livestock help farmers with transportation needs and land preparation and livestock waste can be channelled into organic fertilizer (IYR, 2004). Rice is produced in all the ecological zones of Ghana and the country's requirement for rice is 600,000 metric tonnes annually. When this projection is met, the same quantity of rice straw would be available, based on the estimate of 1:1 ratio of rice grain to straw, and this can support ruminant livestock productivity throughout the dry season. The introduction of the NERICAs is a boost to farmers as there are both upland and lowland varieties for all the ecological zones. The Nerica rice has early maturity,

which allows growing a second crop, growing in areas with relatively short rainy seasons and saving labour on weeding compared to other rice varieties (Kijima, 2008). This also means more rice straw would be made available for feeding.

The feeding value of rice straw like most cereal crop residues is very low due to its high cell wall content, low crude protein content, inadequate energy, poor palatability and low organic matter digestibility. In addition to its high cell wall content, the ruminal degradability of rice straw is limited by its epidermal surface, which contains a high concentration of silica (Widyastuti *et al*., 1987 and Reed *et al*., 1990). The utilisation of rice straw as a significant proportion of the ration would only be successful if the limitations of low crude protein (Ørskov, 1990) and poor digestibility could be overcome. Several attempts have been made to improve the nutritive value of rice straw by various treatments. Considerable effort has been expended to improve the feeding value of cereal straws by using pre-treatments to upgrade digestibility (Bae *et al*., 1997), but commercial application of these pre-treatments is limited due to cost and potential environmental hazards (Singh *et al*., 1993 and Saadullah and Siriwardene, 1993).

A more logical approach to the improvement of the feeding value of rice straw would be through genetic improvement of straw quality, which would

in the long run be cheaper for the smallholder farmer who would then just collect and feed. Rice breeders have so far concentrated their efforts on crop productivity per unit area per unit time and in improving grain quality. Straw quantity and quality have been secondary considerations, except as they directly affect crop yield, such as in resistance to insects, diseases and lodging (Khush and Kumar, 1987) or early vegetative growth to control weeds as in the Nericas. Plant breeders are becoming increasingly aware of the need for whole plant utilisation and hence the need to improve the utility of crop residues (Rexen and Munck, 1984). In all these, grain yield and quality should not be compromised. This was demonstrated when rice was grown hydroponically with decreasing concentrations of silica. This lowered the silica content Two cultivars of rice straw from CRI at Fumesua near Kumasi were found to contain very low levels of silica (2.17 – 2.94 %). Thus if a conscious effort is made by our crop breeders to improve on the straw quality, there would be straws with minimal levels of silica, which would be highly degradable to support ruminant livestock production and still not compromise on the structural integrity of the crop (Abdul-Wahid, 2002).

Supplementation with energy and protein sources is a prerequisite to increasing the efficiency of utilization of rice straw. The supplements act to correct deficiencies of soluble nitrogen and minerals such as phosphorus and sulphur, and also as sources of protein or energy, which escape rumen

fermentation. Forage legumes and tree leaves rich in nitrogen offer the opportunity to be utilised as such in supplementation (Baumer, 1992).

Forage legumes are a dependable source of protein feed for animals. The seeds and leaves are rich in nitrogen. Forage legumes are adequately supplied with protein for livestock feeding, even when harvested at an advanced stage of maturity (Iyeghe-Erakpotobor *et al*., 2008). The high nitrogen content of leguminous species contributes to improving the nutritional quality of the diet of ruminants, whether grazed or cut and fed (Njwe and Kona, 1994). Leaves of fodder trees, however, have constituents like tannins, saponins and non-protein amino acids, which affect fodder utilisation and are toxic to rumen microbes (Lowry *et al*., 1996). Leaves from fodder trees not withstanding the above, are used as they are high in crude protein, minerals and vitamins (Baloyi *et al*., 1997) and are available during the dry season. Sun drying reduces the levels of the plant secondary metabolites. These secondary metabolites (antinutritional factors) mostly found in multipurpose plants (MPTs) could be of benefit to the ruminant animal. The tannins content make some of the MPTs a possible source of by-pass protein necessary for high animal productivity (FFTC, 2005). Forages containing saponins as secondary plant metabolites have anti protozoa activity as well as being a source of by-pass protein. Such forages may have

greater nutritional merit than their nutrient content would imply (Newbold *et al*., 1997).

An important area in ruminant nutrition is the measurement of the amount of microbial protein made available to the animal per unit feed consumed. A simple method, which is non-invasive is used and requires the total collection of urine. This simple method is based on the measurement of purine derivatives in urine (Chen and Gomez, 1995).

Digestibility for any feedstuff is not a constant and depends on the rates of digestion and passage that specific feeds are exposed to in the rumen. This is particularly true for feedstuffs, which contain significant proportions of cell walls and thus digest slowly in the rumen (Mulligan *et al*., 2001). There are a lot of reports in literature on digestibility depressions in response to increased feeding level of concentrate feeds. The depression in digestibility is not similar for all concentrate diets (Woods *et al*., 1999). These digestibility depressions have been associated with increased rumen particulate turnover rates (Lechner-Doll *et al*., 1991; Galyean and Owen, 1991). Interaction between high fibre diets and concentrates in mixed diets in the rumen could be attributed to changes in the rates of digestion and passage. These same attributes could alter digestion in the rest of the gut (Galyean and Owen, 1988). A recent review of the literature has called for more research into

factors affecting the fractional rumen outflow rate of ruminant feeds (Offer and Dixon, 2000). Feed components disappear from the rumen by digestion and passage at specific rates (Galyean and Owen, 1988). It can be inferred from the above that rate of passage has a lot to do with digestibility; however, few studies do digestibility and rumen turnover rates simultaneously. Thus it is important that passage rates of feedstuffs be determined as little can be concluded about changes in high protein feed digestibility in mixed diets from total diet digestibility.

This work sets out to determine the nutritional value of the straws of two varieties of the Nerica rice especially their crude protein contents. From the background that there is an improvement in the protein content of the Nerica 1 and Nerica 2 rice grains, it is possible that some of this has been translated to the straws. The work is also to determine the effect of feeding the two straws of Nerica 1 and Nerica 2 to sheep as basal diet supplemented with *Samanea saman* leaves, which is said to have low forage value despite its high crude protein content. But recently it has been found to have properties beyond its nutritional content that are beneficial to the animal as well as to the environment. The Nerica 1 and Nerica 2 straws would also be supplemented with *Stylosanthes hamata*, a shrub with a high forage value. Their effects on the performance of the sheep would be determined in terms of weight gain, the ammonia-nitrogen levels contributed in the rumen and

the quantities of microbial protein made available to the animals. Any differences or similarities that would be found would be explained through the results of evaluations carried out on the Nerica 1 and Nerica 2 straws, as well as the forages *Stylosanthes hamata* and *Samanea saman*. Very little work has been done on *Samanea saman* leaves in terms of rumen passage and feeding studies. Although a lot of work has been done on *Stylosanthes hamata* but there is dearth of information on rumen passage studies. Thus this work sets out to do studies into the chemical composition, degradation, digestibility and rumen passage of the straws of Nerica 1 and Nerica 2 and the forages *Stylosanthes hamata* and *Samanea saman* and how these would impact on the performance of young Djallonké rams.

CHAPTER THREE

OVERVIEW OF MATERIALS AND METHODS

3.1 Introduction

Five experiments involving three feed evaluation studies (Experiments 1, 2 and 3) and two feeding trials (Experiments 4 and 5) were conducted to assess the usefulness of the straws of Nerica 1 and Nerica 2 (two newly released rice varieties) as basal diets. *Samanea saman* (rain tree) and *Stylosanthes hamata* foliages were used as supplement to evaluate the performance of young Djallonké rams.

3.2 Location of study

The five experiments were carried out at the Livestock Section of the Department of Animal Science, Kwame Nkrumah University of Science and Technology, (KNUST) Kumasi, Ghana, between November 2008 and October 2009. The area is located at altitude 285^{m}, on latitude 06° 40' N and on longitude 001° 33' W; and is within the semi-deciduous forest zone of Ghana. Temperatures are relatively high throughout the year with the highest average temperature of 35.2 °C recorded in March and the lowest of about 20.2 °C recorded in January. The yearly average rainfall is 1510.0 mm (M.S, 2007). The major rainy season occurs from April to July and the minor rainy

season from September to October. The dry season is from November to March.

3.3 Source of Feed Ingredients

The rice straws (Nerica 1 and Nerica 2) were obtained from the Inland/ Valley Bottom Rice Development Project of the Ministry of Food and Agriculture (MoFA) at Nobewam in the Ashanti Akim District of the Ashanti Region. The *Samanea saman* was obtained from the paddocks (fields) of the Department of Animal Science, KNUST. The forage legume *Stylosanthes hamata* used was obtained from the arable farms of the Department of Crop and Soil Science, KNUST. Mature leaves (one year regrowth) of *Stylosanthes hamata* were used. Eight (8) g milled "Kau" (saltpeter) per day (Attoh-Kotoku *et al*., 2008), was used in place of mineral salt lick for each animal, in all the 5 experiments carried out.

3.4 Animals, Housing and Management

Djallonké rams (30 months of age) were used for the digestibility, degradation and passage rate studies (Experiment 1, 2 and 3) and ram lambs (18 – 20 months of age) were used for the growth trials. The sheep were purchased from Konongo, and the villages around Lakeside (Lake Bosomtwe) and the suburbs around KNUST. The rams used for the passage studies were housed in individual metabolism cages while the ram lambs

used for the feeding trials were housed in individual pens measuring 3 m x 1 m, with wooden slated floors, during both the adaptation period and the main study. Each pen was provided with a plastic bucket for water and two wooden feed troughs. The housings were cleaned, disinfected using Izal (Saponated cresol), a germicide and kept empty for a week before the commencement of the study. The animals were quarantined for two weeks on purchase and placed on prophylactic treatment, which included the administration of Peste de Petit Ruminant (PPR) vaccine, antibiotics and vitamins, as well as Ivermectin (0.2 mg kg^{-1})[1] an injectible antihelmintic that takes care of both internal and external parasites, before the commencement of each study.

3.5 Chemical Analyses

3.5.1 *Sample Preparation*

Dried samples, of either forage or rice straw, were finely ground to pass through a 1 mm mesh sieve and stored in plastic bags until required for analysis. Chemical analysis to determine the dry matter, crude protein, ash and acid insoluble ash contents of the two rice straw varieties (Nerica 1 and 2), *Samanea saman* and *Stylosanthes hamata* were performed according to the procedures of the Association of Official Analytical Chemists (A. O. A. C, 1990). The neutral detergent fibre and the acid detergent fibre fractions were

[1] Tilmectin: 100 ml contains 1 g active ingredient Ivermectin.

determined following the technique of Goering and Van Soest (1970). Acid detergent lignin was also determined by the technique of Goering and Van Soest (1990).

3.6 Experimental Designs

A Randomized Complete Block Design (RCBD) within a 2x2 factorial arrangement of treatments was used for two of the feed evaluation studies, ie Experiments 1 and 2. A 4x4 Latin Square design (Steel and Torrie, 1980) was used for the third feed evaluation study, Experiment 3. A Completely Randomized Design in a 2 x 3 Factorial arrangement of treatments was used for the feeding trial studies, Experiments 4 and 5.

3.7 Statistical Analyses

The data from the feeding trials and passage studies were analysed using the general linear model of SAS (2002) and Genstat (2009), GenStat Procedure Library Release 12.1, PL20.1 statistical packages.

CHAPTER FOUR

EXPERIMENT 1

The effect of *Samanea saman* and *Stylosanthes hamata* supplementation on voluntary feed intake, digestibility and purine derivative production in Djallonké sheep fed Nerica 1 rice straw as a basal diet.

4.1 INTRODUCTION: EXPERIMENT 1

Rice straws in general have low nutritive value; thus the need to improve them is imperative as they are an abundant crop residue. The Nerica is a new group of rice varieties for both upland and lowland cropping systems produced through conventional crossbreeding. Nerica is a cross of 2 species of cultivated rice, *Oryza glaberrima* (Steud.) and *Oryza sativa* L. A recent work has shown Nerica 1 straws to have higher crude protein content compared to other varieties (Attoh-Kotoku *et al.*, 2007). The Nerica grains have higher protein content (9 – 11.8 %) and this might have translated into the straws of some of the varieties, as stated above. This study would ascertain whether this increase in CP content would be translated into the digestibility of the straws. There is the need to improve the straws without using antibiotic growth promoters on the backdrop of the EU's regulations on antibiotic growth promoters. Plant protein nitrogen sources can be used to improve

microbial action ie, harnessing legume/MPTs like *Samanea saman* to provide the needed energy, some minerals, vitamins and protein to promote growth.

The forage value of any feed depends on the combination of its palatability, nutritive value and digestibility (Lefroy *et al.,* 1992). Proper feeding of ruminants during the dry season is crucial due to seasonal variation and availability of good quality pasture (Castillo-Caamal *et al*., 2003). This has necessitated investigation of new sources of feeding materials for use as supplements in sheep diets (Fasuya, 2005). Fodder trees and shrubs, which are available during the dry season, can provide protein, energy, minerals and vitamins to keep rumen microbes active, increasing their ability to digest fibres and thus enable livestock to make better use of the poor quality dry season feeds (Lake, 1997; Baloyi *et al*., 1997). The nutritive value of some forages obtained from different plants is well established (Bal *et al*., 2006) but there is little information on *Samanea saman*.

Samanea saman is a multipurpose fodder, which is used in agroforestry systems as shade and its pods as animal fodder. Limited information is available on the use of its foliage as fodder. Very recent research has shown that *in vitro* digestion of the foliage, among other tree foliages, produced very little methane i.e., it has methanogenic properties (Soliva *et al*., 2008). This is very important on the backdrop of ruminant animals' contribution to global

warming. Recent legislation (1831/2003; EC, 2003) introduced within the European Union prohibits the use of growth-promoting antibiotics in animal feeds (Casewell *et al.*, 2003). The removal of antibiotic growth-promoters has led to an increased interest in alternative means of manipulating rumen fermentation.

Digestion of food in the rumen occurs by a combination of microbial fermentation and physical breakdown during rumination. Microbial attack is carried out by a mixed population of bacteria and ciliate protozoa, together with a smaller but possibly metabolically important population of anaerobic fungi (Dehority, 2003). As a result of the location of the rumen, anterior to the abomasum, feedstuffs consumed by ruminants are exposed to microbial attack prior to gastric and intestinal digestion. Maximizing ruminant productivity involves meeting the nutrient requirements for both rumen microbial metabolism and mammalian metabolism in the tissues (Teferedegne, 2000). In ruminants, nutrients that are taken in are subjected first to rumen microbial fermentation and the products ensuing eventually become available as energy (volatile fatty acids) and protein (microbial cells) for animal tissue metabolism (Osuji *et al.*, 1995). Voluntary feed intake is a major determinant of livestock productivity. Limitation to voluntary feed intake is a primary constraint to productivity in animals' fed-forage based diets. The performance of an animal can be determined from the digestibility

of the feed and the quantity of feed ingested (Ndlovu and Hove, 1995). Digestibility in turn can be deduced from pool size, rates of digestion and passage of potentially digestible plus indigestible feed components (Galyean and Owen, 1988). Digestion and retention coefficients are determined by collecting all the excreta, mainly the urine and the faeces, and analysing the feed and the excreta samples. The quantities of most of the nutrients absorbed and retained in the body or stored can then be determined from the analyses.

It is estimated that 40 – 80 % of the total flow of protein reaching the small intestines are from microbial protein (McDonald *et al*., 1995). Nucleic acids leaving the rumen are essentially of microbial origin, as ruminant feeds usually have very low purine content, most of which undergo extensive degradation in the rumen as a result of microbial fermentation. Nucleic acids synthesised by rumen micro-organisms are enzymatically degraded to purine and pyrimidine bases, which are absorbed. Their final end products are excreted in the urine with allantoin being the greatest proportion (Puchala and Kulasek, 1992). Giesecke *et al*. (1984) suggested the use of purine derivatives as an effective measure of rumen microbial growth, when they found a significant relationship between the amounts of purine metabolites excreted in urine of sheep maintained by intragastric infusions. Chen *et al*. (1990) have shown that purine derivatives (hypoxanthine,

xanthine, uric acid and allantoin) could be used to estimate the supply of microbial protein from the rumen to the intestine. Absorbed nucleic acid purines are degraded and excreted in the urine as their derivatives, hypoxanthine, xanthine, uric acid and allantoin (Chen *et al*., 1990; FAO/IAEA, 1997). The excretion of the PDs is directly related to purine absorption. Microbial nitrogen absorption can be calculated from the amount of purine absorbed, with the knowledge of purine-N: total-N ratio in microbial biomass, which can be estimated from urinary PD excretion. The measurement of Purine Derivative (PD) excreted in urine is used, for estimating microbial protein flowing from the rumen. The knowledge of the amount of purine derivatives excreted in urine can be used to estimate the microbial protein supply to the host (FAO/IAEA, 1997).

The aim of this study was to determine the intake, digestibility, rumen ammonia nitrogen, blood urea nitrogen and the level of excretion of purine derivatives when different levels of *Samanea saman* and *Stylosanthes hamata* are fed as supplements to sheep offered Nerica 1 rice straw basal diet.

4.2 MATERIALS AND METHODS: EXPERIMENT 1

4.2.1 *Location of experiment*

This study was carried out at the Livestock Section of the Department of Animal Science, KNUST, Kumasi, Ghana.

4.2.2 *Sample preparation*

The plant protein sources *Samanea saman* and *Stylosanthes hamata* foliages were harvested and dried at 25 °C under shade for three days and the Nerica 1 rice straw was dried at 28 °C under direct sunlight chopped into 6-8 cm lengths before feeding (the leaves were fed whole not milled).

4.2.3 *Experimental design*

Four rumen fistulated Djallonké rams, with an average weight range of 20 - 25 kg, and 30 months of age were used for the digestibility studies in a Randomised Complete Block Design (RCBD), (4 treatments) in a 2 x 2 factorial arrangement of treatments. The factors were 2 types of foliage and 2 levels of offer with the periods (four 7-day periods) as blocks. Two levels each (360 and 480 g) of the foliages *Samanea saman* and the *Stylosanthes hamata* were offered as supplements to create four rumen environments. The treatments were designated T_{SA360}, T_{SA480}, T_{ST360} and T_{ST480} for 360 g *Samanea saman*, 480 g *Samanea saman*, 360 g *Stylosathes hamata* and 480 g *Stylosanthes*

hamata respectively. The supplement levels for the study (360 and 480 g) were informed from an earlier work done by Osafo *et al*. (2008) using *Stylosanthes hamata*. An initial 10 days were allowed the animals to adjust to the diet followed by four 7-day periods, which were used for the measurement of feed intake and collection of faeces and urine. The 7th day was also used for the harvesting of rumen fluid and collection of blood samples every 2 hours over a six hour period.

4.2.4 *Housing, Management and Feeding*

The rams were housed in individual metabolism cages (0.7 x 1.2 m). The cages were provided with plastic buckets for water and had wooden feeding troughs.

At the start of the experiment, the rams were individually weighed, placed in the metabolism cages and allowed *ad libitum* access to water. The animals were offered the treatments ie T_{SA360}, T_{SA480}, T_{ST360} and T_{ST480} of either *Samanea saman* or *Stylosanthes hamata* and the basal diet Nerica 1 was given *ad libitum* at 09.00 hrs throughout the experiment. The rams were fed once a day and the feed was weighed before being supplied.

4.2.5 *Measurements: Data collection, chemical analysis and sampling*

During the first 10 days of each period, feed offered and feed refusals were weighed daily for measuring voluntary feed intake. Feed samples were

randomly collected twice a week for DM analysis using a hot air oven (60 °C) (AOAC, 1990). During the last 7 days of each period, samples of feed offered were collected every day and divided into two parts; the first part was analyzed for DM while the second part was kept in airtight containers and pooled at the end of each period for analyses of ash, N, NDF and ADF in triplicate. All the feed refusals were collected for each animal before feeding from day 11 through 17 (the intake measurement days); these were weighed and sub-samples were obtained and stored in plastic bags pending chemical analysis. Feed samples were composited by period, dried at 60 °C and stored. Feed intake was subsequently calculated by subtracting the feed left over from the offered.

On each of the intake measurement days, all the faeces voided daily for each animal were collected, weighed, mixed and samples taken for analysis before feeding in the morning. Samples of about 20 % of total fresh weight of the faeces were dried in a hot air oven (60 °C) for 48 h and the dried samples analyzed for DM, Ash and N and for NDF and ADF in triplicate. The urine volume was also measured and aliquots taken for each animal daily and stored frozen at -20 °C pending chemical analysis for urine-N and purine derivatives, which would subsequently be used for N-balance and microbial N supply determination. To ensure that the pH of the urine was less than 3

to avoid loss of nitrogen, 100 ml of 0.2 N HCl acid was added every morning after the previous days urine measurement.

4.2.6 *Purine derivatives measurement*

Microbial nitrogen yield was calculated according to Chen and Gomez (1992) in the sheep. All the purine derivatives were determined by Atomic Absorption Spectrophotometry. Standard stock solutions of 100 mg/L of allantoin and uric acid were prepared and diluted to give working concentrations of 10, 20, 30, 40, 50 and 60 mg/L and 20, 40, 60, 80 and 100 mg/L for allantoin and uric acid respectively.

Principle behind allantoin determination: Allantoin is first hydrolysed under a weak alkaline condition at 100 °C to allantoic acid, which is hydrolysed to urea and glyoxilic acid in a weak acid solution. The glyoxilic acid reacts with phenylhydrazine hydrochloride to produce a phenylhydrazone derivative of the acid. The product formed is an unstable chromophore with potassium ferricyanide. The colour is read at 522 nm.

Uric acid absorbs UV at 293 nm, although other compounds may also absorb UV at this wavelength. When samples are treated with uricase, uric acid is converted to allantoin and other compounds that do not absorb at 293 nm. Therefore, the reduction in OD reading after treatment with uricase is correlated with the concentration of uric acid in the sample. After treatment, the OD of the standards should be zero if the conversion is complete.

4.2.7 *Rumen pH, ammonia-N and blood urea-N measurements*

On day 7 of each period rumen fluid was harvested at 0, 2, 4 and 6 h after feeding. A portable pH meter was used to measure the pH of the ruminal fluid immediately after straining through four layers of cheese cloth and stored at -20 °C until required for use. The ruminal fluid samples to be used for rumen NH_3-N were centrifuged at 6000 x g for 10 min and the supernatant used for the determination.

Blood samples were also collected at 0, 2, 4 and 6 h after feeding on day 7 of each collection period. The blood samples were centrifuged at 3000 x g for 20 minutes and the plama removed and analysed for blood urea nitrogen (BUN) according to the method of Roseler *et al*. (1993).

4.2.8 *Statistical analysis*

DM intake, digestibility, nitrogen intake (digestibility and retention); rumen pH, ammonia-N and blood urea-N; excretion of urinary PD and microbial N supply data were analysed as a Randomised Complete Block Design using analysis of variance and the PROC general linear model (GLM) of SAS (2002).

4.3 RESULTS: EXPERIMENT 1

4.3.1 Overview

All the four rams were healthy throughout the four collection periods. They consumed all the forages appreciably. Only the means of the measurements for the four periods were reported.

4.3.2 Chemical Composition of the forages

4.3.2.1 *Dry Matter, OM, CP and detergent fractions*

The chemical composition of the feed samples is presented in Table 4.1. The dry matter values for the rice straws and the two forages *Samanea saman* and *Stylosanthes hamata* indicate that the four feeds were very dry as they had DM values above 900 g/kg DM. The *Samanea saman* forage had the highest organic matter value (930.3 g/kg DM) followed by *Stylosanthes hamata* (870 g/kg DM) and then the Nerica 1 rice straw (867.5 g/kg DM). The crude protein content (202.5 g/kg DM) of *Stylosanthes hamata* was higher than that of the *Samanea* (182.2 g/kg DM), which was also higher than the value for the Nerica 1 rice straw (60.6 g/kg DM). Nerica 1 rice straw had higher NDF value compared to the legumes, which had considerably lower values. The ADF contents were quite similar (308.9 – 346 g/kg DM) among the forages except for *Samanea saman*, which had a higher value (456.6 g/kg DM). The

legume foliages have low hemicellulose contents when compared to the straw of Nerica 1, with *Samanea saman* having the least (15.4 g/kg DM).

Table 4.1 Chemical, sulpher and tannins composition (g/kg DM) of the feed samples

ITEM	**NERICA 1**	***Samanea saman***	***Stylosanthes hamata***	**SD**
Dry Matter (DM) (g/kg)	987.5	965.3	930	4.53
Crude Protein (CP)	60.6	182.2	202.5	19.73
Organic matter (OM)	867.5	930.3	870	12.06
NDF	655.1	472.0	486	22.63
ADF	308.9	456.6	346	12.69
Hemicellulose	346.2	15.4	140	19.9
Ash	120	35	60	10.77
Acid insoluble ash (AIA)	9.1	27.5	35	3.4
Sulphur	nd	5.5	3.4	nd
Condensed Tannins	nd	26.1	23.3	nd
Total Tannins	nd	40.0	nd	

Nd: not determined; NDF, neutral detergent fibre; ADF, acid detergent fibre.

4.3.2.2 *Ash and Acid Insoluble Ash*

The *Samanea samen* legume had the lowest content of ash (35 g/kg DM). The ash content of the rice straw was very high (120 g/kg DM) and double that of the *Stylosanthes hamata* (60 g/kg DM). Nerica 1 had the lowest (9.1 g/kg DM) acid insoluble ash (AIA) compared to (27.5 and 35 g/kg DM) for *Samanea saman* and *Stylosanthes hamata* respectively.

4.3.2.3 *Sulphur, Condensed and Total Tannins*

The *Samanea Saman* foliage had sulphur content of (5.5 g/kg DM) while the *Stylosanthes hamata* had a value of 3.4 g/kg DM. The condensed tannins values were 26.1 and 23.3 g/kg DM for *Samanea Saman* and *Stylosanthes hamata* respectively.

4.3.3 *Feed Intake*

The feed intake of the rams is presented in Table 4.2. The daily rice straw

Table 4.2 Effect of offer level of supplements on intake and weight change of rams on Nerica 1 rice straw basal diet.

Parameters	*Samanea* (g DM/d)		*Stylo* (g DM/d)		LSD	Sig.	FxL
	T_{SA360}	T_{SA480}	T_{ST360}	T_{ST480}			
Initial weight, kg	23	25	20	22			1.000
Final weight, kg	25^{b}	28^{a}	23^{d}	24^{c}	0.77	*	0.002
Change in weight, kg	2^{b}	3^{a}	3^{a}	2^{b}	0.46	*	0.001
Intake (g DM/d)							
Rice straw	702.15^{b}	737.4^{a}	655.5^{c}	668.9^{c}	20.05	**	0.001
Samanea saman	336.25^{b}	447.3^{a}			10.7	**	0.015
Stylosanthes hamata			353.9^{b}	411.8^{a}	10.7	**	0.015
Total intake	$1{,}038.4^{b}$	$1{,}184.7^{a}$	$1{,}009.4^{d}$	$1{,}080.7^{c}$	35.9	**	0.001
R. straw $M^{0.75}$	66.87^{b}	65.96^{b}	69.29^{a}	65.84^{b}	2.5	*	0.896
S. saman $M^{0.75}$	32.02^{b}	40.01^{a}			1.14	*	0.024
S. hamata $M^{0.75}$			37.4^{b}	40.53^{a}	1.14	*	0.024
Total intake $M^{0.75}$	98.90^{b}	105.97^{a}	106.7^{a}	106.37^{a}	3.2	*	0.440

NS, Non-significant, P>0.05; *, P<0.05; **, P<0.01; LSD, Least significant difference;
T_{SA}, treatments with *Samanea*; T_{ST}, treatments with *Stylosanthes*.
$^{a, b, c, d}$means within rows with different superscripts differ significantly (p<0.05).

intake for the rams on the *Samanea saman* supplement were significantly (P<0.01) higher (737.4 and 702.15 gDM/d) for T_{SA480} and T_{SA360} than for rams on the *Stylosanthes hamata* supplement (668.9 and 655.5 g DM/d). The intake of *Samanea saman* increased significantly (P<0.001) as the level of offer increased. It was the same for the *Stylosanthes hamata* foliage. The total dry matter intake increased significantly (P<0.001) as the level of the supplements increased and was highest (1,184.7 gDM/d) for *Samanea saman* T_{SA480} followed by 1,038.4, 1,080.7 and 1,009.4 gDM/d for T_{SA360}, T_{ST480} and T_{ST360} respectively. The straw intake on metabolic weight basis was significantly (P<0.05) higher for T_{ST360} but similar for all the other treatments. Intake of the *Samanea saman* foliage on metabolic weight basis increased significantly (P<0.01) as the level of offer increased. The *Stylosanthes* intake was similar (P>0.05) for T_{ST360} and T_{ST480} on metabolic weight basis.

4.3.4 *Whole tract in vivo digestibility*

As shown in Table 4.3, the apparent whole tract DM digestibility coefficient was significantly (P<0.01) higher in rams on the lower level of offer of *Stylosanthes hamata* compared to the others, which were similar. The OM digestibility coefficient was significantly (P<0.05) lower for the lower level of offer of *Samanea saman* compared to the lower level of offer of the *Stylosanthes hamata* and similar with the other two levels. The lower level of offer of the *Stylosanthes hamata* had similar OM digestibility coefficient value with T_{SA480}

and T_{ST480}. The digestibility coefficient value for nitrogen was significantly (P<0.05) higher for the lower level of offer of *Stylosanthes hamata* compared to

Table 4.3 Effect of foliage type and level of offer on digestibility coefficients of nutrients in rams

NUTRIENTS	*Samanea* (g DM/d)		*Stylo* (g DM/d)				
	T_{SA360}	T_{SA480}	T_{ST360}	T_{ST480}	LSD	Sig.	FxL
DM digestibility	0.796^{b}	0.809^{b}	0.853^{a}	0.817^{b}	0.027	**	0.019
OM digestibility	0.848^{b}	0.859^{ab}	0.884^{a}	0.871^{ab}	0.03	*	0.221
N digestibility	0.609^{c}	0.693^{b}	0.781^{a}	0.687^{b}	0.016	*	0.001
NDF digestibility	0.656^{c}	0.683^{b}	0.818^{a}	0.680^{b}	0.01	**	0.001

NS, Non-significance, P>0.05; *, P<0.05; **, P<0.01; LSD, Least significant difference; T_{SA}, treatments with *Samanea*; T_{ST}, treatments with *Stylosanthes*.
$^{a, b, c, d}$means within rows with different superscripts differ significantly (p<0.05).

the other offer levels. The digestibility coefficient value for nitrogen was significantly (P<0.05) lower for the lower level of offer of *Samanea saman*. Nitrogen digestibility was also significantly (P<0.05) different between the two foliages. However, nitrogen digestibility for the rams on T_{SA480} and T_{ST480} treatments were not significantly (P>0.05) different (0.693 and 0.687). The NDF digestibility was significantly (P<0.01) higher for the rams on the lower level of offer of *Stylosanthes hamata* and significantly (P<0.01) lower for those on the lower level of offer of *Samanea saman*. The NDF digestibility was also significantly (P<0.01) different for the two offer levels of both foliages, with T_{ST360} (0.818) being significantly higher than all the others.

4.3.5 *Nitrogen balance*

As shown in Table 4.4, nitrogen intake was similar (P>0.05) across the two foliages. Nitrogen intake was however significantly (P<0.05) different at the two levels of offer of the two foliages (16. 61; 20.19 and 17.83; 19.83). The nitrogen intake at the two lower levels of offer was similar. The higher level of offer followed the same trend. The excretion of nitrogen in the faeces at the two offer levels was significantly different for the rams on *Stylosanthes* supplement, whilst similar for those on *Samanea saman*. Faecal-N excretion was significantly lower (3.9 g N/d) in rams on T_{ST360} than for the others.

Table 4.4 Effect of supplementation level on nitrogen intake, digestibility and retention in rams fed Nerica 1 rice straw.

	Samanea (g DM/d)		*Stylo* (g DM/d)				
N balance, g/d	T_{SA360}	T_{SA480}	T_{ST360}	T_{ST480}	LSD	Sig.	F x L
N intake	16.61^{c}	20.19^{a}	17.83^{b}	19.83^{a}	0.6	*	0.001
N in faeces	6.5^{a}	6.2^{a}	3.9^{b}	6.2^{a}	0.63	*	0.001
N in urine	0.031^{b}	0.019^{d}	0.027^{cb}	0.037^{a}	0.004	*	0.001
N digested	10.11^{b}	13.99^{a}	13.93^{a}	13.63^{a}	0.69	*	0.001
Digestibility, %	60.87^{c}	69.29^{b}	78.13^{a}	68.73^{b}	3.1	*	0.001
N retention, g/d	10.08^{b}	13.97^{a}	13.90^{a}	13.59^{a}	0.7	*	0.001
% of N intake	60.69^{c}	69.19^{b}	77.96^{a}	68.55^{b}	3.1	*	0.001
% of N digested	99.70^{c}	99.86^{a}	99.78^{b}	99.71^{c}	0.041	*	0.005

NS, Non-significance, P>0.05; *, P<0.05; **, P<0.01; LSD, Least significant difference; T_{SA}, treatments with *Samanea*; T_{ST}, treatments with *Stylosanthes*.
$^{a, b, c, d}$means within rows with different superscripts differ significantly (p<0.05).

The urine-N excretion was significantly (P<0.05) different for the two foliages. The nitrogen excreted in the urine was also significantly (P<0.05) different for the feeding levels of the two foliages. The excretion of nitrogen in the urine was similar for T_{SA360} and T_{ST360} but significantly (P<0.05) lower for T_{SA480} and significantly (P<0.05) higher for T_{ST480}. The nitrogen digested was significantly (P<0.05) lower for the lower level of offer of *Samanea saman* foliage and similar for the others. Nitrogen retention was significantly (P<0.05) different among the two foliage types. It was significantly (P<0.05) lower for T_{SA360}, (10.08) compared to the others (13.97, 13.90 and 13.59), which were similar. Nitrogen retained as % of intake was significantly (P<0.05) higher for T_{ST360}, (77.96) and was significantly (P<0.05) lower for T_{SA360}, (60.69). Nitrogen efficiency was significantly (P<0.05) higher for the higher level of offer of Samanea saman foliage.

4.3.6 *Rumen pH, ammonia-N and blood urea-N*

Table 4.5, shows averaged values (0 to 6 h after feeding) of pH and NH_3-N in the rumen fluid and blood urea-N of rams on the four different levels of offer of the foliages. The pH of the rumen was similar for T_{SA480} and T_{ST480} (6.35 and 6.31) at 0 h but significantly (P<0.05) lower for the lower levels of offer T_{SA360} and T_{ST360} (6.23 and 6.20) at the same time respectively. At 2 h post feeding, the rumen pH was significantly (P<0.05) different between the two foliages. The pH for the two offer levels for Samanea saman were

Table 4.5 Rumen pH, rumen NH_3 and BUN in rams fed different levels of *Samanea saman* and *Stylosanthes hamata*

Rumen parameters	*Samanea saman*		*Stylosanthes hamata*				**P-v**
pH	**T_{SA360}**	**T_{SA480}**	**T_{ST360}**	**T_{ST480}**	**LSD**	**Sig.**	**F x L**
0 h-post feeding	6.23^{b}	6.35^{a}	6.20^{b}	6.31^{a}	0.046	*	0.001
2	6.62^{a}	6.66^{a}	6.52^{c}	6.59^{b}	0.051	*	0.007
4	6.87^{c}	6.98^{a}	6.92^{b}	6.75^{d}	0.04	*	0.001
6	6.49^{a}	6.59^{a}	6.54^{a}	6.42^{b}	0.054	*	0.008
Mean	6.55	6.65	6.55	6.52			
NH_3-N, mg/100 ml							
0 h-post feeding	0.12^{d}	3.24^{a}	0.96^{c}	2.40^{b}	0.046	*	0.001
2	5.30^{b}	5.5^{a}	4.56^{d}	5.10^{c}	0.038	*	0.001
4	8.30^{c}	9.6^{a}	8.70^{b}	7.80^{d}	0.083	*	0.001
6	6.00^{d}	7.1^{a}	7.04^{b}	6.40^{c}	0.046	*	0.001
Mean	4.93	6.36	5.315	5.425			
Blood parameters							
BUN, mg/100 ml							
0 h-post feeding	6.5^{b}	7.6^{a}	5.2^{c}	4.2^{d}	0.069	*	0.001
2	6.9^{b}	7.7^{a}	5.4^{c}	4.5^{d}	0.064	*	0.001
4	7.1^{b}	8.4^{a}	5.5^{c}	4.6^{d}	0.058	*	0.001
6	7.6^{b}	9.1^{a}	6.3^{c}	4.7^{d}	0.065	*	0.001
Mean	7.025	8.2	5.6	4.5			

NS, Non-significance, P>0.05; *, P<0.05; LSD, Least significant difference (5 %).
T_{ST}, treatments with *Stylosanthes*; T_{SA}, treatments with *Samanea*.
$^{a, b, c, d}$means within rows with different superscripts differ significantly (p<0.05).

similar but significantly (P<0.05) higher than the two offer levels for *Stylosanthes hamata*. At 4 h post feeding, the rumen pH for the rams were significantly (P<0.05) different between all the four levels of offer of the foliages. The rumen pH also peaked at 4 h post feeding for all the four

levels of offer. The pH was significantly (P<0.05) higher for the higher level of offer for *Samanea saman* (6.98) and significantly (P<0.05) lower for the higher level of offer *of Stylosanthes hamata* (6.75). At 6 h post feeding, the rumen pH of the rams on the two foliages were significantly (P<0.05) different. The pH at 6 h was also significantly (P<0.05) lower (6.42) for the higher level of offer for *Stylosanthes hamata* and similar for the other levels.

The rumen NH_3-N concentrations were significantly (P<0.05) different between the four levels of offer of the two foliages *Samanea saman* and *Stylosanthes hamata* and also among all the four time periods ie 0 – 6 h post feeding. The rumen NH_3-N concentration at 0 h post feeding was significantly (P<0.05) higher for the higher level of offer for *Samanea saman* (3.24 mg/100 ml) and significantly (P<0.05) lower for the lower level of offer of *Samanea saman* (0.12 mg/100 ml). The rumen NH_3-N concentration at 2 h post feeding was significantly (P<0.05) higher for the higher level of offer for *Samanea saman* (5.5 mg/100 ml) and significantly (P<0.05) lower for the lower level of offer of *Stylosanthes hamata* (4.56 mg/100 ml). The rumen NH_3-N concentration at 4 h post feeding was significantly (P<0.05) higher for the higher level of offer for *Samanea saman* (9.6 mg/100 ml) and significantly (P<0.05) lower for the higher level of offer of *Stylosanthes hamata* (7.80 mg/100 ml). The rumen NH_3-N concentration at 6 h post feeding was significantly (P<0.05) higher for the higher level of offer for

Samanea saman (7.1 mg/100 ml) and significantly (P<0.05) lower for the lower level of offer of *Samanea saman* (6.0 mg/100 ml).

The levels of blood urea-N were significantly (P<0.05) different between the foliages and the two offer levels of each. The blood urea-N levels were significantly (P<0.05) higher for the higher level of offer for *Samanea saman* (7.6; 7.7; 8.4 and 9.1 mg/100 ml) and significantly (P<0.05) lower for the higher level of offer of *Stylosanthes hamata* (4.2; 4.5; 4.6 and 4.7 mg/100 ml) for all the four time periods post feeding ie 0 - 6 h. The blood urea-N levels also increased with time for all the foliages and their offer levels.

4.3.7 *Excretion of urinary PD and microbial N supply in sheep*

Table 4.6 shows the values for digestible organic matter fermented in the rumen (DOMR), microbial N (MN) yield, efficiency of microbial N supply (EMNS), absorption and urinary excretion of purine derivatives (PD) among the four dietary treatments. DOMR was significantly (P<0.01) different between the two foliages and also between the two levels of offer of *Samanea saman* and *Stylosanthes hamata* foliages. Microbial nitrogen reaching the duodenum was significantly (P<0.05) different between the two foliages and also between the two levels of offer for both.

Table 4.6 Urinary excretion of purine derivatives in sheep fed the experimental diets.

	T_{SA360}	T_{SA480}	T_{ST360}	T_{ST480}	LSD	Sig.	Fx L
DOMR (g d^{-1})	498.03^{c}	577.0^{a}	487.19^{d}	513.05^{b}	10.05	* *	0.001
MN (g d^{-1})	15.94^{c}	18.46^{a}	15.59^{d}	16.42^{b}	0.321	* *	0.001
EMNS (g N kg^{-1} DOMR)	32.01^{a}	31.99^{c}	32.00^{b}	32.00^{b}	0.002	*	0.002
P_a (mmol d^{-1})	21.93^{b}	25.39^{a}	21.44^{c}	22.59^{a}	0.441	*	0.001
PD_e (mmol d^{-1})	20.42^{c}	23.33^{a}	20.01^{d}	20.97^{b}	0.371	*	0.001
A_e (mmol d^{-1})	17.35^{c}	19.83^{a}	17.01^{d}	17.83^{b}	0.316	*	0.001
UA_e (mmol d^{-1})	3.06^{c}	3.50^{a}	3.00^{c}	3.15^{b}	0.056	*	0.002

NS, Non-significance, P>0.05; *, P<0.05; **, P<0.01; LSD, Least significant difference. T_{ST}, treatments with *Stylosanthes*; T_{SA}, treatments with *Samanea*.
$^{a, b, c, d}$means within rows with different superscripts differ significantly (p<0.05).
DOMR, digestible organic matter fermented in the rumen. MN, microbial N. P_a, purine absorbed. EMNS, efficiency of microbial N supply. PD_e, purine derivative excreted. A_e, allantoin excreted. UA_e, uric acid excreted.

MN production was significantly (P<0.01) higher (18.46 g d^{-1}) for T_{SA480} and significantly (P<0.01) lower (15.59 g d^{-1}) for T_{ST360}. The EMNS was similar (P>0.05) for the two levels of offer for *Stylosanthes hamata* and significantly (P<0.05) higher for the lower level of offer of Samanea saman. Urinary allantoin excretion in sheep supplemented with the higher level of *Samanea saman* was significantly (P<0.05) higher (19.83 mmol d^{-1}) and significantly (P<0.05) lower (15.59 mmol d^{-1}) for T_{ST360}. Urinary allantoin excretion was significantly (P<0.05) different between all the treatments. Urinary uric acid excretion was significantly (P<0.05) higher for T_{SA480} (3.50 mmol d^{-1}) and significantly (P<0.05) lower for T_{ST360} (3.00 mmol d^{-1}).

The purine derivative excretion was significantly ($P<0.05$) higher for T_{SA480} (23.33 mmol d^{-1}) and significantly ($P<0.05$) lower (20.01 mmol d^{-1}) for T_{ST360}. The purine derivative absorbed followed the same trend.

4.4 DISCUSSION: EXPERIMENT 1

4.4.1 *Introduction*

Experiment 1 was designed to determine whether the potentially different rumen environments produced by the increasing levels of the foliage supplements would induce differences in the apparent digestibilities of the various nutrients in the diets, the levels of rumen NH_3–N, blood urea-N levels and excretion of purine derivatives (PD).

4.4.2 *Chemical composition of Nerica 1, Samanea* and *Stylosanthes*

The dry nature of all the four forages is typical of harvested, dried and stored forages (Chinh and Le Viet Ly, 2001). The chemical composition of Nerica 1 is comparable to the values reported by others for other rice straw varieties; there is dearth of information on the Nerica 1 rice straw as it is new. The dry matter (DM), crude protein (CP) and organic matter (OM) content of Nerica 1 is comparable to values obtained by Karbo *et al.* (2002) when urea-treated and untreated rice straw was supplemented with fonio. The crude protein content for Nerica 1 in the present study (60.6 g/kg DM) is higher than (45 g/kg DM) obtained by Attoh-Kotoku *et al.* (2007) for Nerica 1 from the same site. The variation in the CP content could depend on the field and/or fertilisation and the period of harvest (Shen *et al.*, 1998). The values for the NDF and ADF are comparable to those reported by Hue *et al.* (2008) but lower than those obtained by Jetana *et al.* (2010). The ash content was also

generally comparable to those reported by others (Man and Wiktorsson, 2001; Chinh and Le Viet Ly, 2001; Attoh-Kotoku, 2003; Jetana *et al.,* 2010). The crude protein, organic matter and NDF contents of *Samanea saman* compares favourably with values from earlier studies (Gohl, 1981, Ahn *et al*., 1989, Kaitho *et al*., 1998 and Soliva *et al*., 2008). *Samanea saman* had the lowest ash content and this might be an indication of low minerals content or it could be lower level of contamination with soil. The crude protein content of the *Stylosanthes* foliage was 202.5 g/kg DM, which was higher than that reported by Attoh-Kotoku (2003) and Hue *et al*. (2008) (162.5 and 154 g/kg DM) repectively, but comparable to the 190 g/kg DM reported by Phengsavanh and Ledin (2003) and Mupangwa *et al*. (2000). The CP of *Stylosanthes* forage is affected mainly by harvesting frequency. According to Tarawali *et al*. (2005) the CP content of *Stylosanthes* can decrease very fast from 188 g at a harvesting frequency of 2 months to 94 g/kg DM at 4 months. The CP for this study was very high as the harvest was at one year regrowth. The organic matter and NDF contents are comparable to values reported by other workers (Akinlande, 2002; Bamikole *et al*., 2004). The levels of organic matter in the feedstuffs would make available ample energy to the rumen microbes and together with the crude protein in the legumes complementing what is in the basal diet, would boost the growth of the rams. The value of sulphur in the foliages is above the levels required to maximise digestibility of fibrous carbohydrates (1 – 2 mg S/l) and to maximise microbial growth

efficiency (4 – 10 mg S/l) (Leng, 1993). The sulphur levels present in the two foliages would help the growth of rumen fungi and boost the digestibility of the rice straw and the mature forages and subsequently boost live-weight gain (Akin *et al*., 1983). The condensed tannins content did not seem to have any negative effects on intake of the rams.

4.4.3 ***Effects of supplements on feed intake***

The mean overall pH of 6.57 obtained on all diets suggests that optimal pH conditions existed in the rumen for cellulolysis. This was reflected in the high intake of the diets similar to that obtained by Ye *et al*. (1996). When the supplement levels were increased, there was a corresponding increase in the rice straw intake (35.25 g) for the rams supplemented with *Samanea saman*; this increase was significantly ($P<0.05$) higher compared to that obtained for the rams on the *Stylosanthes* supplement (13.4 g). The intake of the supplements was also higher for the *Samanea* (111.05 g) compared to the *Stylosanthes* (57.9 g). This could be due to the easy fragmentation of the *Samanea saman* foliage compared to *Stylosanthes hamata* foliage. *Samanea saman* leaves have the characteristic to fragment easily and this is important in ruminant nutrition. Rapid reduction to particle size small enough to move out of the rumen should increase voluntary intake. With material of inherently low digestibility, increased rate of passage may be an advantage (Lowry, 1995).

4.4.4 *Effects of supplements on whole tract in vivo digestibility*

The apparent digestibility values for DM, OM, N and NDF show that all the four rumen environments were favourable. The digestibility of DM and OM were highest in rams supplemented with *Stylosanthes* at the two levels. This could be due to the rate of supply of degradable N in the rumen synchronising with the available energy supply (Colin-Schoellen *et al*., 2000). The digestibility of N was significant for the rams on T_{ST360} and lower for those on T_{SA360}. This could be due to the high level of degradable nitrogen, for T_{ST360} energising the rumen microbes thus keeping them active, which in turn increased the digestibility. The digestibility of NDF followed the same pattern, with rams on T_{ST360} having an increased NDF digestion compared to the other. The digestibility value obtained by Lowry (1995) for fallen leaves of *Samanea saman* (26.5 ± 3.9 %) were far lower than the values obtained in this study (80.25 %), bearing in mind that the N content of the senescent leaves used in the Lowry (1995) study is much lower than the freshly harvested and dried leaves used in this study.

4.4.5 *N-balance*

Nitrogen retained as a percentage of intake was greater in the T_{ST360}, T_{SA480} and T_{ST480} supplemented diets than those fed T_{SA360}. This may be due to improved synchrony among highly digestible NDF, OM and N compounds. This is in agreement with Howard *et al.* (2007) who reported that a diet

containing synchrony between carbohydrate and nitrogen compounds generally increased N retention. The higher N-efficiency for rams on T_{SA480} could be due to the high rumen degradable nitrogen and high bypass protein content. The improved N-balance for T_{SA480} could be due to its high rumen bypass protein content, which gets it digested more in the small intestines and also due to its high intake (Doyle *et al*., 1987). Beneficial effects on protein metabolism were achieved by reducing the fermentation of forage protein to ammonia in the rumen, increasing the quantity of protein digested in the small intestine and decreasing urinary N excretion. The other beneficial effects of dietary tannins cited by other authors appear to be more important for preventing excessive ruminal degradation of dietary proteins (McNabb *et al*., 1993) and improving N-digestibility and N-balance (McNabb *et al*., 1996), as seen in this study.

4.4.6 *Effect of supplementation on rumen pH, NH_3-N and BUN*

Blood urea-N was higher in the rams on the *Samanea* supplemented diets and increased with level of supplementation and also with time. The higher levels of blood urea-N for the two offer levels for *Samanea saman* could be due to their higher intake and the level of the by-pass protein, which all work together to increase the N available to the animal (Kaitho *et al*., 1998). A rumen degradable protein value of 493 g/kg DM, a by-pass protein of 507 g/kg DM and an intestinal degradable protein of 184 g/kg DM were

reported by Kaitho *et al*. (1998) for *Samanea saman* leaves. The level of NH_3-N in the rumen varied between the diets. The NH_3-N values generally obtained in the study were comparable to values reported for sheep fed cereal straws with forages of low forage value (Antoniou and Hadjipanayiotou, 1985: 7.42 mg/100 ml; Balcells *et al*., 1993b: 5.91 mg/100 ml), acacia leaves (Antoniou and Hadjipanayiotou, 1985: 6.5 mg/100 ml). Values found in this study were higher than values proposed as minimum for an optimal microbial activity for animals fed lignocellulosic materials (1.65 to 3.79 mg/100 ml) (Balcells *et al*., 1993b) and therefore are potential feed supplements.

4.4.7 ***Effects of supplementation on urinary PD and MN***

MN production was higher (18.46 g d^{-1}) for T_{SA480} due to higher efficiency of microbial protein production leading to higher urinary PD excretion by the sheep. This could also be due to the higher dry matter intake, which was expected to induce higher microbial synthesis (Makkar *et al*., 1988).

Some of the beneficial effects of tannins are efficiency of microbial protein production in the rumen and protection of feed protein from degradation in the rumen. *Samanea saman* with its tannins content improved considerably the rumen environment, which increased microbial nitrogen production leading to positive nitrogen balance. Feeding strategies need to be designed to exploit these beneficial effects for ruminant livestock.

CHAPTER FIVE

EXPERIMENT 2

The determination of the degradation characteristics of Nerica 1 and Nerica 2, *S. saman* and *S. hamata* hays in four different rumen environments.

5.1 INTRODUCTION: EXPERIMENT 2

Agricultural and agro-industrial by-products are of importance in ruminant animal production because there is little competition with humans for some of these feed resources. These feedstuffs can play an important role in providing fodder for ruminants in developing countries. However, their use in ruminant rations depends mainly on ruminal degradation of the different parts of the feedstuffs. Ruminant forages are currently described by three different features; the soluble fraction, insoluble fraction and the rate of degradation (Ørskov *et al*., 1988; Ørskov, 1991). The soluble fraction (a), commonly named washing loss, represents the water soluble components of the organic matter or the dry matter. It includes the soluble sugars and soluble compounds such as polyphenolics liberated during the fermentation process (Ly *et al*., 1997). Besides, these parameters are used for assessing the nutritive value of feeds (Ørskov, 1991; Ly and Preston, 1997). The degradation characteristics of a feed, particularly its rate of degradation, provide an estimate of its rumen digestibility, which, to a large extent,

influences intake (Attoh-Kotoku, 2003). The primary constraint to the productivity of the ruminant animal is the inefficient utilisation of the feed due to the deficiency of critical nutrients. These are nutrients that are critical to the growth of the rumen microbes to ferment the feed or those required to balance the protein/energy ratio absorbed (Singh and Schiere, 1993; El hassan *et al*., 2000 and WARDA, 2006). Within the developing countries, the basic resources for ruminant animals' production are pasture, crop residues and sometimes kitchen waste. These are generally low in total protein, fermentable nitrogen and carbohydrates, in addition to minerals and vitamins, with subsequent reduction in digestibility.

The greatest potential sources of protein feeds with fermentable nitrogen are the leguminous forages, tree foliages, their pods and seeds, which are found in the savannahs and forest areas (Singh and Schiere, 1993; El hassan *et al*., 2000 and WARDA, 2006). These leguminous foliages have a high level of fermentable energy and dry matter digestibility, and can promote higher feed intake because they are not retained in the rumen for long periods (FFTC, 2005). Multipurpose trees (MPT) have the added benefit of providing fuel, shelter, timber and also help in preventing erosion in rural communities (El hassan *et al*., 2000). *Samanea saman* and *Stylosanthes hamata* foliages have been identified as good to modify rumen environments for efficient utilisation of fibre (FFTC, 2005; Omole *et al*., 2007). During an extensive *in*

vitro screening of various leaves, seeds and fruits of tropical multi purpose shrubs and trees (MPT), to test their methane and ammonia generating potential, *Samanea saman* within the MPT leaves was found to have the lowest methanogenic potential (Soliva *et al*., 2008).

Chemical analyses in combination with *in situ* degradability could help in the preliminary evaluation of the likely nutritive value of previously uninvestigated MPT (El Hassan *et al*., 2000). The secondary metabolites (antinutritional factors) mostly found in MPTs could even be of benefit to the ruminant animal. The tannins content makes some of the MPTs possible sources of by-pass protein necessary for high animal productivity (FFTC, 2005). Forages containing saponins as secondary plant metabolites have anti protozoa activity as well as being a source of by-pass protein. Such forages may have greater nutritional merit than their nutrient content would imply (Newbold *et al*., 1997). Nerica 1 and Nerica 2 are two of the new improved rice varieties being developed (bred) for Africa. There is thus the need to investigate their suitability as ruminant feeds. *Samanea saman* is a MPT legume, which has hitherto not been exploited and therefore needs to be assessed for its suitability as a (dry season) protein supplement. *Stylosanthes hamata* has been studied extensively and is being used in this experiment as the baseline to compare *Samanea saman*, as well as assess its degradation characteristics.

The aim of this study was to investigate the effect of different supplement levels on the rumen environment, and how these different environments impact on the degradation of straws of Nerica 1 and Nerica 2, and *Samanea saman* and *Stylosanthes hamata* hays.

5.2 MATERIALS AND METHODS: EXPERIMENT 2

5.2.1 *Location of experiment*

This study was carried out at the Livestock Section of the Department of Animal Science, K.N.U.S.T. Kumasi, Ghana. The detailed location of the study has been described in Section 3.2.

5.2.2 *Sample preparation*

The plant protein sources, *Samanea saman* and *Stylosanthes hamata* whole leaves were harvested and shade dried for three days and the Nerica 1 and Nerica 2 rice straws (Section 3.3) were sun dried and chopped into 4-6 cm lengths before feeding.

5.2.3 *Experimental design and treatment used*

Four rumen fistulated Djallonké rams, with an average weight of 25 kg, were used for the degradability studies in a Randomised Complete Block Design (RCBD), in a 2 x 2 factorial arrangement of treatments. The factors were 2 types of foliage and 2 levels of offer (4 treatments), with the periods as blocks. Two levels each (360 and 480 g) of the foliages *Samanea saman* and the *Stylosanthes hamata* were offered as supplements to create four rumen environments. The treatments were designated T_{SA360}, T_{SA480}, T_{ST360} and T_{ST480} for 360 g *Samanea saman*, 480 g *Samanea saman*, 360 g *Stylosathes hamata* and 480 g *Stylosanthes hamata* respectively. An initial 10 days were given the

animals to adjust to the diet followed by four 4-day periods for incubation of feed samples in and the withdrawal of feed samples from the rumen.

5.2.4 *Housing, Management and Feeding*

The rams were housed in individual metabolic cages that were provided with plastic buckets for water and wooden feeding troughs. The cages were cleaned and disinfected five days before commencement of the study. The animals were given Ivermectin (0.2 mg kg^{-1}), an anthelmintic, that takes care of both internal and external parasites before the commencement of the study.

At the start of the experiment, the rams were individually weighed, placed in metabolism cages and allowed *ad libitum* access to water. The animals were offered either 360 or 480 g of the supplements, *Samanea saman* and *Stylosanthes hamata* and the basal diet Nerica 1 *ad libitum* (1000 g) at 09.00 hrs daily throughout the experiment. The rams were fed once a day and the feed samples were weighed before being supplied.

5.2.5 *Dry matter degradability determination*

Each ram was offered Nerica 1 rice straw and water *ad libitum* during a 10-day adaptation period. The animals were each fed with one of the supplement s T_{SA360}, T_{SA480}; T_{ST360} or T_{ST480} in addition to the basal diet of Nerica 1 rice straw. A total of 2.5 g of shade-dried samples (milled through a

2 mm sieve size) each of *Samanea saman*, *Stylosanthes hamata*, Nerica 1 and Nerica 2 was weighed into nylon bags measuring (8.2 x 15.3 cm, pore size 40 µm) and incubated in the rumen of the rams.

Five of the nylon bags containing the feed samples, *Samanea saman*, *Stylosanthes hamata*, Nerica 1 and Nerica 2 were randomly assigned to each of the four rams for incubation ie five bags/animal. The bags were placed deep into the rumen. The bags were introduced into the rumen through the cannula by tying the bags to a nylon tube using rubber bands. A nylon cord was used to attach the tube to the cannula cap. The samples were incubated for 6, 12, 24, 48 and 72 hours, in the rumen of the four rams. The 72, 48, 24, 12 and 6 hour bags were placed into the rumen at 18.00 h of day one (1), 18.00 h of day 2, 18.00 h of day 3, 6.00 h of day 4 and 12.00 h of day 4 respectively. This method is termed sequential addition (Osuji *et al*., 1993). All the five bags were removed at the same time from the rumen of each of the four rams at 18.00 h of day 4. This method was used as it allows the rumen environment to be disturbed less frequently.

The disappearance of dry matter (DM) from the nylon bags incubated in the rumen was subsequently determined using the technique of Mehrez and Ørskov (1977). The bags, which were removed after incubation from the rumen, were each washed separately several times under a cold stream of tap water for 10-15 minutes, until the water became very clear. This was

done to remove excess ruminal contents and to stop further microbial activity. The bags were washed without detergent and by hand and subsequently dried in an oven at 60 °C for 24 hrs, placed in a dessicator for 30 minutes, and weighed. Dry matter loss was then determined. A set of bags not incubated (zero hour), but containing each of the feed samples, were also washed and dried under similar conditions to give estimates of washing value (Ørskov and McDonald, 1979).

The residues were pooled according to forage type and incubation time and then milled through a 1 mm screen for chemical analyses.

The equation of Ørskov and McDonald (1979):

$P = a + b\,(1 - e^{ct})$ was used to describe the results, where:

P = the potential disappearance of dry matter (DM) at time t;

a = rapidly soluble fraction;

b = potentially degradable but insoluble fraction;

c = rate of degradation and

e = the natural logarithm.

5.2.6 *Statistical Analysis*

The degradation coefficients of the dry matter of each of the four feedstuffs at 6, 12, 24, 48 and 72 hours incubation periods were determined by the differences between the original 2.5 g samples and the weight of the residue. Analyses were perfomed on the data obtained for the dry matter disappearance of each feedstuff using the Neway Excel (FCURVE 6) software package (Chen, 1997). Analyses of variance (ANOVA) was carried out using GenStat 2009 Library Release 12.1 DE for windows XP and differences between means were detected using the Least Significance Differences (LSD) test.

5.3 RESULTS: EXPERIMENT 2

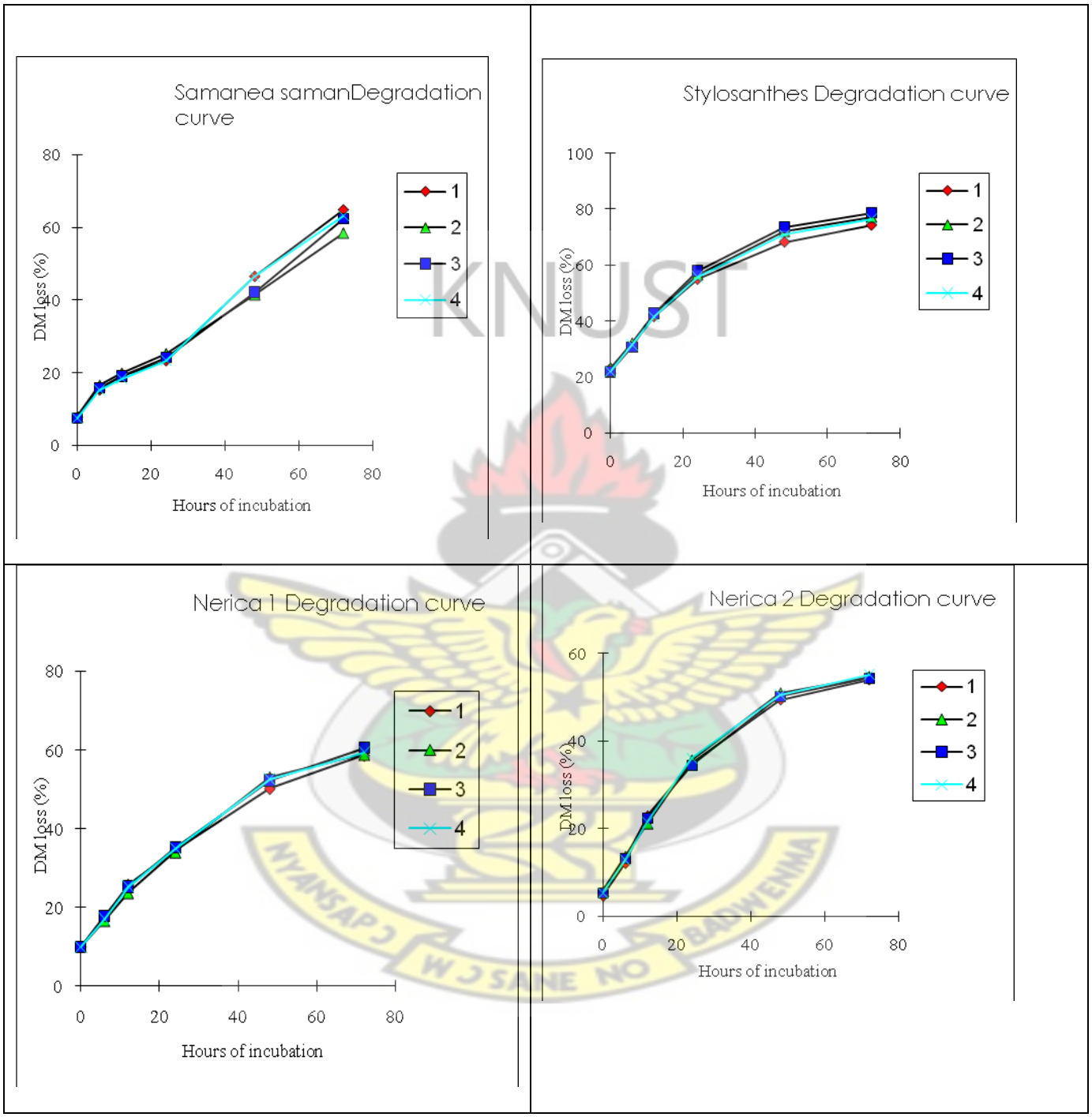
5.3.1 *Overview*

All the four rams were in good condition throughout the four periods after the initial adaptation. Their feed intake was quite appreciable. The means per experimental unit were used in the analysis.

5.3.2 *Dry Matter Disappearance of the feed samples*

Figure 5.1 shows the degradation curves of the feeds tested. After 6 h of incubation *Stylosanthes hamata* DM was the most degraded followed by Nerica 1 and subsequently *Samanea saman*. The DM loss for Nerica 1 after 6 h of incubation was small compared to the other feedstuffs. The degradation of Nerica 1 and *Samanea saman* followed a slow pattern between 6 and 12 h. The DM loss for Nerica 2 increased at a fast rate between 6 and 12 hours as could be seen from the gradient of that portion of the curve and equalled that of Nerica 1 from 20 h up to 30 h. The % DM loss (degradation) between the 48 and 72 h was very small for *Stylosanthes hamata*, Nerica 1 and Nerica 2 as depicted by that portion of the curves. The degradation curve for *Samanea saman* followed the trend of Nerica 1 up to 48 h but did not slow down; it continued the steep ascent up to the 72 hour where it degraded faster than Nerica 2.

Figure 5.1: Degradation characteristics of the four feed samples



*Legend; 1- $T_{ST\ 480}$,
2- T_{ST360}
3- T_{SA480}
4- T_{SA360}

Legend for *S. saman*; 1- $T_{ST\ 360}$
2- $T_{ST\ 480}$
3- $T_{SA\ 480}$
4- $T_{SA\ 360}$

*Legend for *Stylosanthes hamata*; Nerica 1 and Nerica 2 rice straws.

Table 5.1 Dry matter degradability parameters for *Stylosanthes hamata*, *Samanea saman*, Nerica 1 and Nerica 2.

	TREATMENT						P-value		
Item	T_{SA360}	T_{SA480}	T_{ST360}	T_{ST480}	lsd	Sig.	Foliage	Level	F x L
Stylosanthes hamata									
a %	22.6	22.6	22.6	22.6		NS			
b %	58.6^{c}	59.5^{b}	60.4^{a}	56.0^{d}	0.56	*	0.001	0.001	0.001
P %	81.2^{c}	82.0^{b}	83.0^{a}	78.6^{d}	0.23	*	0.001	0.001	0.001
c %/h	0.034^{b}	0.035^{b}	0.032^{c}	0.037^{a}	0.0009	*	0.930	0.001	0.001
Samanea saman									
a %	7.7	7.8	7.7	7.7		NS			
b %	83.7^{b}	83.8^{b}	85.8^{a}	80.4^{c}	0.44	*	0.001	0.001	0.001
P %	91.4^{b}	91.5^{b}	93.6^{a}	88.1^{c}	0.245	*	0.001	0.001	0.001
c %/h	0.003^{b}	0.003^{b}	0.002^{c}	0.005^{a}	0.0002	*	0.001	0.001	0.001
Nerica 1									
a %	10.0	10.0	10.0	10.0		NS			
b %	62.4^{a}	62.6^{a}	62.9^{a}	57.7^{b}	0.54	*	0.001	0.001	0.001
P %	72.3^{c}	72.6^{b}	72.9^{a}	67.6^{d}	0.18	*	0.001	0.001	0.001
c %/h	0.023^{b}	0.022^{c}	0.022^{c}	0.024^{a}	0.0003	*	0.002	0.001	0.001
Nerica 2									
a %	4.4	4.4	4.4	4.39		NS			
b %	56.3^{a}	56.4^{a}	56.5^{a}	54.96^{b}	0.28	*	0.001	0.001	0.001
P %	60.7^{a}	60.8^{a}	60.9^{a}	59.35^{b}	0.8	*	0.036	0.018	0.009
c %/h	0.033^{b}	0.033^{b}	0.032^{b}	0.035^{a}	0.0017	*	0.275	0.054	0.032

a-Rapidly soluble fraction; b-Potentially degradable but water insoluble fraction; c-rate of degradation; P- Potential disappearance of dry matter; LSD-Least significant difference; NS-Non significance, P>0.05; *, P<0.05.
$^{a, b, c, d}$means within rows with different superscripts differ significantly (p<0.05).

Table 5.1 shows the degradation of the feedstuffs in the 4 rumen environments. The washing loss values for all the feed samples were similar for each across the 4 different rumen environments created ie (22.6 %) for *Stylosanthes hamata*, (7.7 %) for *Samanea saman*, (10 %) for Nerica 1 and (4.4 %) for Nerica 2. The rate of degradation (rate constant, c) was significantly (P<0.05) higher for T_{ST480} for all the feed ingredients (0.005, 0.037, 0.024 and 0.035 %/h) than the others. The potentially degradable but water insoluble

fraction (b %) and the potential disappearance of dry matter (P %) were significantly (P<0.05) lower for T_{ST480} when compared for all the feed samples their levels of offer. The potential disappearance of dry matter (P %) was significantly (P<0.05) higher for the lower level of offer of *Stylosanthes hamata* for *Samanea saman*, *Stylosanthes hamata* and Nerica 1. The (P %) was however similar for the offer levels, T_{SA360}, T_{SA480} and T_{ST360} for Nerica 2. The (P %) for *Samanea saman* DM was similar for the two offer levels of *Samanea saman*. The (P %) for Nerica 1 was significantly (P<0.05) different across the two offer levels of *Samanea saman*. The potential disappearance of *Stylosanthes hamata* DM in the two rumen environments created by *Samanea saman* foliage supplements were significantly (P<0.05) different.

The potential degradable but water insoluble portions of Nerica 1 and Nerica 2 DM were similar for T_{SA360}, T_{SA480} and T_{ST360} rumen environments. The (b %) for *Stylosanthes hamata* DM was significantly (P<0.05) different for T_{SA360}, T_{SA480} and T_{SA360}. The rate constant (fraction/h) values were significantly (P<0.05) lower for *Samanea saman* DM compared to the other feedstuffs. There was no lag time for *Samanea saman* in any of the 4 rumen environments. There was lag time (0.4, 0.5, 0.3 and 0.5 h) for *Stylosanthes hamata* DM at all the 4 levels of offer (T_{SA360}, T_{SA480}, T_{ST360} and T_{ST480}). Nerica 1 had a lag time of (0.3 and 0.2 h) for T_{SA360} and T_{SA480} and Nerica 2 also had a lag time of (0.1 and 0.1 h) for T_{SA480} and T_{ST360}. The effective degradability at

an outflow rate (fraction/h) of 0.02 was 45.8, 59.8, 43.4 and 39.5 for *Samanea saman, Stylosanthes hamata*, Nerica 1 and Nerica 2 respectively. The potential disappearance of dry matter was highest for *Samanea saman* (91.15 %) followed by *Stylosanthes hamata* (81.2 %), Nerica 1 (71.35 %) and Nerica 2 (60.44 %). When it came to the foliage levels, the *Stylosanthes hamata* 360 (T_{ST360}) and 480 (T_{ST480}) rumen environments had significant ($P<0.01$) effects on all the feedstuffs.

5.4 DISCUSSION: EXPERIMENT 2

5.4.1 *Introduction*

The same set of sheep used for Experiment 1 was used in Experiment 2. The present study was to determine the effect of the 4 rumen environments on the degradation characteristics of *Samanea saman*, *Stylosanthes hamata,* Nerica 1 and Nerica 2 rice straws.

5.4.2 *The effect of the rumen environments on the degradation parameters*

The washing loss was lowest in Nerica 2 (4.4 %), followed by *S. saman*, which is a legume (7.7 %), Nerica 1 (10.0 %) and *S. hamata* (22.6 %). A study by Lowry (1995) had a washing loss of 26.0 ± 4.8, when fallen milled leaves of *S. saman* were soaked in water for 24 h, which is higher than the value obtained in this study. This could be due to the difference in the length of time the two samples were exposed to water ie 24 h as opposed to 15 minutes under running tap water. It could also be due to the milled fallen leaf samples fragmenting much more readily than the harvested samples. The rate of disappearance of each feedstuff increased progressively as incubation period increased in general, although the rate was faster for *S. hamata* foliage and Nerica 2 rice straw; this did not agree with the observations of Babayemi *et al*. (2002) who observed a faster rate for *S. hamata* and a slower rate for straws. This could be due to the stage of maturity of the forages used. Nerica 1 had a higher percentage degradability of its water insoluble dry matter

compared to that of Nerica 2, which might be due to the slightly higher crude protein content coupled with its fibre being more degradable. The variations in the degradability of the different feedstuffs could be due to differences in the quality and content of fibre (Smith *et al*., 1989).

The legume type and the level of offer did affect the rate and the *in situ* dry matter disappearance. The rate of degradation was very slow for *S. saman* ie (0.325 % per hour) compared to an average of 3.45 % for *S. hamata*. The rate constant for Nerica 2 was 3.33 % against an average of 2.28 % for Nerica 1 straw. The faster rate for Nerica 2 could be attributed to the low potentially degradable (insoluble) fraction values (i.e. what has to be degraded is very small and thus was accomplished in a short time) obtained compared to the other three feedstuffs (Yáñez *et al*., 2004). The lower rate for Nerica 2 could be due to its high content of potential disappearance fraction which needs time to get degraded (Hvelplund and Weisbjerg, 2000).

The lag phase observed for some of the forages is that period in, which there was no net disappearance of substrate. This is in part due to the microbial invasion of new substrate material, for example, cell walls. In this study, the *S. saman* did not have any lag phase. Nerica 1 had a lag phase for two of the treatments but the periods were short (0.1 h each). *S. hamata* had a lag phase for all the 4 treatments, with the time periods ranging from, 0.3 - 0.5 h. The

zero lag time for *S. saman* leaves could be due to the peculiar ease of fragmentation that deciduous tree leaves have (Kennedy and Lowry, 1996). The lag phase for the *S. hamata* legume could also be due to the use of older plants almost to the point of leaf shattering, thus having tougher fibre content. The washing loss and the percentage degradability values at 48 h for *S. hamata* in this study were lower than values obtained by Aina *et al*. (2004). This could be due to their use of young and tender material, which had less fibre. Degradability results after 24 h incubation obtained by Lowry (1995) for *S. saman* (47.8 ± 0.04) was higher than the value obtained in this study (24.9) for the 24 h. While *S. saman* tree leaf was not as palatable as fallen Siris leaf sheep achieved a substantial intake of *S. saman* in the study by Lowry (1995); this was despite its low digestibility compared to fallen Siris leaf. The substantial intake of *S. saman* by sheep was also observed in this present study. This is consistent with the model discussed above that the material rapidly fragmented to particles small enough to pass out of the rumen, but that these particles were of low digestibility.

The washing loss values obtained in this experiment are in the range of the dry matter loss obtained by Ly and Preston (1997) and Ly *et al*. (1997) for leaves of tropical trees and shrubs. The difference between feedstuffs could be due to their individual characteristics, mainly species and stage of maturity (Arhab *et al*., 2007). The foliage type and their levels had substantial

effects on the degradability of the water insoluble portions of the feedstuffs and on their rates of degradation. The *S. saman* was fragmenting whether the levels of supplement were low or high, as observed by Lowry (1989). The rate of degradation for *S. saman* was comparable to values obtained by Ahn *et al*. (1989). The *in sacco* DM degradability values obtained for *S. saman* in this study for water insolubles (91.6 %) were higher than values (63.4; 69.3 %) obtained for goats (Ahn *et al*., 1989; Ash, 1990). This might be due to the different ecologies of the two studies and the differences in maturity of the leaves.

There were differences in the degradation parameters for the Nerica 1 and Nerica 2 rice straws. The degradation curve patterns were similar for *S. saman* and Nerica 1. The same could be said of *S. hamata* and Nerica 2. The nutrient profiles of the feedstuffs could be a factor though at a glance they are all very different. The *S. saman* curve pattern even after 48 h still had a steep gradient while the other 3 feedstuffs had more gentle gradients. This still affirms the works of Lowry (1989) and Ahn *et al*., (1989) on the complete crumbling (degradation) of *S. saman* foliage in the rumen.

This study shows that *Samanea saman* had the highest potential disappearance of dry matter in the rumen and the slowest degradation rate meaning a substantial amount would be degraded over a period of time and

because it has the characteristic to crumble very easily, a substantial amount would also move to the small intestines to be digested providing the flux of essential amino acids to the small intestines and increase in the absorption of Eaa into the blood and subsequently better animal performance. *Stylosanthes hamata* degrades very fast in the rumen from its rate constant value and has an appreciable amount of (P) thus a high amount of its N would be degraded in the rumen energizing the microbes for high fibre fermentation leading to improved performance of animals. Nerica 1 has a substancial amount of (P) and a slower rate compared to the Stylo and would provide energy over a longer period for microbial activity whereas Nerica 2 would provide energy that would be degraded faster over a short period.

CHAPTER SIX

EXPERIMENT 3

Ruminal particulate passage rate of two improved varieties of rice straws, Nerica 1 and Nerica 2 and *Samanea saman* and *Stylosanthes hamata* foliage hays.

6.1 INTRODUCTION: EXPERIMENT 3

Particulate rate studies seek to unravel what happens after degradation in the rumen. That is how fast or how slow the degraded materials are moved out of a compartment of the ruminant stomach to another and how long they stay in the rest of the gut before being absorbed and/or excreted. The passage rate could affect intake and the microbial flora, and this influences the productivity of the ruminant livestock. The performance of an animal can be determined from the digestibility of the feed and the quantity of feed ingested. Digestibility can be determined from the rumen pool size, rates of digestion and the passage of potentially digestible and indigestible feed components. Feed intake in ruminants consuming fibrous forage is primarily determined by rumen fill, which in turn is directly related to the rate of digestion and passage of fibrous particles from the rumen (Van Soest, 1994). The disappearance of feed components from the rumen depends on their digestion at a specific rate and their passage at a specific rate (Zinn and

Ware, 2007). These rates are affected when diets consisting of crop residues are consumed due to the nutrient deficiencies, level of intake, chemical composition and particle size (Zinn and Ware, 2007). Differences in these rates among forages are due probably to the fibre composition and intake. End products of fermentation in the rumen and the rates of digestion and passage affect production from a given diet.

Rates of digestion and passage are thought to be of greater importance with fibrous diets as GIT fill might limit the intake of such diets. The rates of passage are also important for concentrate diets as dysfunctions such as lactic acidosis could occur (Galyean and Owens, 1988).

The indigestible fraction of any feed can only disappear from the digestive tract by passage at a specific rate. The most important factor leading to differences in digestion rates and ruminal microbial populations among ruminants appears to be related to the kinetics of digesta passage (Renecker and Hudson, 1990). Roughage feeders are generally said to have longer retention times, larger gut fill and more complete digestion of forage than concentrate selectors (Hofmann, 1989). Although digestibility generally improves with longer retention time, gut fill as an outcome of longer retention may limit feed intake. Consequently, for any forage type, there is likely to be an associated optimal retention time for ruminants that graze

native forages, which have markedly different seasonal nutritive values (Jiang, 1993). *Samanea saman* (monkey pod) is a tree crop legume and though it yields a high level of forage and the foliage has a high crude protein content (Attoh-Kotoku *et al*., 2010) studies are limited regarding its use as an animal feed. There is also a dearth of information on the associative effects of the foliage on diet digestibility and passage rate in ruminants. Furthermore, not much information is available on the rates of passage of straws of new rice varieties Nerica 1 and Nerica 2 developed by IRRI/CRI recently.

The Nericas 1 and 2 are new improved varieties of rice that have been released by CRI and SARI, and preliminary work on the nutrient composition of the straws show an improvement on the crude protein content over existing varieties (Attoh-Kotoku *et al*., 2007). A lot of work has been done with *Stylosanthes hamata* in a number of feeding studies, but there is limited data regarding its passage rate in ruminants.

The objective of this experiment was to determine the passage rates, transit times (TT) and mean retention times (MRT) of the foliages *Samanea saman* and *Stylosanthes hamata*, and Nerica 1 and Nerica 2 rice straws in sheep using potassium dichromate as a marker.

6.2 MATERIALS AND METHODS: EXPERIMENT 3

6.2.1 *Location of experiment*

This study was carried out at the Livestock Section of the Department of Animal Science, K.N.U.S.T. Kumasi, Ghana. The location has already been described in Section 3.2.

6.2.2 *Sample preparation*

All the four samples comprising the two rice straw varieties, Nerica 1 and Nerica 2 (chopped into about 6 - 8 cm lengths), *Samanea saman* and *Stylosanthes hamata* were mordanted by the method of Uden *et al*. (1980). A 100 g of each of the samples to be mordanted was first weighed and washed to remove all traces of dirt. The weighed sample was placed in a stainless steel container and potassium dichromate, representing 33 % of the weight of the sample, was spread on it and distilled water was added to dissolve the marker and submerge the substrate. The container was then covered and blocks of laterite were placed on the straw as a form of load to help the samples to submerge. The mordant was left to stand overnight after which it was placed in an oven at 100 °C for at least 24 hours. This was followed by thorough washing of the baked material until the water was faintly coloured. The washed mordanted feed was subsequently transferred into a solution of ascorbic acid at a concentration of 1:2 (w/w) and left to stand for about one hour. The feed was washed several times in running water and then dried in

the oven at 65 °C for 48 hours. The mordanted feed was then stored in plastic bags until required for the passage study in the rams.

6.2.3 *Experimental design*

Four rumen fistulated Djallonké rams, with weights ranging between 27 - 29 kg, were used for the passage studies in a 4 x 4 Latin Square Design. The factors were 4 feed samples and 4 fistulated Djallonké rams. Four periods were used with 16 days per period, 10 days for adjusting to diet and 6 days for collection of grab samples.

6.2.4 *Housing, Management and Feeding*

The rams were housed indoors and kept in individual metabolic cages (0.7 x 1.9 m) for sheep. The cages were provided with plastic buckets for water and wooden feeding troughs. The cages were cleaned and disinfected before the commencement of the study. The animals were offered 360 g of the supplement *Stylosanthes hamata* after which 1.5 kg of the basal diet, Nerica 1 was supplied. The rams were fed once a day at 09.00 hrs.

6.2.5 *Marker Administration*

The four rumen fistulated Djallonké rams were used in the chromium mordant study. A dose of twenty grams (20 g) of each of the chromium-mordanted feeds, *Samanea saman* and *Stylosanthes hamata* foliages, Nerica 1

and Nerica 2 straws, (refer to section 6.2.2) was administered through the cannula of each sheep. The feeds were randomly assigned for each period and one feed was dosed per animal per period. The periods were separated by at least 10 days to ensure that the Cr from the previous dosing had been eliminated from the gut. Rectal grab samples were taken at specified periods within 144 hours. The samples were collected at 12 hour intervals for the first day (first 24 hours) with an initial zero hour collection. The next twelve hours, had 3 hour collection intervals followed by a 12 hour collection. This was followed by 6 hour intervals for the next 24 hours, then a 12 hour collection. Finally, the collection was done 24 hourly for the last three days. Fifty six grab samples were collected for each of the four feed mordants (straws and foliages) dosed. The samples were dried at 65 °C in an oven for 48 hours as collected. The dried samples were milled through a 1 mm mesh sieve and stored in covered plastic containers prior to chromium determination/analysis.

6.2.6 *Determination of Chromium in Feed and Faeces*

A milled grab sample of 0.2 g was weighed into a digestion tube followed by the addition of 1 ml 60 % perchloric acid, 2 ml concentrated nitric acid (HNO_3) and 2 ml concentrated hydrochloric acid (HCL). The acids were added in the order of concentrated hydrochloric acid, followed by 60 % perchloric acid and then concentrated nitric acid. The digestion lasted for

about two hours in a Gallenkamp thermostatic controlled water bath until the solution turned yellowish. The contents of the digestion tubes were emptied into smaller tubes and deionised distilled water washings of the digestion tubes were added to obtain uniform solutions of 10 ml each. This was left to stand overnight.

The determination of chromium was carried out by Atomic Absorption Spectrophotometry (372 nm) with the aid of a Perkin Elmer 1100B Atomic Absorption Spectrophotometer at the laboratory of the Anglo Gold Ashanti Mines in Obuasi.

The graphical method of Grovum and Williams (1977) was used for the estimations of the passage rates (k_1 and k_2), transit time (TT) and mean retention times (MRT) of the foliages, *Samanea saman* and *Stylosanthes hamata* and Nerica 1 and Nerica 2 rice straws.

The equation:

$\log_e Y = \log_e A - kt$, was used for estimation of the parameters.

Where:

$\log_e Y$ = natural logarithms of chromium concentration in faeces at zero time

$\log_e A$ = natural logarithms of chromium concentration in faeces

after a given time and

t = time after marker administration.

Regression analyses of the natural logarithm of the chromium concentration in faeces with time after dosing (Grovum and Williams, 1977) was performed on the linear portions of the descending curves. The regression coefficients and the Y-intercepts of the descending curves correspond to the slowest digesta fractional passage rate constants (k_1) in the fore gut and A_1 respectively. Regression analyses of the natural logarithm of the residual chromium concentrations in faeces with the collection times were performed on the linear portions of the residual curves. The regression coefficients and the Y-intercepts of the residual curves correspond to the second slowest rate constant (k_2) in the hind gut and A_2 respectively.

The time of first appearance of the marker in the faeces (TT) and the time the digesta spends being fermented in the rumen and the hind gut for all the four feedstuffs were subsequently calculated as:

$$TT = \frac{(A_2 - A_1)}{(k_2 - k_1)}$$

$$t_{½} = \frac{0.693}{k}$$

where:

k = either k_1 or k_2

The mean retention time (MRT) for particulate markers through the entire gastrointestinal tract was estimated for the foliages according to Grovum and Phillips (1973). ie

$$MRT = \frac{1}{k_1} + \frac{1}{k_2} + TT$$

6.3 RESULTS: EXPERIMENT 3

6.3.1 *Overview*

All the animals were in good health throughout the entire period of the experiment and consumed the rice straw basal diet.

6.3.2 *Mean digesta retention times and gastrointestinal DM content*

Elimination curves describing the passage of particulate matter of *Samanea saman* leaves through the gastrointestinal tract of sheep is shown in Figure 6.1. The R^2 values obtained for *Samanea saman* were 0.815 and 0.768 for the descending phase and the residual respectively. The Y- intercepts were 5.832 for the descending phase and 6.069 for the residual.

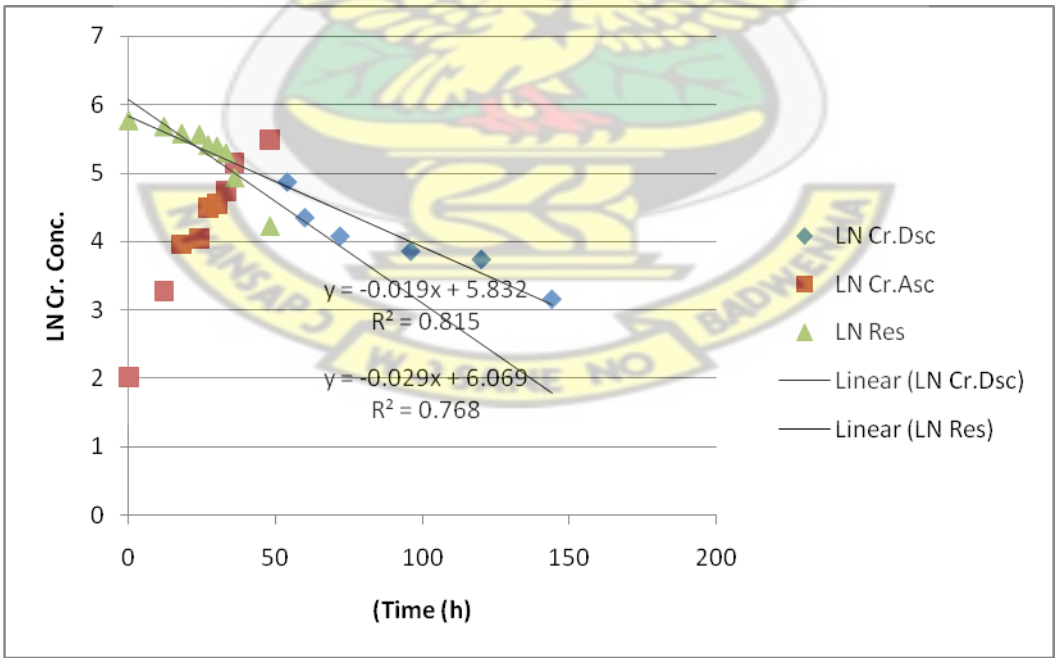


Figure 6.1 Ruminal passage rates of *Samanea saman*

The elimination curves describing the passage of particulate matter of the forage *Stylosanthes hamata* through the gastrointestinal tract of sheep is shown in Figure 6.2. The R^2 values obtained for *Stylosanthes hamata* were 0.855 and 0.736 for the descending phase and the residual respectively. The Y- intercepts were 6.672 for the descending phase and 6.946 for the residual.

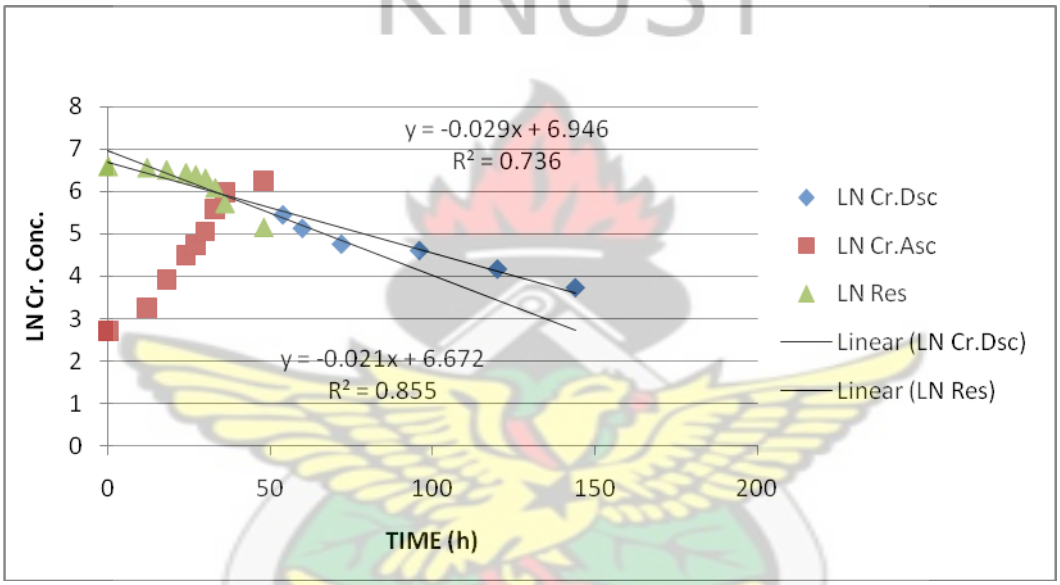


Figure 6.2 Ruminal passage rates of *Stylosanthes hamata*

Elimination curves describing the passage of particulate matter for Nerica 1 rice straws through the gastrointestinal tract of sheep is shown in Figure 6.3. The R^2 values for the descending and the residual slopes for Nerica 1 were 0.789 and 0.561 respectively. The Y- intercepts were 7.193 for the descending phase and 7.579 for the residual.

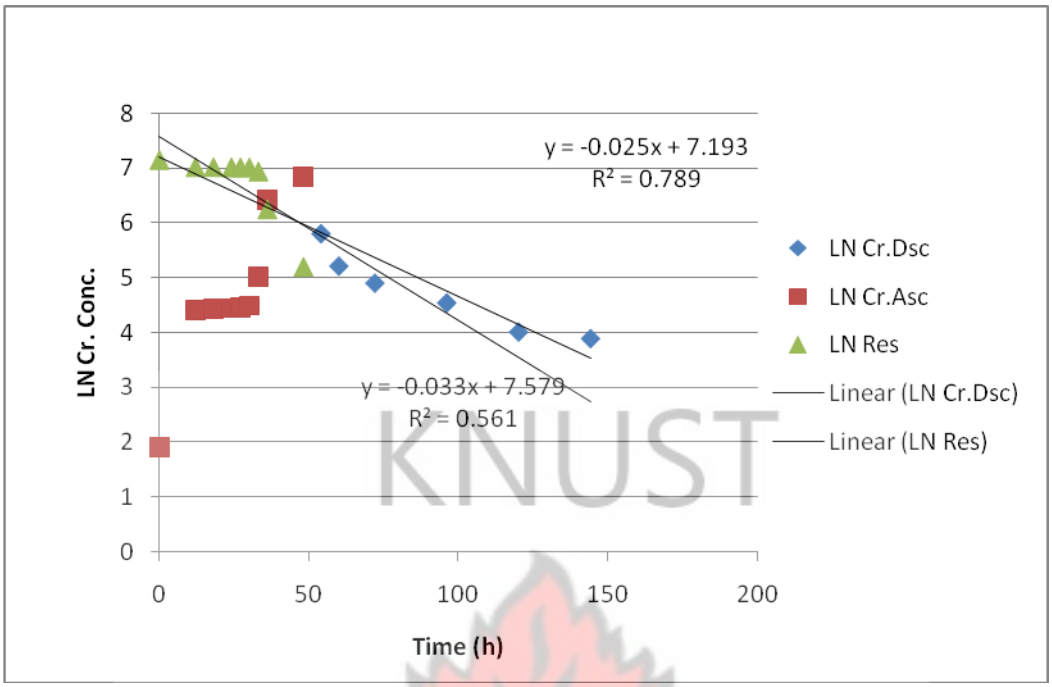


Figure 6.3 Ruminal passage rates of Nerica 1

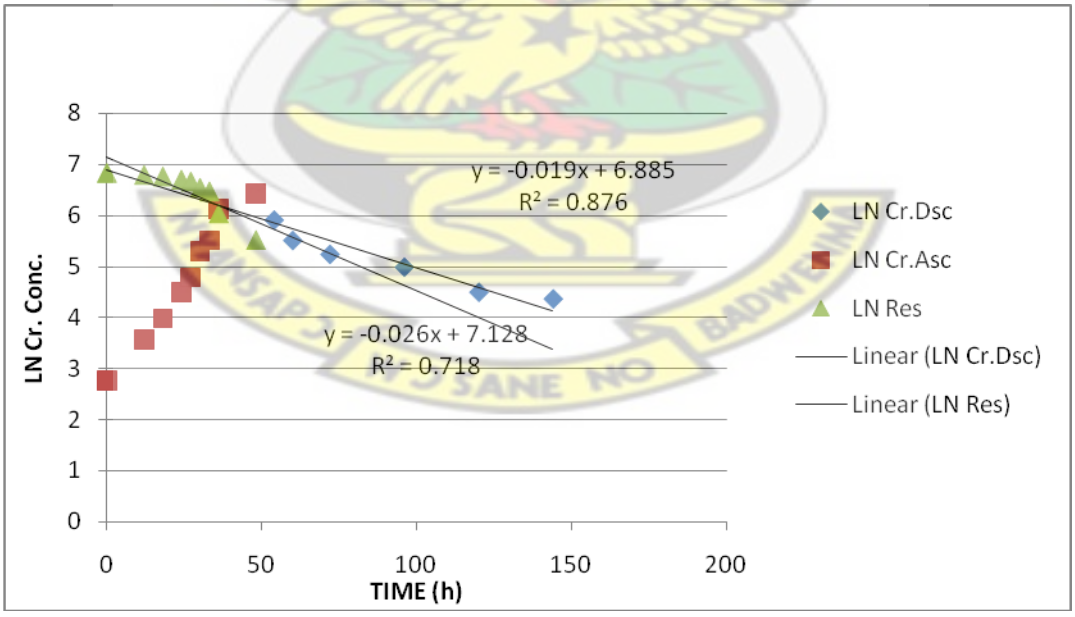


Figure 6.4 Ruminal passage rates of Nerica 2

Figure 6.4 shows the elimination curves describing the passage of particulate matter for Nerica 2 rice straws through the gastrointestinal tract of sheep. The R^2 values for the descending and the residual slopes for Nerica l were 0.876 and 0.718 respectively. The Y- intercepts were 6.885 for the descending phase and 7.128 for the residual.

Table 6.1: Y-intercept and regression figures for the descending and residual curves

	Descending Curve					Residual Curve			
	Intercept		$Slope_1$	R^2		Intercept		$Slope_2$	R^2
Samanea	5.832		0.019	0.815		6.069		0.029	0.768
Stylo	6.762		0.021	0.855		6.946		0.029	0.736
Nerica 1	7.193		0.025	0.789		7.579		0.033	0.561
Nerica 2	6.885		0.019	0.876		7.128		0.026	0.718

Table 6.1 shows the Y-intercepts and the regression coefficients of the descending and residual curves of the two rice straw varieties and the two foliages *S. saman* and *S. hamata*. These were fitted into the equations of Grovum and Phillips (1973) and Grovum and Williams (1977) for the calculation of the passage parameters. Table 6.2 shows the passage parameters derived from the regression analyses on the descending and residual slopes in Figures 6.1 – 6.4. Particulate matter MRT was significantly

(P<0.05) different between *Samanea saman* (110.81) and Nerica 2 (125.8). The MRT was similar (P>0.05) for *Samanea saman*, *Stylosanthes hamata*, and Nerica l ie 110.81; 116.35 and 118.55 respectively. The transit time (TT) was similar (P>0.05) for *Stylosanthes hamata* and Nerica 2 (34.25 and 34.71 h). It was however, significantly (P<0.05) lower for the *Samanea saman* foliage and significantly (P<0.05) higher for Nerica l as can be seen from the values (23.70 and 48.25 h respectively).

Table 6.2 Passage parameters for the four feedstuffs

	Foliage		Rice straw				
Item	Samanea	Stylo	Nerica l	Nerica 2	SEM	Sig.	p-v
TT (h)	23.70^{d}	34.25^{c}	48.25^{a}	34.71^{b}	0.054	*	0.001
k_1/h	0.019^{c}	0.021^{b}	0.025^{a}	0.019^{c}	0.0007	**	0.001
k_2/h	0.029^{b}	0.029^{b}	0.033^{a}	0.026^{c}	0.0007	*	0.001
t½ (h)	36.47^{a}	33.00^{b}	27.72^{c}	36.47^{a}	0.324	*	0.001
t½ (h)	23.90^{b}	23.90^{b}	21.00^{c}	26.65^{a}	0.651	**	0.001
MRT (h)	110.81^{d}	116.35^{c}	118.55^{b}	125.80^{a}	0.031	**	0.001

NS, Non-significance, P>0.05; *, P<0.05; **, P<0.01; SEM, Standard error of the mean.

$^{a, b, c, d}$means within rows with different superscripts differ significantly (p<0.05). TT-Transit time; k_1, k_2-Passage rate constants for the rumen and hind gut respectively; MRT-Mean retention time; t½, time spent by digesta in each of the compartments.

The rate of passage was significantly different for the foliages *Samanea saman* and *Stylosanthes hamata*. The rate of passage in the rumen (k_1) was not significantly different between *Samanea saman* and Nerica 2 which had the

same value of 0.019/h; but significantly (P<0.05) different between *Stylosanthes hamata* and Nerica l (0.021 and 0.025/h). The rate of passage in the hind gut (k_2) was similar for *Samanea saman* and *Stylosanthes hamata* (0.029/h) whilst being significantly (P<0.05) different for the straws, Nerica l and Nerica 2 (0.033 and 0.026/h). The length of time (t½) the digesta stayed in the rumen followed the same pattern as the rate of passage in the rumen; there was significant (P<0.05) difference between the *Samanea saman*, *Stylo* and Nerica l (36.47; 33.00 and 27.72) but the values for Nerica 2 and *Samanea saman* were similar (36.47). The value for the t½ in the hindgut was similar for *Samanea saman* and *Stylosanthes* (23.90) and significantly different for Nerica 2, the foliages and Nerica 1 (26.65, 23.90 and 21.00).

6.4 DISCUSSION: EXPERIMENT 3

There is dearth of information on passage rate parameters of the feedstuffs assessed in the present study. The MRT is said to be the single most useful measure of rate of passage (Warner, 1981). From literature there have been calls for more research into factors that affect the fractional rumen outflow rate of ruminant feeds (Offer and Dixon, 2000). Differences in the elimination pattern of particle markers were apparent from the overall MRTs obtained. The volume of forage that an animal can process depends largely on the refractory properties of the digesta and the amount of time it spends in the gut (Robbins, 1993). This is usually different for solutes (e.g. cell content) and particles (e.g. fibrous content) (Munn and Dawson, 2006). The *Samanea saman* forage had the shortest transit time (TT) of 23.70 h and this could be explained by the observation made earlier that it fragments readily into small particles, and this may have influenced its rapid movement in the rumen, with little digestion (Lowry, 1995). *Samanea saman* is the only feedstuff with zero lag time in the present degradation studies (Section 5.3.2). The longest TT of (48.25 h) was observed for Nerica l and this could be explained by the low degradation rate and a lag time, which allowed invasion of the material by rumen microbes and was subsequently degraded. Transit times for *Stylosanthes hamata* and Nerica 2 had similar values, which could be due to the maturity of the *Stylosanthes hamata* foliage which implies a high fibre content that need to be broken down before it can pass through the rumen.

Both *Stylosanthes hamata* and Nerica 2 had similar content of potentially degradable but water insoluble fractions in addition to lag times ranging from 0.1 - 0.425 h, which all add up to increase the transit time.

Samanea saman and Nerica 2 had the slowest rate of passage and spent the longest time in the rumen compared to the Stylo and Nerica 1. This could allow for a longer contact time with the microbes thus providing more digestible dry matter. These parameters would subsequently inform the stockman in formulating mixed rations. A decrease in particle size facilitates passage of feed particles from the rumen. Concievably, increasing the digestibility of an ingredient such as rice straw would accelerate particle size reduction and thereby allow for faster passage from the rumen. The mean retention time (MRT) for Nerica 2 was longer compared to the other three feedstuffs and this could be due to the refractory nature of the fibre, which could only be partially degraded as it has a very low potentially degradable content in addition to a low washing loss and an average lag time of 0.25 h, as observed in the degradability studies (Section 5.3.2). Generally, the rate of passage of particulate matter was high for all the feedstuffs in the hindgut compared to the passage in the rumen. This was also manifested in the time the feeds spent in the rumen and the hindgut. More time was spent in the rumen compared to the hindgut due to the lag time observed for most of the

feedstuffs in the rumen, which allowed for some degradation and fermentation to take place before passage to the hindgut.

Only limited information from comparative studies is available concerning particulate passage rate in sheep fed *Samanea saman*. Results from passage studies vary due to methodological differences (type and dose of the marker), nature of the diet and feeding conditions (Watson and Norton, 1982; Katoh *et al*., 1988; Domingue *et al*., 1991). The positive effect of forage inclusion in diets on particulate rumen outflow rate has been linked with increased rumination and saliva flow, which affects reticular motility and rumen osmolarity (Froetschel, 1995; Valdes *et al*., 2000) and do increase rumen particulate outflow rate. The rate could also be linked to mechanical stimulation of propulsive movements of the reticulo-rumen. Another factor, which affects the rate, is the positive relationship between digesta weight and the duration of reticular contraction (Okine *et al*., 1989). The relative ease of fragmentation is important in ruminant nutrition suggesting that it was possible to have low digestibility associated with a relatively high intake, an effect probably linked with the relatively ease of fragmentation of deciduous leaf material. When this is combined with a greater rate of passage, due to easier fragmentation, it would seem that these species could supply digestible organic matter at a greater rate (Lowry, 1995). The quality of the NDF is reflected in the turnover rates of the fibre fractions. Turnover rate of

pdNDF (potentially digestible NDF) is much faster than that of iNDF (indigestible NDF) because pdNDF disappears from the rumen both by digestion and passage whilst iNDF can disappear only by passage (Rinne *et al*., 2002; Huhtanen *et al*., 2006). The above could be used to explain the longest mean retention time for Nerica 2. Potentially Nerica 2 had about 40 % of its DM being non degradable thus delaying its passage through the gut. Generally the fractional passage rates were lower for the rumen when compared to the rates in the hind gut. The time available for fermentation of the feedstuffs in the rumen was however longer than the time available for digestion in the hind gut.

The implications of this study on passage parameters are that the four feeds could be fed at different levels considering their passage rates and MRTs. For livestock feeding programmes; it would inform the stockman in formulating feed packages for his animals ie the different quantities in a mixed ration with the knowledge of the average time each feed ingredient would spend in the gut. A greater proportion of *S. saman* DM, would be digested *in vivo* as a consequence of a slower rate of digestion or DM passage in the rumen.

CHAPTER SEVEN

EXPERIMENT 4

The effects of feeding rice straw from two improved varieties with *Stylosanthes hamata* supplementation on the growth performance of young Djallonké rams.

7.1 INTRODUCTION: EXPERIMENT 4

The major constraints facing stockowners in increasing the productivity of ruminant livestock under tropical conditions are the quality and quantity of feed and fodders available during the long dry season. This situation leads to slow growth rates, poor working performances and ill-health (Thu and Preston, 1999). The feedstuffs often provide inadequate energy, protein, minerals and vitamins to support optimal animal productivity (Reed *et al*., 1990). In order to sustain the productivity of small ruminant livestock in Ghana and thus increase the income of small-scale sheep farmers, there is the need to develop a feeding system based on a low-cost basal diet (Attoh-Kotoku, 2003).

Rice straw is an abundant by-product of (paddy) rice threshing and is relatively more digestible than other straws and stovers and can be used in feeding ruminants (Adegbola, 2002). Rice straw is available all the year round in large quantities in all the regions of Ghana due to its cultivation in

both upland and valley bottoms and so can be used as the main basal diet for ruminant livestock. Rice straw though in itself has a relatively low CP value of about 4.2 % on the average (Udo and El-Harith, 1985; Nour, 1986; Osafo *et al*., 2008) and an organic matter digestibility of between 40 to 50 % (Pearce, 1984) it could be used if adequately supplemented. When fed alone, the voluntary intake is very low, which results in low intake of required nutrients (energy and crude protein) by the sheep leading to low growth rates and poor reproductive performance (Hue *et al*., 2003).

The grains of the 2 Nerica rice varieties that have been released by CRI have a 2 % increase in crude protein (CP) level when compared to the other varieties already being cultivated. Coincidentally, the same can be said for the straws, which have a slightly higher CP content when compared to the existing varieties (Attoh-Kotoku *et al*., 2007). These rice varieties are being promoted for production by farmers in Ghana. Subsequently, the straws need to be evaluated to provide comprehensive information to farmers.

A diet based on rice straw could be improved and the cost of production kept low by supplementing with non-conventional sources of protein (Prasad and Reddy, 1998) for instance protein rich foliages or legumes such as *Stylosanthes hamata*. Plant protein supplementation of such low-cost basal diet offers the opportunity to improve the productivity of lamb gimmers. Increased production of meat and milk are the obvious benefits from

strategic supplementation of ruminant livestock fed poor quality forages. The improved body condition of animals, which is a major response to balancing nutrition in dairy, meat or draft animals, also affects work performance and reproductive efficiency (Melaku *et al*., 2004). There is the need therefore to utilize alternative low-cost feeds for ruminants at such critical periods (the dry season). In general, the supplements to such diets for ruminants should include a source of fermentable N, minerals for the rumen organisms and a source of protein that is protected from degradation in the rumen but moves rapidly to the lower tract to improve the essential amino acid supply to the animal (Teferedegne, 2000).

Leguminous forages, tree foliages, their seeds and pods are by far the greatest potential source of protein meals, soluble N and minerals. When fed with pasture or straw, they provide many of the nutrients deficient in the basal forage and create a rumen environment more efficient for microbial growth, which is also often accompanied by a higher rate of digestion of the basal forages. Changes in the relative palatability of legumes and grasses will often help to maintain an adequate proportion of legume in pastures. During the wet season, ruminant animals tend to selectively graze the more competitive grass component in preference to associated legumes such as *Stylosanthes hamata* and *Macroptilium atropurpureum* (Keoghan, 1980).

Stylosanthes hamata is a leguminous species, which occurs naturally in the tropical, subtropical and temperate regions of the Americas, Africa and Southeast Asia. The crude protein content of *Stylosanthes* is on the average 170 g/kg DM, the variation is mainly due to age at harvesting (Mannetje and Jones, 1992; Tarawali *et al*., 2005). It has been used as a protein supplement and increased the growth rates when added up to 6 % of the diet DM without any negative effects on health (Chanphone and Mikled, 2003). Using *Stylosanthes hamata* as supplement for the two improved rice straw varieties, Nerica 1 and Nerica 2, might help exploit the potential of these improved rice straws as feeds for small ruminants.

The objective of this work was to determine:

1. The intake and growth performance of grower rams offered Nerica 1 and Nerica 2 rice straws supplemented with *Stylosanthes hamata*.

7.2 MATERIALS AND METHODS: EXPERIMENT 4

7.2.1 *Location of study*

The study was carried out at the Livestock Section of the Department of Animal Science, KNUST, Kumasi, Ghana, during the months of December, 2008 to February, 2009. The location of the study area has been described in Section 3.2.

7.2.2 *Source of Feeds*

The Nerica 1 and Nerica 2 rice straws were obtained from the experimental farms of the Inland/Valley Bottom Rice Development Project of the Ministry of Food and Agriculture (MOFA) at Nobewam in the Ashanti Akim District of the Ashanti Region. The *Stylosanthes hamata* was obtained from the plantations of the Department of Crop Science, KNUST. Mature leaves (one year re-growth) of *Stylosanthes hamata* were used.

7.2.3 *Experimental Design*

Forty eight (48) Djallonké rams ranging in weight from 13.8 – 15 kg and 18 months of age were obtained from Konongo and its environs. The rams were used in a 3 x 2 factorial completely randomised design feeding trial over a six-week period. The factors were two rice straw varieties (Nerica 1 and Nerica 2) and level of *Stylosanthes hamata* (240, 360 and 480 g/ram/d)

supplementation. There were six dietary treatments with eight replicates per treatment. The rams were randomly assigned to the six dietary treatments.

7.2.4 *Animals, Housing and Management*

The rams were identified by plastic ear tags and housed in individual well-ventilated pens with slated floors measuring (3 x 1 m). The pens were cleaned, disinfected and allowed to air for a week before the commencement of the study. The rams were treated with Ivermectin, an injectable, which caters for both internal and external parasites. They were adjusted to the experimental diets for 10 days.

7.2.5 *Diets and Feeding*

The *Stylosanthes hamata* was harvested and dried before being fed to the experimental animals. (Refer to Section 3.3). The rice straw was chopped into about 4 - 6 cm lengths, weighed and offered to the animals. The rams were individually offered rice straw *ad libitum* (about 1000 g) with *Stylosanthes hamata* at one of the 3 levels (240, 360 or 480 g/d). The two diets were offered in separate wooden feeding troughs and water was supplied in 10 litre plastic bowls *ad libitum*. The straw rations for each day were offered as two equal meals at 9.00 a.m. and 4.00 p.m. and the supplements were offered once a day in the morning at 8.00 a.m. The supplement constituted 19.34 – 32.43 % of the diet offered.

The pens were cleaned daily and the previous day's refusals removed, weighed and recorded daily at 8 00 a.m., before offering the next day's rations, which were also weighed and recorded. Feed intake was subsequently calculated as difference between feed offered and refusals. Samples of the straw and forage supplement fed and any refusals per treatment were bulked separately over a 7-day period and 30 % of the total refusals taken as sub-samples, milled and stored until required for chemical analyses.

7.2.6 *Growth Measurements*

The rams were weighed at the beginning of the experiment and every two weeks thereafter until the end of the 6-weeks study. The mean of the initial and final weights of the replicate rams represented the initial and final live weights. Feed and water were withdrawn overnight before weighing.

7.2.7 *Chemical Analyses*

The bulked samples of the feed offered and refusals were used for the chemical analyses. The samples were thoroughly mixed and sub-samples taken and milled to pass through a 1 mm sieve sized screen using a hammer mill (Cyclotec 1093 Sample Mill). The samples were then analysed for their contents of DM, CP, ADL, ash and AIA in accordance with the procedures of

AOAC (1990). ADF and NDF were analysed according to the method outlined by Goering and van Soest (1970).

7.2.8 *Statistical Analysis*

The data was analysed using the general linear model of Genstat Version PL20.1. Analyses of variance (ANOVA) were carried out using GenStat 2009 Library Release 12.1 DE for windows XP and differences between means were detected using the Least Significance Difference (LSD) test.

7.3 RESULTS: EXPERIMENT 4

7.3.1 *Overview*

The rams were in good health during the entire period of the study but there were 5 mortalities.

7.3.2 *Feed intake and weight change in rams*

Table 7.1 shows the live weight and feed intake of the rams. It can be seen from Table 7.1 that there was no significant (P>0.05) difference in the final weight of the rams due to the offer levels of supplement. There were no interactions between the 2 rice straw varieties and the levels of offer of *Stylosanthes hamata* as can be seen from the P-values in Table 7.1. The average daily gain was significantly (P<0.05) higher for the T_{360} for the Nerica 2 rice

Table 7.1 Effect of supplement level and straw variety on intake and ADG of rams.

Parameter	Nerica 1			Nerica 2					P-v
S. hamata offer level	T_{240}	T_{360}	T_{480}	T_{240}	T_{360}	T_{480}	lsd	Sig.	VxL
Initial weight [M], kg	14.0^{a}	14.0^{a}	13.94^{a}	14.0^{a}	14.0^{a}	14.0^{a}	0.46	NS	0.975
Final weight [M], kg	15.98^{a}	16.5^{a}	16.45^{a}	15.96^{a}	16.63^{a}	16.4^{a}	0.69	NS	0.930
Average daily gain (ADG), g	47.0^{d}	59.5^{b}	59.8^{b}	46.7^{d}	62.5^{a}	57.1^{c}	1.05	*	0.745
Initial weight [$M^{0.75}$], kg	7.24^{a}	7.24^{a}	7.21^{a}	7.24^{a}	7.24^{a}	7.24^{a}	0.18	NS	0.975
Final weight [$M^{0.75}$], kg	7.99^{a}	8.19^{a}	8.17^{a}	7.99^{a}	8.23^{a}	8.15^{a}	0.26	NS	0.931
ADG [$M^{0.75}$], g	17.9^{d}	22.6^{b}	22.7^{b}	17.8^{d}	23.7^{a}	21.71^{c}	0.39	*	0.742
Intake									
Straw (g DM/d)	629.8^{b}	644.2^{b}	603.7^{c}	624.0^{b}	665.5^{a}	606.5^{c}	20.3	*	0.165
S. hamata (g DM/d)	221.8^{c}	329.3^{b}	431.3^{a}	221.9^{c}	328.8^{b}	433.1^{a}	4.01	*	0.708
Total (g DM/d)	851.6^{c}	973.5^{b}	1035.0^{a}	845.9^{c}	994.3^{b}	1039.7^{a}	21.1	*	0.209
Straw (g DM/$M^{0.75}$/d)	87.03^{b}	89.01^{b}	83.42^{c}	86.22^{c}	91.96^{a}	83.8^{c}	3.49	*	0.244
S. hamata (g DM/$M^{0.75}$/d)	30.67^{c}	45.45^{b}	59.82^{a}	30.68^{c}	45.51^{b}	59.88^{a}	1.18	*	0.895
Total (g DM/$M^{0.75}$/d)	117.6^{c}	134.52^{b}	143.23^{a}	116.9^{c}	137.47^{b}	143.66^{a}	4.46	*	0.375

NS, Non-significant, P>0.05; *, P<0.05; LSD, Least significant difference;
$^{a, b, c, d}$means within rows with different superscripts differ significantly (p<0.05).

straw and significantly (P<0.05) lower for the two lower levels of offer for the two rice straw varieties. The ADG on metabolic weight basis followed the same trend as the ADG. The straw intake was significantly (P<0.05) higher for the T_{360} level of offer of supplement for the two rice straw varieties and significantly (P<0.05) lower for the highest level of offer of the supplement for both rice straw varieties Nerica 1 and Nerica 2. The daily *S. hamata* intake increased significantly (P<0.05) as the offer levels increased for both rice straw varieties. The total DM intake followed the same trend as the supplement for both straw varieties. The intake on metabolic weight basis of the Stylo and the total intake increased significantly (P<0.05) as the offer levels increased for both rice straw varieties. There was no significant difference in the intake of the 2 rice straw varieties for each of the three levels of offer of the supplement.

Table 7.2 Chemical composition of Nerica 2 (g/kg DM)

ITEM	NERICA 2
Dry Matter (DM) (g/kg)	964.1
Crude Protein (CP)	52.5
Organic matter (OM)	844.1
NDF	609.0
ADF	359.2
Hemicellulose	256.5
Ash	120
Acid insoluble ash (AIA)	7.5

7.4 DISCUSSION: EXPERIMENT 4

7.4.1 *Feed intake and ADG of the rams*

There was no significant effect of Nerica 1 and Nerica 2 rice straw varieties on intake and performance. The rice straw intake followed the same trend for Nerica 1 and Nerica 2 rice varieties; the intake increased up to the 360 g offer level and then reduced at the highest level of offer (480 g). Total DM intake increased as the level of of offer of *Stylosanthes hamata* increased. The higher total intake of the T_{480} animals did not translate into improved weight gain when compared with the other lower levels. This could be due to higher passage rate of the digesta, which did not allow much time for the feed to be exposed to the rumen microbes and the digestive enzymes. Melaku *et al*. (2004) reported that increasing the level of fodder leaves as supplement in diets reduced nutrient digestibility due to increased passage rate, thus lower levels should be fed. Ngwa and Tawah (1989) in a study concluded that small quantities of up to 30 % of total DM intake of a legume crop would substantially increase DMI. The possibility of an increase in passage rate could also account for the higher intake for the rams on the 480 g offer. The dry matter intakes of rice straw observed in this study were higher than the values (300 – 500 g/kg DM) obtained by Ngwa and Tawah (1989) under similar conditions. The DMI of rice straw was however comparable to the 613 – 676 g obtained by Hue *et al*. (2008) for *Stylosanthes* supplemeted diets.

There was no significant (P>0.05) difference in the gain between T_{360} and T_{480} for Nerica 1 rice straw but the gain was a significantly (P<0.05) higher for the T_{360} as compared to T_{480} for Nerica 2. The intake of the supplement increased as the inclusion level increased, this, however, was not the case for the basal diet, which might be due to a substitution effect as the drop in the straw intake was significant (P<0.05). There was an improvement in the live weight of all the rams. The different values for the DMI may be due to the differences in the availability of N supply in the rumen and the passage rates of the different feeds. The total concentration of condensed tannins in the *S. hamata* did not seem to have any negative effect on intake or performance of the rams. Barry and McNabb (1999) observed that the concentration of condensed tannins in *Lotus corniculatus* (30 – 40 g/kg DM) in the diet of sheep increased the absorption of essential amino acids without affecting voluntary feed intake.

Stylosanthes hamata could be fed at 360 g as supplement to poor quality feed resources for best performance. Feeding beyond 360 g could cause substitution effect on the poor quality feed resources.

CHAPTER EIGHT

EXPERIMENT 5

Effects of feeding two improved rice straw varieties with *Samanea saman*, supplementation on intake and growth performance of young rams.

8.1 INTRODUCTION: EXPERIMENT 5

Tree foliages are of importance in animal production because they do not compete with humans as food, and can provide significant protein supplement, especially in the dry season. The effective nutrition of the ruminant is the combination of the products of rumen microbial fermentation and unfermented feed that escapes from the rumen (Teferedegne, 2000). A lot of work has already been done on a number of legume tree crops as fodder for ruminant livestock, but there is still a great number of the less known species, which have great potential.

Since there are no known techniques which predict palatability and intake, the nutritive value (VFI x DMD) of forage tree species can only be accurately determined by feeding trials. Feeding trials have the added advantage of also providing information on animal health and productivity (liveweight gain).

There is therefore the need to carry out studies into their nutritive qualities and their suitability to be utilized as supplements during the dry season.

Samanea samen ("Rain tree") is a leguminous multipurpose tree with a very huge crown, which is used mostly as an ornamental along roads and in parks for shade (Durr, 2001). The pods have been used extensively in livestock feeding systems (Barcelo *et al.*, 2003; Jetana *et al.*, 2010). The leaves have not been used extensively as animal fodder as it has been considered to be of very low fodder value. There is thus a dearth of information on its use for livestock. The little work that has been done on it shows it has a lot of potential. There is the need to develop feeding systems based on low cost diets in order to sustain the productivity of small ruminant livestock and thus, increase the income of the small-scale farmer (Attoh-Kotoku, 2003).

Multipurpose trees of the genera *Leucaena* and *Sesbania* have been reported to improve the efficiency of microbial N synthesis and N retention when supplemented to sheep fed teff straw (Umunna *et al.*, 1995). Similarly, supplementation of dried *Elaeis guineense* leaves at 25 % or less was found to be suitable in hay-based diets for sheep (Osakwe *et al.*, 2004). Increasing the level of tree fodder leaves as supplement in diets reduced nutrient digestibility due to increased passage rate, thus lower levels should be used (Melaku *et al.*, 2004). The maximum level of feeding these plant proteins need

to be assessed/determined for improved nutrition of young growing ruminant livestock. Leaves or foliages of multipurpose tree species often contain secondary compounds, which in low amounts may improve the productivity of the animals by binding with the dietary proteins during mastication and protecting the proteins from microbial attack in the rumen (Barry and McNabb, 1999; Norton, 2000). Despite the high CP content of *Samanea saman* leaves 190 – 279.4 g/kg DM (Ahn *et al*., 1989; Kaitho, 1997; Chumpawadee and Pimpa, 2009) there are very few research reports on feeding trials with livestock. There is therefore the need to identify and utilise alternative low cost feeds for ruminants at critical periods of the year.

The objectives of this study were to investigate:

i) The effect on feed total intake when *Samanea saman* was fed as a supplement to young rams fed on Nerica 1 and Nerica 2 straw as basal diets.

ii) The effect on live weight changes in rams following *Samanea saman* supplementation.

8.2 MATERIALS AND METHODS: EXPERIMENT 5

8.2.1 *Location of study*

The study was carried out at the Department of Animal Science, KNUST during the months of February to April, 2009. The details of the location are as described in Section 3.2 previously.

8.2.2 *Source of Feeds*

The details of the source of feeds are as described in Section 3.3.

8.2.3 *Experimental Design*

Forty-eight (48) Djallonké rams (different from the set used for experiment 3) weighing between 12 and 13.5 kg and about 17 months of age (using dentition), were used in a completely randomised 2 x 3 factorial design feeding trial over a six week period. The rams were obtained from Lakeside (Lake Bosomtwe catchment area) and the villages surrounding KNUST in the Ashanti Region of Ghana.

The details are as described in Section 7.2.3.

8.2.4 *Animals and Management*

The details are as described in Section 7.2.4.

8.2.5 *Diets and Feeding*

The plant protein *Samanea saman* was harvested and shade dried before being fed to the experimental animals. (Refer to Section 3.3).

The details are as described in Section 7.2.5.

8.2.6 *Growth Measurements*

The details are as described in Section 7.2.6.

8.2.7 *Chemical Analyses*

The details are as described in Section 7.2.7.

8.2.8 *Statistical Analysis*

The details are as described in Section 7.2.3.

8.3 RESULTS: EXPERIMENT 5

8.3.1 *Overview*

Almost all the animals consumed the dried leaves with relish. There was a better improvement in weight compared to the *Stylosanthes hamata* work.

8.3.2 *Feed intake and ADG of rams*

The final weight, as can be seen from Table 8.1, was significantly (P<0.05) lower 14.93; 14.72 kg for the lower level of offer T_{240}, and significantly (P<0.05) higher but similar (15.31 and 15.76 kg; 15.35 and 15.77 kg) for T_{360} and T_{480} for both rice straw varieties. The average daily gain (ADG) increased significantly (P<0.05) as the offer level of the *Samanea saman* foliage increased for Nerica 1 and Nerica 2 straws. The rams on Nerica 2 straw variety for T_{480}

Table 8.1 Effect of supplement level and straw variety on intake and ADG of rams.

Parameter	Nerica 1			Nerica 2					
S. saman level	T_{240}	T_{360}	T_{480}	T_{240}	T_{360}	T_{480}	Lsd	Sig.	VxL
Initial weight [M], kg	13.16^{a}	13.05^{a}	13.03^{a}	13.01^{a}	12.99^{a}	12.94^{a}	0.22	NS	0.304
Final weight [M], kg	14.93^{b}	15.31^{a}	15.76^{a}	14.72^{b}	15.35^{a}	15.77^{a}	0.49	*	0.729
Average daily gain (ADG), g	42.14^{e}	53.81^{d}	65.00^{b}	40.71^{e}	56.19^{c}	67.38^{a}	1.5	*	0.003
Initial weight [$M^{0.75}$], kg	6.91^{a}	6.87^{a}	6.86^{a}	6.85^{a}	6.84^{a}	6.82^{a}	0.09	NS	0.311
Final weight [$M^{0.75}$], kg	7.60^{b}	7.74^{b}	7.91^{a}	7.52^{b}	7.75^{b}	7.91^{a}	0.23	*	0.200
ADG [$M^{0.75}$], g	16.54^{e}	19.87^{d}	22.89^{b}	16.12^{e}	20.52^{c}	23.52^{a}	0.57	*	0.003
Intake									
Straw (g DM/d)	677.0^{a}	676.8^{a}	669.3^{a}	668.7^{a}	674.6^{a}	666.3^{a}	36.8	NS	0.717
S. saman (g DM/d)	231.5^{c}	346.2^{b}	464.5^{a}	233.6^{c}	347.8^{b}	468.5^{a}	7.62	*	0.484
Total (g DM/d)	908.6^{c}	1023^{b}	1133.8^{a}	902.3^{c}	1022.4^{b}	1134.8^{a}	35.9	*	0.957
Straw (g DM/$M^{0.75}$/d)	97.98^{a}	98.57^{a}	97.59^{a}	97.62^{a}	98.59^{a}	97.66^{a}	5.56	NS	0.946
S. saman (g DM/$M^{0.75}$/d)	33.50^{c}	50.42^{b}	67.73^{a}	34.10^{c}	50.83^{b}	68.67^{a}	1.18	*	0.156
Total (g DM/$M^{0.75}$/d)	131.50^{c}	148.99^{b}	165.32^{a}	131.72^{c}	149.42^{b}	166.33^{a}	5.57	*	0.710

NS, Non-significant, P>0.05; *, P<0.05; LSD, Least significant difference;
$^{a, b, c, d, e}$means within rows with different superscripts differ significantly (p<0.05).

however, had the highest (67.38 g) significant (P<0.05) gain. The ADG on metabolic weight basis followed the same trend. Intake of the *Samanea saman* foliage increased significantly (P<0.05) as the offer level increased for both rice straw varieties. The total intake followed the same trend ie increased significantly (P<0.05) as the offer level increased. There was, however, no significant (P>0.05) difference in the intake of the 2 rice straw varieties Nerica 1 and Nerica 2 among the 6 treatments. The straw intake on metabolic weight basis was not significant between the treatments. The intake of the *Samanea saman* foliage on metabolic weight basis as well as the total intake on metabolic weight basis also increased significantly (P<0.01) as the level of offer of the foliage increased.

8.4 DISCUSSION: EXPERIMENT 5

8.4.1 *Feed intake and ADG of the rams*

There were important differences in physical properties between the *Samanea saman* leaf material and that of the rice straw. The leaves fragmented much more readily than the rice straw samples though the degree was not quantified. The intake of the rice straws were similar between the six treatments, which is an indication that the level of the supplement could be increased further since as at 480 g/d there was no substitution for the straw. Earlier studies have indicated that, compared to matured grass, tree leaves fragment more easily, digest to a lesser extent but do so more rapidly (rate of digestion faster), so that indigestible particles leave the rumen rapidly (Kennedy and Lowry, 1996). When *Samanea saman* foliage was offered as the sole diet to groups of sheep the dry matter intake was as high as 802 g/d, though DMD was as low as 26.5 % and DDMI was 215 g/d (Lowry, 1995). The dry matter intake increased as the level of the supplement increased and this is probably due to an increase in the supply of nitrogen to the rumen microbes, which may have resulted in an increase in microbial yield and subsequently more microbial protein digestion and absorption from the duodenum.

The magnitude of gain of about 65.0 and 67.38 g per day at the 480 g/d inclusion levels for the rams on Nerica 1 and Nerica 2 might be due to the

by-pass protein property that *Samanea saman* has due to the presence of condensed tannins (Kaitho *et al*., 1998). In an earlier study on browse nitrogen degradability and digestibility, it was found that *Samanea saman, Gliricidia sepium* and a few others had high by-pass protein (BP) levels and a high proportion of the BP was digested in the intestines (507, 184 and 416, 317) respectively; therefore, these browses had a high potential for use as protein supplements (Kaitho *et al*., 1998). It is frequently suggested that forages with comparatively high concentration of rumen-undegradable protein may be utilised more efficiently than those with high proportions of readily degradable protein (Buxton, 1996). This may explain the increased weight gain of the rams supplemented with *Samanea saman*. This could be due to the quantity and characteristic of the rumen-degraded (493 g/kg) and rumen-undegraded or BP (507 g/kg) protein in the legume and its effect on microbial protein production (Buxton, 1996).

Microbial protein production is influenced by the proportion of feedstuff N that is soluble and degradable in the rumen, in addition to the DE available 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).

The implications for this study are that *Samanea saman* foliage has a higher efficiency of microbial protein synthesis and a decreased protein degradability of feed proteins in the rumen. These are beneficial for ruminants as they increase the supply of non-ammonia N to the lower intestine for production purposes, resulting in higher milk and meat production. *Samanea saman* foliage can be used as ruminant livestock feed as it has a high voluntary intake. It has the capacity to provide the animal with essential amino acids for quality production due to its by-pass protein property. All these effects lead to protein sparing in the ruminant leading to reductions in methane production and N excretion to the environment, thereby reducing emissions of environmental pollutants besides producing more meat and milk. Thus our farmers are encouraged to use *Samanea saman* foliage as a supplement during the dry season for all the benefits enumerated above.

Increase in the efficiency of microbial protein synthesis and decrease in the protein degradability of feed proteins in the rumen are beneficial for ruminants as they increase the supply of non-ammonia N to the lower intestine for production purposes, resulting in higher milk and meat production. In addition, these effects lead to protein sparing in the ruminant leading to reductions in methane production and N excretion to the environment, thereby reducing emissions of environmental pollutants

besides producing more meat and milk. Feeding strategies need to be designed to exploit these beneficial effects (Makkar, 2003). The higher animal performance observed when the diet contains low levels of tannins has generally been attributed to the protection of the feed protein from degradation in the rumen leading to the flux of essential amino acids (Eaa) to the small intestines and increase in the absorption of Eaa into the blood (Waghorn and Shelton, 1997). Studies by Makkar (1995a, 1997b) showed that these beneficial effects of tannins *in vivo* could also be due to higher efficiency of microbial protein synthesis in the rumen. Another factor, which influences the microbial N supply to the small/lower intestines could be a greater proportion of DM, which may be digested *in vivo* as a consequence of a slower rate of digestion or DM passage in the rumen, despite the reduced microbial population or their activity (Makkar *et al*., 1988).

Sheep can be fed *Samanea saman* at 480 g/d as supplement during the dry season to Nerica 1 and Nerica 2 rice straws as basal diet for improved productivity in terms of quality gain 67.09 g/d.

CHAPTER NINE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

9.1 GENERAL DISCUSSION

The chemical composition of the forages used in this study was similar to those reported by other researchers and where differences were observed, these may be due to differences in rates of fertiliser application, maturity, period of harvest (Shen *et al*., 1998; Gulsen *et al*., 2004; Kamalak *et al*., 2005a), variety, environmental conditions and agronomic factors (Buxton, 1996). It is well established that the cell wall content of forages increase with increasing maturity (Gulsen *et al*., 2004; Kamalak *et al*., 2005b, c). The crude protein in the legumes would complement the levels of organic matter in the feedstuffs thus making ample energy available to the rumen microbes, which would subsequently boost the productivity of young rams. The concentration of sulphur in the foliages would also maximise microbial growth efficiency (Leng, 1993) and would in turn maximise digestibility of the basal diet. The condensed tannins content of the *Samanea saman* and *Stylosanthes hamata* foliages may have made available some amount of rumen non-degradable protein, which might have reflected in the good average daily gains of the young rams during the feeding trials.

The apparent digestibility values for DM, OM, N and NDF obtained show that all the four rumen environments were favourable. Nitrogen retained as percentage of intake was greater in T_{ST360}, T_{SA480} and T_{ST480} supplemental diets than for those fed T_{SA360}. This may be due to improved synchrony between highly digestible NDF, OM and N compounds. More urinary PD was excreted by sheep on T_{SA480} diet and this could be due to the higher dry matter intake compared to the other treatments. The higher intake was expected to induce higher microbial synthesis.

The pH values in this study showed typical rumen buffering capacity when straw diets were ingested, and were optimal for the growth of cellulolytic bacteria as suggested by Mould *et al*. (1983). Similar values were reported by Mgheni *et al*. (1993) and Ye *et al*. (1996) in sheep fed untreated, urea-supplemented or urea-treated rice straw diets. The rate of degradation of straw is optimal when rumen pH is maintained at 6.7±0.15; cellulolysis is inhibited below 6.0-6.1 (Mould *et al*., 1983). The mean overall pH of 6.57 obtained for all diets in this study suggested that optimal pH conditions existed in the rumen for cellulolysis. The critical level of NH_3-N has been variously reported as between 50 and 280 mg of NH_3-N per litre of rumen liquor (Durand 1987). The level of NH_3-N obtained in this study suggested that all diets were adequate in NH_3-N to support optimal fermentation. Overall digestibility was favourable for all the 4 rumen environments. The

digestibility of DM and OM were highest in rams supplemented with *Stylosanthes hamata* at all the two levels and this could be due to a high rate of supply of degradable N in the rumen. The higher N efficiency for rams on T_{ST360} could be due to low faecal and urinary excretion of N. The improved N-balance for T_{SA480} could be due to its rumen by-pass protein content, which gets digested more in the small intestines.

More urinary PD was excreted by sheep on T_{SA480} diet and this could be due to the higher dry matter intake compared to the other treatments. The higher intake was expected to induce higher microbial synthesis. Another factor, which influences the microbial N supply to the small/lower intestines could be a greater proportion of DM, which may be digested *in vivo* as a consequence of a slower rate of digestion or DM passage in the rumen, despite the reduced microbial population or their activity (Makkar *et al*., 1988). Studies by Makkar (1995a, 1997b) showed that the beneficial effects of tannins *in vivo* could also be due to higher efficiency of microbial protein synthesis in the rumen.

The degradation rate constant was very low for *Samanea saman* and its ruminal particulate passage rate in the foregut was also the lowest with Nerica 2 having the same value. A greater proportion of DM is effectively degraded when the rate is very low (Chen, 1997). *Samanea saman* however

had the lowest MRT, which might be due to its nature of crumbling very fast and the rumen undegradable protein moving into the hind gut. Nerica 1 had the highest passage rate constant in both the rumen and the hind gut though it had a low degradation rate constant. This could be explained by the fact that it has a very high potentially degradable but water insoluble fraction, which would be effectively degraded because of the low rate constant. The apparent NDF digestibility coefficient was quite high (≥ 0.656) for all the diets and it might have contributed to the increase in the passage rate of Nerica 1. A decrease in particle size facilitates passage of feed particles from the rumen. Concievably, increasing the digestibility of an ingredient such as rice straw would accelerate particle size reduction and thereby allow for faster passage from the rumen. Nerica 1 and Nerica 2 had higher intakes even at low levels of supplementation. In the growth studies Nerica 2 rams had highest significant ADG on LW and $W^{0.75}$ basis for both foliages.

9.2 CONCLUSIONS

Samanea saman foliage elicit high voluntary intake of the basal diets Nerica 1 and Nerica 2 and also had very high DOMR (577 g/d).

Samanea saman elicited optimal pH (6.98) condition of the rumen, gave favourable rumen NH_3-N (9.6 mg/100 ml) levels to maximise fibre digestion for the rumen microbes. BUN levels were also very high (9.1 mg/100 ml) and

this could be recycled through the saliva for optimal NH_3 levels for rumen microbial proliferation and cellulolysis.

Samanea saman foliage elicited positive (13.97 g/d) N-balance and very high (99.86 %) N-efficiency.

Samanea saman foliage elicited the highest microbial N production.

Samanea saman foliage contains appreciable levels of condensed tannins which could provide some by-pass protein (for quality production) which are beneficial in providing the critical amino acids they require for improved growth performance and also makes the feed palatable.

Samanea saman foliage contains appreciable levels of sulphur, which is one of the critical nutrients that are required by the rumen microbes for their proper functioning.

Samanea saman foliage can be fed up to 480 g/d for best performance in terms of optimal rumen environment, voluntary intake and better gain.

Stylosanthes hamata had appreciable levels of sulphur and this would help the growth of rumen fungi and boost the digestibility of the rice straw and the matured forages and subsequently boost live weight gain and productivity.

Stylosanthes hamata has a higher proportion of its N degradable in the rumen thus eliciting higher digestibilities of the nutrients DM, OM, N and NDF.

Stylosanthes hamata elicited optimal pH (6.92) condition of the rumen, gave favourable rumen NH_3-N (8.7 mg/100 ml) levels to maximise fibre digestion for the rumen microbes.

Increasing the level of offer beyond 360 g/d for *Stylosanthes hamata* reduced the intake of the basal diet Nerica 1 and Nerica 2.

Nerica 1 has 85 % of its DM degradable in the rumen and elicits high voluntary intake even at very low supplementation levels.

Nerica 1 has appreciable levels of CP (60.6 g/kg DM).

Nerica 2 has a high rate of degradation 33.0 % in the rumen and elicits high voluntary intake even at very low supplementation levels.

Sheep can be fed *Samanea saman* at 480 g/d as supplement during the dry season to Nerica 1 and Nerica 2 rice straws as basal diet for improved productivity in terms of quality gain 67.09 g/d.

9.3 RECOMMENDATIONS

i) Based on the foregoing *Samanea saman* is recommended to be fed to sheep as supplement at 480 g/d.

ii) *Stylosanthes hamata* is recommended to be fed as supplement at 360 g/d for best performance in sheep.

iii) Nerica 1 and Nerica 2 rice straws can be fed as basal diet to sheep during the dry season.

iv) Further research is necessary on *Samanea saman* to determine its methanogenic properties, the level of by-pass protein that leaves the rumen and the performance of rams when supplemented above 480 g/d.

9.4 CONTRIBUTION TO SCIENTIFIC KNOWLEDGE

i) *Samanea saman* has been established as an important feed resource and can be used as a rumen manipulating agent and livestock feed supplement, which was hitherto not known in Ghana.

ii) *Samanea saman* could be fed up to 480 g per day to rams for higher microbial N production and positive N-balance and digestibility for improved daily gains.

iii) Nerica 1 and Nerica 2 rice straws can be fed to ruminant livestock as basal diet during the dry season.

iv) The passage rate and MRT have been established for *Samanea saman, Stylosanthes hamata*, Nerica 1 and Nerica 2 rice straws.

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APPENDICES

APPENDIX (AP) 1: Data for digestibility results

AP 1.1. Feed intake values for *Samanea saman* and *Stylosanthes hamata*

Obs	Rep	Trt	STRINT	SA/STINT	TOTINT	STRINTM	SA/STINM	TOTINTM
1	1	1	691.7	341	1032.7	66.29	32.68	98.97
1	1	2	776	449	1225	70.25	40.65	110.90
1	2	1	661.3	349.5	1010.8	69.92	36.96	106.88
1	2	2	681.4	415.7	1097.1	66.40	40.51	106.91
2	1	1	699	320.7	1019.7	66.77	30.64	97.41
2	1	2	755	437	1192	67.53	39.09	106.62
2	2	1	654.9	351.3	1006.2	69.51	37.29	106.79
2	2	2	657.9	410.6	1068.5	65.66	40.98	106.64
3	1	1	706.5	335.9	1042.4	66.62	31.67	98.29
3	1	2	696.9	452.3	1149.2	61.78	40.09	101.87
3	2	1	650.7	357.8	1008.5	68.55	37.69	106.24
3	2	2	639	402	1041	62.90	39.57	102.48
4	1	1	711.4	347.4	1058.8	67.74	33.08	100.81
4	1	2	721.6	450.9	1172.5	64.35	40.21	104.56
4	2	1	655.1	356.9	1012	69.27	37.74	107.01
4	2	2	697.1	419	1116.1	68.39	41.11	109.50

Obs- observation; Rep-replicate; Trt- treatment; STRINT- straw intake; SAINT- samanea intake; STINT- stylosanthes intake; TOTINT- total intake; STRINTM- straw intake on metabolic weight basis; SA/STINM- Samanea or Stylosanthes intake on metabolic weight basis; TOTINTM- total intake on metabolic weight basis.

AP 1.2. Values for short term feed intake in digestibility studies

Obs	Rep	Trt	INI WT	FIN WT	CHINWT	ADG	INIWTM	FNWTM	CHINMWT	ADGM
1	1	1	22.8	24.4	1.6	0.06	10.43	10.98	0.54	0.02
1	1	2	24.6	27.2	2.6	0.09	11.05	11.91	0.86	0.03
1	2	1	20	23	3	0.11	9.46	10.50	1.05	0.04
1	2	2	22.3	24.6	2.3	0.08	10.26	11.05	0.78	0.03
2	1	1	22.9	24.8	1.9	0.07	10.47	11.11	0.64	0.02
2	1	2	25	28	3	0.11	11.18	12.17	0.99	0.04
2	2	1	19.9	22.6	2.7	0.10	9.42	10.37	0.94	0.03
2	2	2	21.6	23.3	1.7	0.06	10.02	10.61	0.59	0.02
3	1	1	23.3	25.8	2.5	0.09	10.61	11.45	0.84	0.03
3	1	2	25.3	28.6	3.3	0.12	11.28	12.37	1.09	0.04
3	2	1	20.1	23	2.9	0.10	9.49	10.50	1.01	0.04
3	2	2	22	24	2	0.07	10.16	10.84	0.69	0.02
4	1	1	23	25	2	0.07	10.50	11.18	0.68	0.02
4	1	2	25.1	28.2	3.1	0.11	11.21	12.24	1.02	0.04
4	2	1	20	23.4	3.4	0.12	9.46	10.64	1.18	0.04
4	2	2	22.1	24.1	2	0.07	10.19	10.88	0.68	0.02

INIWT- initial weight; FINWT- final weight; CHIINWT- change in weight; ADG- average daily gain; INIWTM- initial weight on metabolic weight basis; FNWTM- final weight on metabolic weight basis; ADGM- average daily gain on metabolic weight basis.

AP 1.3. Values for DM, OM, N and NDF digestibility and nitrogen retention

Obs	Rep	Trt	DM	OM	N	NDF	TOT N	FeaN	UrinN	ND	ND'GES	Nreten	%of Int	%ofNdig
1	1	1	0.8	0.861	0.614	0.657	16.78	6.65	0.035	10.13	60.37	10.1	60.16	99.65
1	1	2	0.8	0.847	0.695	0.681	21.03	6.7	0.017	14.33	68.14	14.31	68.06	99.88
1	2	1	0.827	0.873	0.778	0.819	18.01	3.28	0.025	14.73	81.79	14.71	81.65	99.83
1	2	2	0.823	0.848	0.7	0.686	19.83	5.72	0.038	14.11	71.15	14.07	70.96	99.73
2	1	1	0.799	0.833	0.603	0.652	16.72	6.47	0.029	10.25	61.3	10.22	61.13	99.72
2	1	2	0.815	0.867	0.702	0.685	20.23	6.09	0.02	14.14	69.9	14.12	69.8	99.86
2	2	1	0.869	0.905	0.784	0.815	17.69	3.75	0.027	13.94	78.8	13.91	78.65	99.81
2	2	2	0.849	0.889	0.682	0.681	19.44	6.54	0.038	12.9	66.36	12.86	66.16	99.71
3	1	1	0.794	0.842	0.6	0.65	16.38	6.39	0.028	9.99	60.99	9.96	60.82	99.72
3	1	2	0.799	0.89	0.69	0.682	19.32	6.01	0.018	13.31	68.89	13.29	68.8	99.86
3	2	1	0.837	0.882	0.794	0.821	17.63	4.03	0.028	13.6	77.14	13.57	76.98	99.79
3	2	2	0.802	0.869	0.679	0.664	19.47	6.36	0.037	13.11	67.33	13.07	67.14	99.72
4	1	1	0.792	0.856	0.62	0.663	16.57	6.53	0.032	10.04	60.59	10.01	60.4	99.68
4	1	2	0.821	0.833	0.686	0.684	20.18	6	0.021	14.18	70.27	14.16	70.16	99.85
4	2	1	0.879	0.876	0.767	0.818	17.96	4.49	0.029	13.47	75	13.44	74.84	99.78
4	2	2	0.795	0.877	0.685	0.693	20.58	6.28	0.035	14.3	69.48	14.27	69.31	99.76

DM- dry matter; OM- organic matter; N- Nitrogen; NDF- neutral detergent fibre; TOT N- total nitrogen; FeaN- feacal nitrogen; UrinN- nitrogen in urine; ND- nitrogen digested; ND'GES- nitrogen digestibility; Nreten- nitrogen retained

AP 1.4. Rumen pH, NH_3-N and BUN values

			pH					NH3-N					BUN			
Obs	Rep	Trt	0 h	2 h	4 h	6 h		0 h	2 h	4 h	6 h		0 h	2 h	4 h	6 h
1	1	1	6.26	6.58	6.88	6.46		0.1	5.27	8.28	3.97		6.45	6.88	7.05	7.56
1	1	2	6.33	6.69	6.99	6.6		3.23	5.45	9.7	5.08		7.67	7.75	8.45	9.09
1	2	1	6.15	6.49	6.91	6.5		0.99	4.54	8.69	5.02		5.18	5.45	5.5	6.3
1	2	2	6.29	6.6	6.78	6.4		2.35	5.08	6.83	3.38		4.17	4.51	4.56	4.73
2	1	1	6.24	6.61	6.86	6.5		0.11	5.29	8.29	3.98		6.49	6.85	7.09	7.57
2	1	2	6.37	6.65	7.01	6.57		3.26	5.53	9.65	5.06		7.55	7.73	8.36	9.14
2	2	1	6.19	6.55	6.97	6.55		0.93	4.59	8.73	5.06		5.23	5.42	5.54	6.25
2	2	2	6.34	6.55	6.76	6.39		2.39	5.09	6.85	3.41		4.19	4.48	4.59	4.71
3	1	1	6.21	6.63	6.85	6.52		0.14	5.31	8.34	4.02		6.51	6.93	7.11	7.62
3	1	2	6.36	6.68	6.97	6.63		3.25	5.49	9.56	5.13		7.59	7.68	8.42	9.08
3	2	1	6.22	6.5	6.87	6.52		0.97	4.57	8.68	5.07		5.22	5.39	5.49	6.34
3	2	2	6.28	6.62	6.7	6.45		2.42	5.11	6.79	3.45		4.23	4.46	4.62	4.67
4	1	1	6.2	6.65	6.89	6.47		0.13	5.32	8.28	4.05		6.54	6.92	7.13	7.65
4	1	2	6.34	6.63	6.95	6.54		3.22	5.55	9.5	5.12		7.62	7.67	8.38	9.07
4	2	1	6.17	6.53	6.93	6.59		0.95	4.54	8.74	5.01		5.15	5.37	5.48	6.32
4	2	2	6.34	6.57	6.77	6.43		2.45	5.13	6.78	3.37		4.21	4.55	4.61	4.68

NH_3-N – rumen ammonia nitrogen; BUN – blood urea nitrogen

AP 1.5. Values for microbial nitrogen parameters

Obs	Rep	Trt	DOMR	MN	EMNS	Pa	PDe	Ae	UAe
1	1	1	498.08	15.9	32.09	21.97	20.41	17.3	3.02
1	1	2	577.09	18.36	32	25.4	23.31	19.88	3.48
1	2	1	487.2	15.6	31.87	21.36	20.03	17.03	2.95
1	2	2	513.1	16.45	32.07	22.65	20.99	17.73	3.21
2	1	1	497.96	15.74	32.03	21.87	20.39	17.4	3.09
2	1	2	576.91	18.49	31.94	25.45	23.32	19.79	3.45
2	2	1	487.3	15.55	32.05	21.46	19.92	16.95	2.99
2	2	2	513.04	16.51	32.03	22.61	20.87	17.9	2.96
3	1	1	498.03	16.1	31.97	21.94	20.48	17.22	2.98
3	1	2	577.1	18.41	31.9	25.32	23.35	19.8	3.56
3	2	1	487.26	15.44	32.3	21.55	20.07	16.99	3.08
3	2	2	513.11	16.32	31.93	22.51	21.11	17.87	3.2
4	1	1	498.05	16.02	31.95	22	20.4	17.48	3.15
4	1	2	576.9	18.62	32.12	25.39	23.34	19.85	3.51
4	2	1	486.99	15.77	31.79	21.39	20.02	17.07	3.02
4	2	2	512.95	16.4	31.99	22.59	20.92	17.8	3.23

DOMR – organic matter digested in the rumen; MN – microbial nitrogen; EMNS – efficiency of microbial nitrogen synthesis; Pa – purine derivative absorbed; PDE – purine derivative excreted; Ae – allantoin excreted; UAe – uric acid excreted

APPENDIX (AP) 2: Data for degradability results

AP 2.1. Values for degradability parameters

			Samanea			Stylosanthes			Nerica 1			Nerica 2		
Obs	Rep	Trt	b	P	c	b	P	c	b	P	c	b	P	c
1	1	1	83.4	91.3	0.00301	58.4	80.94	0.0349	62.8	72.16	0.0231	55.86	59.98	0.032
1	1	2	83.7	91.75	0.0028	59.72	81.78	0.0351	61.89	72.59	0.0218	56.28	60.51	0.0315
1	2	1	86.2	93.85	0.0021	60.38	83.16	0.0311	62.52	72.79	0.0217	56.43	59.87	0.0318
1	2	2	80.1	88	0.0048	55.7	78.49	0.0365	57.91	67.58	0.0239	55.1	59.7	0.0347
2	1	1	83.8	91.6	0.00307	58.3	81.25	0.0338	62.48	72.32	0.0229	56.38	61.3	0.034
2	1	2	83.9	91.45	0.0032	59.8	82.06	0.0352	62.7	72.61	0.0222	56.39	60.9	0.0338
2	2	1	85.5	93.65	0.0019	60.32	83.07	0.0317	63.05	72.93	0.0221	56.35	60.96	0.0316
2	2	2	80.48	88.3	0.0051	55.87	78.53	0.0372	57.65	67.82	0.0241	54.89	58.9	0.0339
3	1	1	83.6	91.28	0.00295	58.7	81.29	0.0341	62.32	72.35	0.0232	56.53	61	0.031
3	1	2	84	91.2	0.0031	59.41	82.11	0.0349	62.65	72.51	0.0219	56.43	60.79	0.0315
3	2	1	85.6	93.4	0.00205	59.99	82.96	0.0326	62.93	73.05	0.0219	56.67	61.03	0.0325
3	2	2	80.42	87.9	0.0049	56.15	78.72	0.0377	58	67.45	0.0237	55.01	59.37	0.0356
4	1	1	84	91.42	0.00299	59	81.32	0.0334	62	72.37	0.0228	56.47	60.52	0.035
4	1	2	83.6	91.6	0.00291	59.07	82.05	0.0341	62.07	72.69	0.0223	56.5	61	0.0345
4	2	1	85.9	93.5	0.00197	60.91	82.83	0.032	63.1	72.83	0.0222	56.55	61.78	0.0331
4	2	2	80.6	88.2	0.0052	56.3	78.66	0.0365	57.24	67.55	0.0242	54.84	59.43	0.0352

b – water insoluble but potentially degradable portion; c – rate of degradation; P – potential disappearance

APPENDIX (AP) 3: Data for passage parameters

OBS	REP	TRT	TT	k1	k2	ft1/2	ht1/2	MRT
1	1	1	23.6	0.0181	0.029	36.5	23.82	110.8
1	1	2	34.29	0.02	0.0278	34	23.8	116.4
1	1	3	48.23	0.0248	0.032	27.74	20	118.57
1	1	4	34.68	0.0186	0.025	36.45	26.71	125.85
2	2	1	23.8	0.019	0.028	36.48	23.97	110.85
2	2	2	34.13	0.0218	0.0297	32	23.98	116.41
2	2	3	48.31	0.025	0.034	27.75	22	118.59
2	2	4	34.75	0.018	0.027	36.5	26.7	125.78
3	3	1	23.75	0.021	0.0279	36.46	23.94	110.71
3	3	2	34.3	0.023	0.028	32.5	23.87	116.3
3	3	3	48.19	0.025	0.0334	27.68	23	118.5
3	3	4	34.74	0.02	0.0255	36.44	26.5	125.75
4	4	1	23.65	0.0192	0.0312	36.45	23.91	110.88
4	4	2	34.28	0.0187	0.031	33.5	23.95	116.29
4	4	3	48.27	0.024	0.0327	27.7	19	118.54
4	4	4	34.66	0.0195	0.0265	36.49	26.69	125.82

TT-Transit time; k_1-passage rate constant for the rumen; k_2-passage rate constant for the hind gut; MRT-Mean retention time; ft½- time spent by digesta in the rumen; ht½- time spent by digesta in the hind gut.

APPENDIX (AP) 4: Data for the feeding trials

AP 4.1. Values for feeding trial studies using *Stylosanthes hamata* as supplement

Obsv	Rep	Trt	Strint	Stint	Toint	Inwt	Fnwt	ADG	Inmw	Fnmw	ADMG	Strntm	Stntm	Tontm
1	1	1	636.98	220.88	857.86	14	16.3	0.055	7.24	8.11	0.021	88.01	30.52	118.53
1	1	2	623.57	330.69	954.26	14	16	0.048	7.24	8.00	0.018	86.16	45.69	131.85
1	1	3	611.89	430.38	1042.27	14.5	17.3	0.067	7.43	8.48	0.025	82.35	57.92	140.27
1	2	1	620.45	222.10	842.55	13.5	16	0.060	7.04	8.00	0.023	88.10	31.53	119.63
1	2	2	647.95	322.81	970.76	14	16	0.048	7.24	8.00	0.018	89.53	44.60	134.13
1	2	3	577.05	442.02	1019.08	14	16	0.048	7.24	8.00	0.018	79.73	61.07	140.80
2	1	1	635.38	220.50	855.88	14	15.5	0.036	7.24	7.81	0.014	87.79	30.47	118.25
2	1	2	642.43	322.40	964.83	13.5	15.7	0.052	7.04	7.89	0.020	91.22	45.78	136.99
2	1	3	611.01	433.81	1044.81	14	17	0.071	7.24	8.37	0.027	84.42	59.94	144.36
2	2	1	639.45	221.40	860.86	13.5	15.4	0.045	7.04	7.77	0.017	90.79	31.44	122.23
2	2	2	669.26	331.79	1001.05	14.5	17.6	0.074	7.43	8.59	0.028	90.07	44.65	134.72
2	2	3	633.79	430.36	1064.15	14	16.5	0.060	7.24	8.19	0.023	87.57	59.46	147.03
3	1	1	606.31	223.26	829.57	13.5	15.3	0.043	7.04	7.74	0.017	86.09	31.70	117.79
3	1	2	607.76	330.26	938.02	14.5	17.3	0.067	7.43	8.48	0.025	81.79	44.45	126.24
3	1	3	623.48	431.67	1055.15	13.5	15.5	0.048	7.04	7.81	0.018	88.53	61.29	149.82
3	2	1	615.40	217.48	832.88	15	17	0.048	7.62	8.37	0.018	80.74	28.53	109.27
3	2	2	670.14	328.86	999.00	14	17	0.071	7.24	8.37	0.027	92.59	45.44	138.03
3	2	3	582.55	432.38	1014.93	13.5	15.5	0.048	7.04	7.81	0.018	82.72	61.39	144.11
4	1	1	635.57	224.48	860.05	15	17.7	0.064	7.62	8.63	0.024	83.39	29.45	112.84
4	1	2	673.71	326.26	999.98	13.5	16	0.060	7.04	8.00	0.023	95.66	46.33	141.98
4	1	3	625.84	430.48	1056.31	14	17	0.071	7.24	8.37	0.027	86.47	59.48	145.95
4	2	1	633.14	217.50	850.64	14	16	0.048	7.24	8.00	0.018	87.48	30.05	117.53
4	2	2	675.95	329.21	1005.17	14.5	17.5	0.071	7.43	8.56	0.027	90.97	44.30	135.27
4	2	3	645.01	430.88	1075.89	14.5	16.5	0.048	7.43	8.19	0.018	86.80	57.99	144.79
5	1	1	637.71	223.48	861.19	13.5	16	0.060	7.04	8.00	0.023	90.55	31.73	122.28
5	1	2	638.14	332.43	970.57	14	17	0.071	7.24	8.37	0.027	88.17	45.93	134.10
5	1	3	577.36	425.43	1002.79	13.5	16	0.060	7.04	8.00	0.023	81.98	60.41	142.38
5	2	1	603.50	221.52	825.02	14	16	0.048	7.24	8.00	0.018	83.38	30.61	113.99
5	2	2	672.62	324.29	996.90	13.5	15.8	0.055	7.04	7.92	0.021	95.50	46.04	141.55
5	2	3	586.01	435.83	1021.84	14.5	17.5	0.071	7.43	8.56	0.027	78.86	58.65	137.52
6	1	1	634.29	215.36	849.64	13.5	15	0.036	7.04	7.62	0.014	90.06	30.58	120.64
6	1	2	673.90	333.07	1006.98	14	17	0.071	7.24	8.37	0.027	93.11	46.02	139.13
6	1	3	574.10	432.71	1006.81	13.5	16	0.060	7.04	8.00	0.023	81.51	61.44	142.95
6	2	1	627.02	223.45	850.48	13.5	15	0.036	7.04	7.62	0.014	89.03	31.73	120.76
6	2	2	683.90	334.57	1018.48	13.5	16.6	0.074	7.04	8.22	0.028	97.11	47.50	144.61
6	2	3	632.62	438.86	1071.48	13.5	16.5	0.071	7.04	8.19	0.027	89.82	62.31	152.14

7	1	1	607.86	220.31	828.17	14	16	0.048	7.24	8.00	0.018	83.99	30.44	114.43
7	1	2	636.40	331.38	967.79	14.5	16.5	0.048	7.43	8.19	0.018	85.65	44.60	130.24
7	1	3	579.35	432.71	1012.06	14	16	0.048	7.24	8.00	0.018	80.05	59.79	139.83
7	2	1	631.31	227.50	858.81	14.5	17	0.060	7.43	8.37	0.022	84.96	30.62	115.58
7	2	2	629.50	324.29	953.79	14	16	0.048	7.24	8.00	0.018	86.98	44.81	131.78
7	2	3	594.12	429.31	1023.43	13.5	16	0.060	7.04	8.00	0.023	84.36	60.96	145.31
8	1	1	644.10	226.26	870.36	14.5	16	0.036	7.43	8.00	0.014	86.68	30.45	117.13
8	1	2	658.00	327.90	985.90	14	16.5	0.060	7.24	8.19	0.023	90.91	45.31	136.22
8	1	3	626.31	433.40	1059.72	14.5	16.8	0.055	7.43	8.30	0.021	84.29	58.33	142.61
8	2	1	621.60	224.02	845.62	14	15.3	0.031	7.24	7.74	0.012	85.88	30.95	116.84
8	2	2	674.43	334.76	1009.19	14	16.5	0.060	7.24	8.19	0.023	93.18	46.25	139.44
8	2	3	600.70	425.07	1025.77	14.5	16.7	0.052	7.43	8.26	0.020	80.84	57.21	138.05

Strint – straw intake; Stint – Stylosanthes intake; Toint – total intake; Inwt – initial weight; Fnwt – final weight; ADG – average daily gain; Inmw – initial metabolic weight; Fnmw – final weight on metabolic basis; ADMG – average daily gain on metabolic basis; Strntm – straw intake on metabolic weight basis; stntm – Stylosanthes intake on metabolic weight basis; Tontm – total weight on metabolic weght basis

AP 4.2. Values for feeding trial studies using *Samanea saman* as supplement

Obsv	Rep	Trt	Strnt	Sant	Tont	Inwt	Fnwt	Adg(g)	Inmw	Fnmw	Adgm	Strntm	Santm	Tontm
1	1	1	653	236	889	13.1	14.6	35.71	6.89	7.47	13.79	94.78	34.25	129.03
1	1	2	606	349	955	13	15	47.62	6.85	7.62	18.38	88.47	50.95	139.42
1	1	3	647	468	1115	12.8	15.8	71.43	6.77	7.92	27.50	95.57	69.13	164.70
1	2	1	634	231	865	13	15.5	59.52	6.85	7.81	22.90	92.55	33.72	126.28
1	2	2	686	350	1036	13	16	71.43	6.85	8.00	27.38	100.15	51.09	151.24
1	2	3	621	478	1099	13	15	47.62	6.85	7.62	18.38	90.66	69.78	160.44
2	1	1	659	230	889	14	15	23.81	7.24	7.62	9.10	91.02	31.77	122.79
2	1	2	721	330	1051	13	14.5	35.71	6.85	7.43	13.82	105.26	48.18	153.43
2	1	3	677	476	1153	12.9	14.9	47.62	6.81	7.58	18.42	99.41	69.90	169.31
2	2	1	690	236	926	12.9	14.4	35.71	6.81	7.39	13.86	101.32	34.65	135.98
2	2	2	713	347	1060	13	15	47.62	6.85	7.62	18.38	104.09	50.66	154.74
2	2	3	640	467	1107	13	16.5	83.33	6.85	8.19	31.83	93.43	68.18	161.61
3	1	1	675	238	913	13.2	14.9	40.48	6.93	7.58	15.57	97.40	34.34	131.75
3	1	2	663	350	1013	13.1	15.3	52.38	6.89	7.74	20.14	96.23	50.80	147.02
3	1	3	667	471	1138	13.1	15.1	47.62	6.89	7.66	18.33	96.81	68.36	165.17
3	2	1	728	233	961	12.9	14.1	28.57	6.81	7.28	11.10	106.90	34.21	141.12
3	2	2	696	339	1035	13	14.7	40.48	6.85	7.51	15.65	101.61	49.49	151.09
3	2	3	700	465	1165	12.9	15.9	71.43	6.81	7.96	27.44	102.79	68.28	171.07
4	1	1	683	239	922	12.9	14.4	35.71	6.81	7.39	13.86	100.29	35.10	135.39
4	1	2	699	341	1040	13	15	47.62	6.85	7.62	18.38	102.04	49.78	151.82
4	1	3	637	468	1105	13.2	16.2	71.43	6.93	8.07	27.26	91.92	67.53	159.45
4	2	1	614	229	843	13	15.5	59.52	6.85	7.81	22.90	89.64	33.43	123.07
4	2	2	608	348	956	12.9	15.9	71.43	6.81	7.96	27.44	89.28	51.10	140.38
4	2	3	694	468	1162	12.8	16.8	95.24	6.77	8.30	36.38	102.51	69.13	171.64
5	1	1	703	233	936	13	15	47.62	6.85	7.62	18.38	102.63	34.01	136.64
5	1	2	657	359	1016	13.2	15.7	59.52	6.93	7.89	22.79	94.81	51.80	146.61
5	1	3	615	454	1069	13	15	47.62	6.85	7.62	18.38	89.78	66.28	156.06
5	2	1	647	231	878	13	14.5	35.71	6.85	7.43	13.82	94.45	33.72	128.18
5	2	2	646	352	998	13	15	47.62	6.85	7.62	18.38	94.31	51.39	145.69
5	2	3	691	464	1155	12.9	15.4	59.52	6.81	7.77	22.95	101.47	68.14	169.60
6	1	1	677	236	913	13	15.5	59.52	6.85	7.81	22.90	98.83	34.45	133.28
6	1	2	652	354	1006	13	16	71.43	6.85	8.00	27.38	95.18	51.68	146.86
6	1	3	697	457	1154	13	16.5	83.33	6.85	8.19	31.83	101.75	66.72	168.47
6	2	1	611	236	847	13.1	14.6	35.71	6.89	7.47	13.79	88.68	34.25	122.93
6	2	2	723	344	1067	13.3	15.3	47.62	6.96	7.74	18.48	103.88	49.43	153.30
6	2	3	648	467	1115	12.9	15.4	59.52	6.81	7.77	22.95	95.15	68.58	163.73
7	1	1	604	224	828	13.1	15.6	59.52	6.89	7.85	22.85	87.66	32.51	120.17
7	1	2	677	340	1017	12.9	15.9	71.43	6.81	7.96	27.44	99.41	49.93	149.34

7	1	3	633	479	1112	13.2	16.2	71.43	6.93	8.07	27.26	91.34	69.12	160.46
7	2	1	707	236	943	13	14.5	35.71	6.85	7.43	13.82	103.21	34.45	137.66
7	2	2	636	352	988	13	16	71.43	6.85	8.00	27.38	92.85	51.39	144.23
7	2	3	623	472	1095	13	16	71.43	6.85	8.00	27.38	90.95	68.91	159.85
8	1	1	662	216	878	13	14.5	35.71	6.85	7.43	13.82	96.64	31.53	128.18
8	1	2	689	347	1036	12.9	14.9	47.62	6.81	7.58	18.42	101.17	50.95	152.13
8	1	3	681	443	1124	13.2	15.7	59.52	6.93	7.89	22.79	98.27	63.92	162.19
8	2	1	619	237	856	13	14.5	35.71	6.85	7.43	13.82	90.36	34.60	124.96
8	2	2	639	350	989	13	15	47.62	6.85	7.62	18.38	93.28	51.09	144.38
8	2	3	613	467	1080	13	16	71.43	6.85	8.00	27.38	89.49	68.18	157.66

Strint – straw intake; Stint – Samanea intake; Toint – total intake; Inwt – initial weight; Fnwt – final weight; Adg – average daily gain; Inmw – initial metabolic weight; Fnmw – final weight on metabolic basis; Adgm – average daily gain on metabolic basis; Strntm – straw intake on metabolic weight basis; stntm – Samanea intake on metabolic weight basis; Tontm – total weight on metabolic weght basis

APPENDIX 5: ANOVA TABLES

DIGESTIBILITY INTAKE

Variate: Straw Intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	2368.1	789.4	1.26	
REP *Units* stratum					
FAC_A	1	36.0	36.0	0.06	0.816
FAC_B	1	712.9	712.9	1.14	0.314
FAC_A.FAC_B	1	36.0	36.0	0.06	0.816
Residual	9	5640.6	626.7		
Total	15	8793.7			

Variate: Straw Intake on Metabolic basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	24.606	8.202	1.63	
REP *Units* stratum					
FAC_A	1	151.157	151.157	30.04	<.001
FAC_B	1	36.059	36.059	7.17	0.025
FAC_A.FAC_B	1	0.091	0.091	0.02	0.896
Residual	9	45.288	5.032		
Total	15	257.201			

Variate: Samanea and Stylo Intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	151.73	50.58	1.13	
REP *Units* stratum					
FAC_A	1	0.00	0.00	0.00	1.000
FAC_B	1	13432.81	13432.81	300.11	<.001
FAC_A.FAC_B	1	400.00	400.00	8.94	0.015
Residual	9	402.84	44.76		
Total	15	14387.38			

Variate: Samanea and Stylo Intake on Metabolic basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.7905	0.5968	1.18	
REP *Units* stratum					
FAC_A	1	54.2089	54.2089	107.05	<.001
FAC_B	1	40.4334	40.4334	7.17	<.001
FAC_A.FAC_B	1	3.7241	3.7241	0.02	0.024
Residual	9	4.5573	0.5064		
Total	15	104.7143			

Variate: Total Intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	3536.8	1178.9	2.34	
REP *Units* stratum					
FAC_A	1	36.0	36.0	0.07	0.795
FAC_B	1	20334.8	20334.8	40.31	<.001
FAC_A.FAC_B	1	676.0	676.0	1.34	0.277
Residual	9	4539.9	504.4		
Total	15	29123.5			

Variate: Total Intake on Metabolic basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	38.610	12.870	3.17	
REP *Units* stratum					
FAC_A	1	386.409	386.409	95.10	<.001
FAC_B	1	0.125	0.125	0.03	0.865
FAC_A.FAC_B	1	2.651	2.651	0.65	0.440
Residual	9	36.569	4.063		
Total	15	464.364			

Variate: Initial Weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.24500	0.08167	1.69	
REP *Units* stratum					
FAC_A	1	36.00000	36.00000	744.83	<.001
FAC_B	1	16.00000	16.00000	331.03	<.001
FAC_A.FAC_B	1	0.00000	0.00000	0.00	1.000
Residual	9	0.43500	0.04833		
Total	15	52.68000			

Variate: Initial Weight on Metabolic basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.028722	0.009574	1.70	
REP *Units* stratum					
FAC_A	1	4.273564	4.273564	744.83	<.001
FAC_B	1	1.899962	1.899962	331.03	<.001
FAC_A.FAC_B	1	0.000527	0.000527	0.00	0.767
Residual	9	0.050713	0.005635		
Total	15	6.253488			

Variate: Final Weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.1950	0.3983	1.74	
REP *Units* stratum					
FAC_A	1	36.0000	36.0000	156.90	<.001
FAC_B	1	16.0000	16.0000	66.73	<.001
FAC_A.FAC_B	1	4.0000	4.0000	17.43	0.002
Residual	9	2.0650	0.2294		
Total	15	59.2600			

Variate: Final Weight on Metabolic basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.13331	0.04444	1.73	
REP *Units* stratum					
FAC_A	1	4.02580	4.02580	157.09	<.001
FAC_B	1	1.77506	1.77506	69.26	<.001
FAC_A.FAC_B	1	0.42443	0.42443	16.56	0.003
Residual	9	0.23065	0.02563		
Total	15	6.58925			

Variate: Change in Weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.37000	0.12333	1.48	
REP *Units* stratum					
FAC_A	1	0.00000	0.00000	0.00	1.000
FAC_B	1	0.00000	0.00000	0.00	1.000
FAC_A.FAC_B	1	4.00000	4.00000	48.00	<.001
Residual	9	0.75000	0.08333		
Total	15	5.12000			

Variate: Change in Weight on Metabolic basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.039763	0.013254	1.45	
REP *Units* stratum					
FAC_A	1	0.003699	0.003699	0.40	0.541
FAC_B	1	0.002123	0.002123	0.23	0.641
FAC_A.FAC_B	1	0.454866	0.454866	49.73	<.001
Residual	9	0.082325	0.009147		
Total	15	0.582776			

Variate: ADG

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0004719	0.0001573	1.48	
REP *Units* stratum					
FAC_A	1	0.0000000	36.00000	0.00	1.000
FAC_B	1	0.0000000	16.00000	0.00	0.000
FAC_A.FAC_B	1	0.0051020	0.0051020	48.00	<.001
Residual	9	0.0009566	0.0001063		
Total	15	0.0065306			

Variate: ADG on Metabolic basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.00005072	0.00001691	1.45	
REP *Units* stratum					
FAC_A	1	0.00000472	0.00000472	0.40	0.541
FAC_B	1	0.00000271	0.00000271	0.23	0.641
FAC_A.FAC_B	1	0.00058019	0.00058019	49.73	<.001
Residual	9	0.00010501	0.00001167		
Total	15	0.00074334			

Variate: DM Digestibility

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0014667	0.0004889	1.71	
REP *Units* stratum					
FAC_A	1	0.0042576	0.0042576	14.90	0.004
FAC_B	1	0.0005406	0.0005406	1.89	0.202
FAC_A.FAC_B	1	0.0023281	0.0023281	8.15	0.019
Residual	9	0.0025716	0.0002857		
Total	15	0.0111644			

Variate: OM Digestibility

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0007385	0.0002462	0.71	
REP *Units* stratum					
FAC_A	1	0.0022563	0.0022563	6.50	0.031
FAC_B	1	0.0000040	0.0000040	0.01	0.917
FAC_A.FAC_B	1	0.0006003	0.0006003	1.73	0.221
Residual	9	0.0031230	0.0003470		
Total	15	0.0067220			

Variate: N Digestibility

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0001207	0.0000402	0.39	
REP *Units* stratum					
FAC_A	1	0.0271426	0.0271426	263.08	<.001
FAC_B	1	0.0001051	0.0001051	1.02	0.339
FAC_A.FAC_B	1	0.0317731	0.0317731	307.96	<.001
Residual	9	0.0009286	0.0001032		
Total	15	0.0600699			

Variate: NDF Digestibility

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.00021161	0.00007054	1.78	
REP *Units* stratum					
FAC_A	1	0.02581248	0.02581248	651.11	<.001
FAC_B	1	0.01199889	0.01199889	302.67	<.001
FAC_A.FAC_B	1	0.02690536	0.02690536	678.67	<.001
Residual	9	0.00035680	0.00003964		
Total	15	0.06528515			

Variate: Total N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.2512	0.4171	2.98	
REP *Units* stratum					
FAC_A	1	0.7225	0.7225	5.16	0.049
FAC_B	1	31.1922	31.1922	222.57	<.001
FAC_A.FAC_B	1	2.4649	2.4649	17.59	0.002
Residual	9	1.2613	0.1401		
Total	15	38.8922			

Variate: Faecal N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.1133	0.0378	0.24	
REP *Units* stratum					
FAC_A	1	6.7470	6.7470	43.14	<.001
FAC_B	1	4.1108	4.1108	26.28	<.001
FAC_A.FAC_B	1	7.0093	7.0093	44.81	<.001
Residual	9	1.4077	0.1564		
Total	15	19.3880			

Variate: Urine N

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0014667	0.0004889	0.28	
REP *Units* stratum					
FAC_A	1	$2.031E^{-04}$	$2.031E^{-04}$	36.51	<.001
FAC_B	1	$5.063E^{-06}$	$5.063E^{-06}$	0.91	0.365
FAC_A.FAC_B	1	$4.731E^{-04}$	$4.731E^{-04}$	85.04	<.001
Residual	9	$5.006E^{-05}$	$5.562E^{-06}$		
Total	15	$7.359E^{-04}$			

Variate: N Digested

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.4257	0.4752	2.53	
REP *Units* stratum					
FAC_A	1	11.8853	11.8853	63.27	<.001
FAC_B	1	12.6558	12.6558	67.38	<.001
FAC_A.FAC_B	1	17.7873	17.7873	94.69	<.001
Residual	9	1.6906	0.1878		
Total	15	45.4446			

Variate: N Digestibility

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	7.477	2.492	0.65	
REP *Units* stratum					
FAC_A	1	277.324	277.324	72.61	<.001
FAC_B	1	1.241	1.241	0.32	0.583
FAC_A.FAC_B	1	327.083	327.083	85.64	<.001
Residual	9	34.374	3.819		
Total	15	647.499			

Variate: N Retention

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.4219	0.4740	2.51	
REP *Units* stratum					
FAC_A	1	11.7872	11.7872	62.33	<.001
FAC_B	1	12.6718	12.6718	67.00	<.001
FAC_A.FAC_B	1	17.9712	17.9712	95.03	<.001
Residual	9	1.7021	0.1819		
Total	15	45.5542			

Variate: % of Intake Retained

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	7.475	2.492	0.65	
REP *Units* stratum					
FAC_A	1	275.363	275.363	71.66	<.001
FAC_B	1	1.114	1.114	0.29	0.603
FAC_A.FAC_B	1	331.662	331.662	86.31	<.001
Residual	9	34.583	3.843		
Total	15	680.198			

Variate: Retained % of N Digested

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0000922	0.0000307	0.05	
REP *Units* stratum					
FAC_A	1	0.0006839	0.0006839	1.06	0.331
FAC_B	1	0.0089184	0.0089184	13.77	0.005
FAC_A.FAC_B	1	0.0612955	0.0612955	94.67	<.001
Residual	9	0.0058269	0.0006474		
Total	15	0.0768169			

Variate: PH 0 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0017188	0.0005729	0.71	
REP *Units* stratum					
FAC_A	1	0.0068063	0.0068063	8.38	0.018
FAC_B	1	0.0637562	0.0637562	78.54	<.001
FAC_A.FAC_B	1	0.0000562	0.0000562	0.07	0.798
Residual	9	0.0073062	0.0008118		
Total	15	0.0796437			

Variate: PH 2 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.000819	0.000273	0.26	
REP *Units* stratum					
FAC_A	1	0.031506	0.031506	30.47	<.001
FAC_B	1	0.012656	0.012656	12.24	0.007
FAC_A.FAC_B	1	0.000506	0.000506	0.49	0.502
Residual	9	0.009306	0.001034		
Total	15	0.054794			

Variate: PH 4 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0063188	0.0021063	3.29	
REP *Units* stratum					
FAC_A	1	0.0315062	0.0315062	49.26	<.001
FAC_B	1	0.0033062	0.0033062	5.17	0.049
FAC_A.FAC_B	1	0.0770063	0.0770063	120.40	<.001
Residual	9	0.0057562	0.0006396		
Total	15	0.1238937			

Variate: PH 6 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.003350	0.001117	0.98	
REP *Units* stratum					
FAC_A	1	0.013225	0.013225	11.56	0.008
FAC_B	1	0.000625	0.000625	0.55	0.479
FAC_A.FAC_B	1	0.048400	0.048400	42.29	<.001
Residual	9	0.010300	0.001144		
Total	15	0.075900			

Variate: NH_3-N 0 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0019687	0.0006562	0.79	
REP *Units* stratum					
FAC_A	1	0.0000063	0.0000063	0.01	0.933
FAC_B	1	20.8164062	20.8164062	24958.89	<.001
FAC_A.FAC_B	1	2.8140062	2.8140062	3374.00	<.001
Residual	9	0.0075062	0.0008340		
Total	15	23.6398938			

Variate: NH_3-N 2 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0056750	0.0018917	3.42	
REP *Units* stratum					
FAC_A	1	1.2996000	1.2996000	2351.04	<.001
FAC_B	1	0.5625000	0.5625000	1017.59	<.001
FAC_A.FAC_B	1	0.1122250	0.1122250	203.02	<.001
Residual	9	0.0049750	0.0005528		
Total	15	1.9849750			

Variate: NH_3-N 4 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.008319	0.002773	1.04	
REP *Units* stratum					
FAC_A	1	5.652506	5.652506	2110.35	<.001
FAC_B	1	0.351056	0.351056	131.07	<.001
FAC_A.FAC_B	1	10.256006	10.256006	3829.05	<.001
Residual	9	0.024106	0.002678		
Total	15	16.291994			

Variate: NH_3-N 6 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.0064750	0.0021583	2.63	
REP *Units* stratum					
FAC_A	1	0.4356000	0.4356000	531.58	<.001
FAC_B	1	0.2970250	0.2970250	362.47	<.001
FAC_A.FAC_B	1	7.4529000	7.4529000	9095.06	<.001
Residual	9	0.0073750	0.0008194		
Total	15	8.1993750			

Variate: BUN 0 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.001350	0.000450	0.24	
REP *Units* stratum					
FAC_A	1	22.184100	22.184100	11955.50	<.001
FAC_B	1	0.013225	0.013225	7.13	0.026
FAC_A.FAC_B	1	4.431025	4.431025	2387.98	<.001
Residual	9	0.016700	0.001856		
Total	15	26.646400			

Variate: BUN 2 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	22.043025	0.0000307	0.51	
REP *Units* stratum					
FAC_A	1	0.0006839	0.0006839	13776.89	<.001
FAC_B	1	0.009025	0.009025	5.64	0.042
FAC_A.FAC_B	1	2.958400	2.958400	1849.00	<.001
Residual	9	0.014400	0.001600		
Total	15	25.027300			

Variate: BUN 4 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.000875	0.000292	0.22	
REP *Units* stratum					
FAC_A	1	29.160000	29.160000	22478.80	<.001
FAC_B	1	0.160000	0.160000	123.34	<.001
FAC_A.FAC_B	1	4.906225	4.906225	3782.10	<.001
Residual	9	0.011675	0.001297		
Total	15	34.238775			

Variate: BUN 6 h

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.000425	0.000142	0.09	
REP *Units* stratum					
FAC_A	1	32.433025	32.433025	19958.78	<.001
FAC_B	1	0.012100	0.012100	7.45	0.023
FAC_A.FAC_B	1	9.610000	9.610000	5913.85	<.001
Residual	9	0.014625	0.001625		
Total	15	42.070175			

INCUBATION SCHEDULE

ROUND 1

HOURS	ANIMAL NUMBERS				Date/Time
	1	2	3	4	
72	Nerica 2	Samanea	Nerica 1	Stylosanthes	5/6/09; 6 pm
48	Samanea	Nerica 1	Stylosanthes	Nerica 2	5/6/09; 6 pm
24	Nerica 1	Stylosanthes	Nerica 2	Samanea	5/6/09; 6 pm
12	Stylosanthes	Nerica 2	Samanea	Nerica 1	5/6/09; 6 pm
6	Nerica 2	Samanea	Nerica 1	Stylosanthes	5/6/09; 6 pm

ANOVA TABLES: DEGRADABILITY STUDIES.

Variate: Potential degradability for *Stylosanthes hamata* foliage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.06973	0.02324	1.13	
REP *Units* stratum					
FAC_A	1	2.54403	2.54403	123.51	<.001
FAC_B	1	12.99602	12.99602	630.96	<.001
FAC_A.FAC_B	1	27.09202	27.09202	1315.32	<.001
Residual	9	0.18537	0.02060		
Total	15	42.88717			

Variate: Potentially degradable but water insoluble fraction (*Stylosanthes hamata*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.2012	0.0671	0.56	
REP *Units* stratum					
FAC_A	1	2.8730	2.8730	23.84	<.001
FAC_B	1	12.2150	12.2150	101.37	<.001
FAC_A.FAC_B	1	28.0370	28.0370	232.68	<.001
Residual	9	1.0845	0.1205		
Total	15	44.4108			

Variate: Rate constant for (*Stylosanthes hamata*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.375E-09	4.583E-07	1.48	
REP *Units* stratum					
FAC_A	1	2.500E-09	2.500E-09	0.01	0.930
FAC_B	1	3.481E-05	3.481E-05	112.69	<.001
FAC_A.FAC_B	1	1.892E-05	1.892E-05	61.26	<.001
Residual	9	2.780E-06	3.089E-07		
Total	15	5.789E-05			

Variate: Potential degradability for *Samanea saman* foliage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.23420	0.07807	3.34	
REP *Units* stratum					
FAC_A	1	1.44000	1.44000	61.54	<.001
FAC_B	1	29.16000	29.16000	1246.15	<.001
FAC_A.FAC_B	1	31.36000	31.36000	1340.17	<.001
Residual	9	0.21060	0.02340		
Total	15				

Variate: Potentially degradable but water insoluble fraction (*Samanea saman*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.06420	0.0214	0.29	
REP *Units* stratum					
FAC_A	1	1.69000	1.69000	22.61	0.001
FAC_B	1	28.09000	28.09000	375.87	<.001
FAC_A.FAC_B	1	30.25000	30.25000	404.77	<.001
Residual	9	0.67260	0.07473		
Total	15	60.76680			

Variate: Rate constant for (*Samanea saman*)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	4.032E-08	1.344E-08	0.64	
REP *Units* stratum					
FAC_A	1	9.950E-07	9.950E-07	47.49	<.001
FAC_B	1	8.955E-06	8.955E-06	427.43	<.001
FAC_A.FAC_B	1	8.985E-06	8.985E-06	428.86	<.001
Residual	9	1.886E-07	2.095E-08		
Total	15	1.916E-05			

Variate: Potential degradability for Nerica 1 rice straw

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.04000	0.01333	1.02	
REP *Units* stratum					
FAC_A	1	19.36000	19.36000	1476.61	<.001
FAC_B	1	25.00000	25.00000	1906.78	<.001
FAC_A.FAC_B	1	31.36000	31.36000	2391.86	<.001
Residual	9	0.11800	0.01311		
Total	15	75.87800			

Variate: Potentially degradable but water insoluble fraction (Nerica 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.3795	0.1265	1.13	
REP *Units* stratum					
FAC_A	1	17.0363	17.0363	151.84	<.001
FAC_B	1	27.7993	27.7993	247.76	<.001
FAC_A.FAC_B	1	26.2913	26.2913	234.32	<.001
Residual	9	1.0098	0.1122		
Total	15	72.5160			

Variate: Rate constant for (Nerica 1)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.700E-07	5.667E-08	1.29	
REP *Units* stratum					
FAC_A	1	8.100E-07	8.100E-07	18.46	0.002
FAC_B	1	1.102E-06	1.102E-06	25.12	<.001
FAC_A.FAC_B	1	8.702E-06	8.702E-06	198.28	<.001
Residual	9	3.950E-07	4.389E-08		
Total	15	1.118E-05			

Variate: Potential degradability for Nerica 2 rice straw

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	1.0265	0.3422	1.34	
REP *Units* stratum					
FAC_A	1	1.5376	1.5376	6.03	0.036
FAC_B	1	2.1316	2.1316	8.36	0.018
FAC_A.FAC_B	1	2.7556	2.7556	10.80	0.009
Residual	9	2.2958	0.2551		
Total	15	9.7470			

Variate: Potentially degradable but water insoluble fraction (Nerica 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	0.13315	0.04438	1.46	
REP *Units* stratum					
FAC_A	1	1.56250	1.56250	51.35	<.001
FAC_B	1	2.10250	2.10250	69.10	<.001
FAC_A.FAC_B	1	2.65690	2.65690	87.32	<.001
Residual	9	0.27385	0.03043		
Total	15	6.72890			

Variate: Rate constant for (Nerica 2)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
REP stratum	3	9.467E-06	3.156E-06	2.62	
REP *Units* stratum					
FAC_A	1	1.626E-06	1.626E-06	1.35	0.275
FAC_B	1	5.881E-06	5.881E-06	4.89	0.054
FAC_A.FAC_B	1	7.701E-06	7.701E-06	6.47	0.032
Residual	9	1.082E-05	1.202E-06		
Total	15	3.549E-05			

ANOVA TABLES FOR PASSAGE KINETICS STUDIES.

Variate: TT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
ROWS stratum	3	6.469E-03	2.156E-03		
ROWS.COLS. *Units* stratum					
TRT	3	1.215E+03	4.049E+02	70345.49	<.001
Residual	9	5.181E-02	5.756E-03		
Total	15	1.215E+03			

Variate: k1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
ROWS stratum	3	9.507E-06	3.169E-06	3.21	
ROWS.COLS.*Units* stratum					
TRT	3	8.164E-05	2.721E-05	27.60	<.001
Residual	9	8.876E-06	9.862E-07		
Total	15	1.000E-04			

Variate: k2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
ROWS stratum	3	9.302E-06	3.101E-06	2.98	
ROWS.COLS. *Units* stratum					
TRT	3	9.949E-05	3.316E-05	31.88	<.001
Residual	9	9.361E-06	1.040E-06		
Total	15	1.181E-04			

Variate: t1/2 Fore gut

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
ROWS stratum	3	0.6232	0.2077	0.99	
ROWS.COLS. *Units* stratum					
TRT	3	205.2603	68.4201	326.81	<.001
Residual	9	1.8842	0.2094		
Total	15	207.7676			

Variate: t1/2 Hindgut

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
ROWS stratum	3	2.4409	0.8136	0.96	
ROWS.COLS. *Units* stratum					
TRT	3	63.8708	21.2903	25.14	<.001
Residual	9	7.6217	0.8469		
Total	15	73.9334			

Variate: MRT

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
ROWS stratum	3	0.022350	0.007450	3.98	
ROWS.COLS. *Units* stratum					
TRT	3	462.004300	154.001433	82255.96	<.001
Residual	9	0.016850	0.001872		
Total	15	462.043500			

ANOVA TABLES FOR *STYLOSANTHES HAMATA* SUPPLEMENTED FEEDING TRIAL

Variate: Straw intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	444.3	444.3	1.10	0.301
FAC_B	2	19927.3	9963.6	24.64	<.001
FAC_A.FAC_B	2	1524.1	762.1	1.88	0.165
Residual	42	16982.9	404.4		
Total	47	38878.6			

Variate: Straw intake on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	96.05	48.02	4.00	0.026
FAC_B	2	16.71	16.71	1.39	0.244
FAC_A.FAC_B	2	292.35	146.17	12.19	<.001
Residual	42	503.72	11.99		
Total	47	908.83			

Variate: Stylo Intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	2.40	2.40	0.15	0.699
FAC_B	2	354065.26	177032.63	11209.50	<.001
FAC_A.FAC_B	2	10.99	5.49	0.35	0.708
Residual	42	663.31	15.79		
Total	47	354741.96			

Variate: Stylo intake on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	1699.889	849.944	624.49	<.001
FAC_B	2	0.024	0.024	0.02	0.895
FAC_A.FAC_B	2	5111.056	2555.528	1877.66	<.001
Residual	42	57.163	1.361		
Total	47	6868.132			

Variate: Total intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	519.9	519.9	1.19	0.282
FAC_B	2	302421.1	151210.6	345.72	<.001
FAC_A.FAC_B	2	1423.2	711.6	1.63	0.209
Residual	42	18369.7	437.4		
Total	47	322734.0			

Variate: Total intake on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	1766.59	883.30	45.24	<.001
FAC_B	2	15.70	15.70	0.80	0.375
FAC_A.FAC_B	2	4105.73	2052.86	105.15	<.001
Residual	42	819.96	19.52		
Total	47	6707.99			

Variate: Initial weight (Stylo)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.0052	0.0052	0.03	0.875
FAC_B	2	0.0104	0.0052	0.03	0.975
FAC_A.FAC_B	2	0.0104	0.0052	0.03	0.975
Residual	42	8.7188	0.2076		
Total	47	8.7448			

Variate: Initial weight on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.00078	0.00078	0.02	0.875
FAC_B	2	0.00155	0.00078	0.02	0.975
FAC_A.FAC_B	2	0.00155	0.00078	0.02	0.975
Residual	42	1.30714	0.03112		
Total	47	1.31102			

Variate: Final weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.0052	0.0052	0.01	0.916
FAC_B	2	3.0913	1.5456	3.31	0.046
FAC_A.FAC_B	2	0.0679	0.0340	0.07	0.930
Residual	42	19.5888	0.4664		
Total	47	22.7531			

Variate: Final weight on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.00072	0.00072	0.01	0.916
FAC_B	2	0.43376	0.21688	3.35	0.045
FAC_A.FAC_B	2	0.00922	0.00461	0.07	0.931
Residual	42	2.72091	0.06478		
Total	47	3.16461			

Variate: ADG

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.0000000	0.0000000	0.00	1.000
FAC_B	2	0.0018185	0.0009093	8.36	<.001
FAC_A.FAC_B	2	0.0000645	0.0000322	0.30	0.745
Residual	42	0.0045677	0.0001088		
Total	47	0.0064508			

Variate: ADG on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.0000000	0.0000000	0.00	0.995
FAC_B	2	0.00025468	0.00012734	8.51	<.001
FAC_A.FAC_B	2	0.00000898	0.00000449	0.30	0.742
Residual	42	0.00062813	0.00001496		
Total	47	0.00089179			

ANOVA TABLES FOR *SAMANEA SAMAN* SUPPLEMENTED FEEDING TRIAL

Variate: Straw intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	1.0	1.0	0.00	0.980
FAC_B	2	518.0	259.0	0.17	0.846
FAC_A.FAC_B	2	2013.0	1006.0	0.65	0.527
Residual	42	64990.0	1547.0		
Total	47	67522.0			

Variate: Straw intake on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.14	0.14	0.00	0.946
FAC_B	2	12.98	6.49	0.21	0.808
FAC_A.FAC_B	2	21.28	10.90	0.36	0.700
Residual	42	1273.99	30.33		
Total	47	1308.91			

Variate: Samanea intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	28.52	28.52	0.50	0.484
FAC_B	2	113767.88	56883.94	996.77	<.001
FAC_A.FAC_B	2	324177.04	162088.52	2840.25	<.001
Residual	42	2396.88	57.07		
Total	47	440370.31			

Variate: Samanea intake on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	2.858	2.858	2.08	0.156
FAC_B	2	2498.490	1249.245	910.88	<.001
FAC_A.FAC_B	2	6928.065	3464.033	2525.79	<.001
Residual	42	57.602	1.371		
Total	47	9487.015			

Variate: Total intake

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	27.	27.	0.02	0.885
FAC_B	2	102369.	51185.	40.48	<.001
FAC_A.FAC_B	2	317483.	158741.	125.53	<.001
Residual	42	53112.	1265.		
Total	47	472991.			

Variate: Total intake on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	4.26	4.26	0.14	0.710
FAC_B	2	2405.66	1202.83	39.46	<.001
FAC_A.FAC_B	2	6865.96	3432.98	112.61	<.001
Residual	42	1280.36	30.48		
Total	47	10556.25			

Variate: Initial Weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.10083	0.10083	3.39	0.073
FAC_B	2	0.05542	0.02771	0.93	0.402
FAC_A.FAC_B	2	0.07292	0.03646	1.23	0.304
Residual	42	1.25000	0.02976		
Total	47	1.47917			

Variate: Initial weight on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.016133	0.016133	3.54	0.067
FAC_B	2	0.008587	0.004294	0.94	0.398
FAC_A.FAC_B	2	0.010929	0.005465	1.20	0.311
Residual	42	0.191275	0.004554		
Total	47	0.226925			

Variate: Final weight

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.9479	0.4740	1.32	0.279
FAC_B	2	1.3669	1.3669	3.79	0.058
FAC_A.FAC_B	2	4.9213	2.4606	6.83	0.003
Residual	42	15.1337	0.3603		
Total	47	22.3698			

Variate: Final weight on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.13389	0.06694	1.30	0.283
FAC_B	2	0.19508	0.19508	3.79	0.058
FAC_A.FAC_B	2	0.70271	0.35136	6.82	0.003
Residual	42	2.16285	0.05150		
Total	47	3.19452			

Variate: ADG

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.0009148	0.0004574	2.06	0.140
FAC_B	2	0.0003837	0.0003837	1.73	0.195
FAC_A.FAC_B	2	0.0030534	0.0015267	6.89	0.003
Residual	42	0.0093034	0.0002215		
Total	47	0.0136554			

Variate: ADG on metabolic weight basis

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
FAC_A	1	0.00013277	0.00006638	2.09	0.137
FAC_B	2	0.00005308	0.00005308	1.67	0.204
FAC_A.FAC_B	2	0.00043635	0.00021817	6.85	0.003
Residual	42	0.00133716	0.00003184		
Total	47	0.00195935			