EFFECT OF ROUGHAGE QUALITY AND PERIOD OF MEAL TERMINATION ON RUMEN FILL

By

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DECLARATION

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DEDICATION

I solely dedicate this work to Allah who facilitates its successful completion while overlooking my human frailties with unimaginable magnanimity. *Allahuma fagfirli dhunuubi wa taqabal minni innaka antal gafuuru raheem (aamin).*

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God bless.

ABBREVIATIONS

AADFD=Apparent acid detergent fibre digestibility

ADF= Acid detergent fibre

ADFI= Acid detergent fibre intake

AGE=age

ANDFD= Apparent neutral detergent fibre digestibility

ANN=Artificial neural network

AOMD=Apparent organic matter digestibility

CHO=Non-fibre, non-protein carbohydrate

CP=Crude protein

DDM=Dry matter digestibility

DM= Dry matter

DMI= Dry matter intake

DVR=Digital video recorder

ED=Effective degradation

GLM=General linear model

GIT=Gastro-intestinal tract

LBW=Body weight

MBW=Mature body weight

ME=Metabolizable energy

MEI= Metabolizable energy per day

MEIWT= Metabolizable energy/kg body weight

MGT=Housing system

NDF=Neutral detergent fibre

NDFI=Neutral detergent fibre intake

NTH=Non-treated hay

OMI=Organic matter intake

PD=Potential degradation

PHY=Physiological state

RF=Rumen fill

RFD=Rumen fill (dry)

SPT=Specie/type

USH=Urea-sprayed hay

UTH=Urea-treated hay

VFI=Voluntary feed intake

VGH=Veld grass hay

THESIS OUTPUT

Conference abstract

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2. Adebayo R. A. and Nsahlai I. V., 2014. Effect of roughage quality on reticulo-rumen fill. South Africa Society of Animal Science KZN Branch mini symposium. 1st October, 2014, Ukulinga research farm, UKZN.

3. Adebayo R. A., 2014. Can rumen fill be predicted using artificial neural network? College of Agriculture, Engineering and Earth Science postgraduate research day. 27th October, 2014. University of KwaZulu-Natal, Westville campus, pp 122.

General Abstract

This study was conducted to test the hypotheses that (1) reticulo-rumen fill remains the same with changes in nutritional quality of roughages and (2) irrespective of when meal termination occurs, reticulo-rumen fill in morning, afternoon or evening would be equal. Based on these hypotheses, while it sought to develop a generic model for predicting the 'fill' of the reticulo-rumen of goats, it specifically determined (1) the reticulo-rumen fill and digesta loads in other compartments of the GIT of goats upon termination of meal in the morning, afternoon and evening (2) the effect of period of meal termination on the size of reticulo-rumen fill and other digesta loads (3) the effect of diet quality on feed intake, water intake, weight changes, digestibility and feeding behaviour of goats. Complementary to this, it lends a hand using artificial neural network (ANN) for prediction of reticulo-rumen fill. The study used 18 goats which were in groups of six assigned to three dietary treatments comprising urea-treated hay (UTH), urea-sprayed hay (USH) and non-treated hay (NTH). Reticulo-rumen fill decreased with increased quality of roughages while treatments also affected digesta load in other distal compartments of the digestive tract. Also, reticulo-rumen fill measured in the evening was larger than those of morning and afternoon. By implication, period of measurement also influenced the size of the fill. Besides, diet quality enhanced dry matter intake but its effect on water intake was not significant. Also, dietary treatments have great impact on dry matter degradation, digestibility of nutrients and the feeding behaviour of goats. ANN explained 37% and 22% of the variation between the observed and predicted reticulo-rumen fill of goats, in its training and validation model, respectively. In conclusion, ANN could be used for prediction of reticulo-rumen fill of goats.

Key words; Reticulo-rumen fill; roughage; artificial neural network; urea; goats.

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Chapter 1

GENERAL INTRODUCTION

1.1 Background

Rumen fill is defined as the amount of herbage or roughage within the rumen and it is determined by the total intake and rate at which ingested ones leave the rumen (Weston and Hogan, 1971). It is an important indicator for long-term control of roughage intake in ruminants (Galyean and Oltjein, 1988) and its prediction is crucial to productivity of livestock (Yearsley *et al*., 2001). Roughages are plant-based highly fibrous feedstuffs that are readily available and are consumed by ruminants. They do not only subsist but relish them, and by pre-gastric fermentation in the rumen, they are able to derive much energy relative to non-ruminants (Allen, 1996).

This peculiar nature of ruminants to relish roughages is due to the presence of rumen compartment and billions of microbes surviving in it. These microflora assist in degradation of roughages to improve their intake and more importantly create space in the rumen. However, confinement of feed particles in dacron bags during *in sacco* experiment restricts microbial colonization rate such that actual rate may not be known (Nsahlai, 1991). In the rumen, microbes degrade the cellulose contents of the fibres and convert them into volatile fatty acids namely; acetate, propionate and butyrate. All these are absorbed through the wall of the reticulo-rumen into the blood stream by means of which they flow into the liver where they are also converted into adenosine triphosphate (ATP) in the form of energy useful for growth, pregnancy, milk production, body system maintenance, wool production and other purposes for which the animals are kept. Hence, increasing the intake of roughages or making their metabolism more efficient is synonymous with increasing productivity (Grovum, 1988).

Several signals on short-term and long-term are essentially integrated if roughages intake has to be increased. The start and stop signals, distension and fill of reticulo-rumen, digestibility of nutrients and animal metabolic size are some of the short-term signals. Start signal is when feed is available for animals and no other functions preclude eating (De Jong, 1986) and metabolic size is the weight of the animal when intake is adjusted to it or faecal output (Conrad, 1964).

Although the rumen capacity of a ruminant is large, space for them to forage or continue eating could only be created until a certain level of fill in the rumen (Hoffman, 1989). Hence, ruminants terminate feed consumption when the reticulo-rumen is filled. This results in physical limitation on intake and a potential difference in the energetic efficiency (Waldo, 1986), yet, rumen fill does not remain constant at a maximum even in nutritionally limited diet and animals due to continuous degradation by the rumen microbes and escape of particles (Gill and Romney, 1994). However, due to fibrous bulk in poor quality roughages, their intake is less than optimum (Jung and Allen, 1995) but other factors such as rumen fill and eating time can also explain this (Van Soest, 1994).

Neutral detergent fibre (NDF) of roughages is considered a major dietary factor affecting feed intake (Kendall *et al*., 2009) and which contributes significantly to space occupying properties of digesta load in the rumen and it is linearly correlated with dry matter intake. However, while NDF concentration in the rumen digesta load is generally pre-notion to be 1700 g per 100 kg of body weight, the intake of NDF more than 320 g/kgBW is also controlled by fill factors (Hoover, 1986). Invariably, increase in dietary NDF increases the reticulo-rumen fill, decreases dry matter intake and influences animal behaviour (Tjardes *et al*., 2002).

Rumen fill is also a function of initial bulk density and space it occupied in the rumen over time (Merten, 1987). Addition of bulk into the rumen reduces rumen capacity and depresses intake.

Neutral detergent fibre (NDF) and acid detergent fibre (ADF) composition in the cell wall of forages are major parameters of their nutritional components. All these, along with the forage maturity, species, cut size, processing methods, chemical treatment and conservation methods influence the feeding or eating behaviour of ruminants (Polat *et al.*, 2013). Nonetheless, dietary preferences and choices of animals are also influenced by constantly changing environment and human intervention in the production industry (Dicko and Sikena, 1992).

One of the intervention measures by man is to improve the quality of roughage with inclusion or treatment of the roughage with rumen degradable protein or rumen non-degradable protein. A good example is treating forages with urea. It is an effective method that improves the nutritional quality of the roughage, increases intake, improves digestibility and supports growth of the animals.

Using artificial neural network (ANN) is an innovation with powerful prediction technique that mimics the human brain and its effectiveness can also be examined in ruminant nutrition via reticulo-rumen fill studies.

1.2 Justification

Ruminant production ordinarily had witnessed quite appreciable dynamics since time immemorial. Despite the progress achieved, feeding still takes the largest percentage of production cost. One lingering challenge to ruminant producers is on how to predict sufficient feed quantities that can be consumed to achieve optimum production.

Degree of hunger stimulates eating and also affects a number of variables of ingestive behaviour and rate of feed intake. Therefore, reticulo-rumen fill is related to hunger and might regulate eating behaviour and other behavioural types exhibited by ruminants (Gregorini *et al*., 2007). Invariably, selection and intake of diets depend not only on available plant resources but also feeding behaviour and reticulo-rumen fill (Dicko and Sikena, 1992).

Seasonal fluctuation in the availability and quality of forages from place to place due to changes in temperature, humidity, precipitation, soil fertility and soil moisture content is another important challenge in ruminant production (Ben Salem and Smith, 2008). A better understanding of how to improve roughage quality and its influence on feeding behaviour, dry matter intake and reticulo-rumen fill enhances the development of management strategies aimed at maximizing the use of forages available for increased ruminant production and resolving these challenges at both times of deficit and lush.

1.3 Research question

Does rumen fill at meal termination remain the same throughout the day?

1.4 Research hypotheses

1. Artificial neural network (ANN) has the ability to predict rumen fill.
2. Reticulo-rumen fill will increase with the nutritional quality of roughage.
3. Reticulo-rumen fill will be similar irrespective of when meal termination occurs (i.e. morning =afternoon =evening).

1.5 Objectives:

1.5.1 Main objective

1. To develop a generic model for predicting the reticulo-rumen fill of goats.

1.5.2 Specific objectives:

1. To determine reticulo-rumen fill in the morning, afternoon and evening.
2. To determine the effect of diet quality on feed intake, water intake, live weight change and feeding behaviour in goats.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

Much work has been done globally to salvage the acute shortage of food. Ruminants as a vital source of animal proteins for the growing population cannot be discarded and are still very much relevant. Feed accounts for the highest cost of input in livestock production (Nsahlai and Apaloo, 2007) and the ruminant production systems generally rely on conventional feedstuffs (Alonso-Diaz *et al*., 2010). There is need to determine the effect of roughage quality and period of meal termination on rumen fill with the aim of improving ruminant production. It provides livestock producers with knowledge that enhances efficient management and optimum use of pastures and forages at both times of lush and deficit while consequently ameliorating the food crisis. This chapter explores available literature, review them and create a sound theoretical background to the study. Emphasis will be laid on goats, rumen fill, and effect of protein supplementation on roughages and urea treatment of roughages.

2.2 RUMINANTS FEED AND FEEDING

The diet that characterizes the ecological niche of ruminants in the wild before domestication is as important as when they became domesticated. This niche has direct bearing on the digestive anatomy of ruminants. Approximately 180 species of ruminants exist in the world today and a peculiar phenomenon to all is the presence of multiple stomachs by presence of which they engage in rumination which is the process of chewing or re-chewing the cud (Fisher, 2002). However, digestive tracts of these ruminants are not uniform as they are highly specialized to process specific diets fit to the ecological niche of their wild ancestors.

Consequently, ruminants are classified into concentrate selectors, intermediate feeders and grazers (Fisher, 2002).

Concentrate selectors sometimes secrete compounds that make it possible for them to consume higher concentrations of plant secondary compounds such as tannins, and exhibit hindgut fermentation which aids hemicellulose digestion following exposure to hydrochloric acid in the abomasum. Examples of ruminants in this category are moose and giraffe. Goat (*Capra hircus*) is an intermediate feeder between concentrate selectors and grazers. Grazers possess smaller parotid gland secreting salivary buffers relative to large rumen that is instinctively specialized to grasses and forbs which relatively prolong foregut or ruminal fermentation and slow down the rate of passage. They are efficient processors of feed with large digestible cellulose and not suited for indigestible fibre nor concentrated secondary compounds. Not even for diets low in fibre content. Good examples of ruminants with these anatomical descriptions are cattle (*Bos taurus* and *Bos indicus*) and sheep (*Ovis aries*).

The success of small ruminant production largely depends on nutrition and this on the contrary, imposes very strong limitation. This is because of the failure to identify species have very high nutrient requirements than large ruminants (Hernández and Sánchez, 2014). Sheep and goats that are relatively affordable and manageable at low cost do not meet their required acceptable levels of production when fed on forages unlike cattle. They are, however, on free range as they naturally know what to look for as feed to meet their daily requirements for production. Hence, it becomes essential to supplement low quality grass forage when they are in confinement.

2.3 SMALL RUMINANT PRODUCTION

Although, ruminants are faced with multifarious array of plant materials in terms of types and quality, sheep and goats make meticulous selection and propitious mixture of a wide spectrum of plants to meet their needs and make the best of them for their performance. All plants causing toxicosis are also avoided (Ngwa *et al*., 2003). Besides, they are usually fed *ad-libitum* regardless of the system in which they are raised as feeding strategies and tactics aiming at optimal production must take voluntary feed intake as a key factor (Pulina and Bencini, 2004).

Ørskov (1998) observed that it is not important to determine the amount of feed ruminants are likely to consume when they are rationed below their *ad-libitum* intake potential, or given high quality feeds which induce little or no physical limitation to intake. It becomes a serious weakness which will pose a greater problem, if roughage-based diets of poor quality are fed *ad-libitum* to these animals. Nevertheless, DelCurto *et al.* (2000) established that ruminants, most especially those of the Intermountain West, do consume low quality forages with less than 7% CP for such a long period in their annual production cycle. Yet, Garcia *et al*. (2003) asserted empirically that ruminants on free grazing can always maximize quality of their forages regardless of the stocking rate in both conditions of low quantity-high quality or low quality-high quantity i.e. throughout the season.

Despite all these peculiarities to small ruminants, unlike cattle, they have higher intake level to satisfy maintenance needs and this results in higher passage rate of feed and lower digestibility of fibre; they have more selective feeding behaviour; they have their intake more affected by forage particle size and fibre content; they can ruminate smaller particle size; they spend more time on ingestion and rumination and have higher grain digestibility (Pulina *et al*., 2013). In addition, sheep and goats play a role in wastes and residues recycle, transforming them from sources of pollution to inputs like fertilizer or biogas. They require low investment, avail opportunity for simple marketing facility, adapt to simple management skills for even children, and their browsing habits, most especially goats, make them very suitable for small investment production even on free range (Preston, 2005).

2.4 DESCRIPTION, NUTRITION AND PRODUCTION OF GOATS

Miranda and Mattiello (2010) described goats as sociable specie of ruminant, so inquisitive and intelligent and domesticated by man for the past 10,000 years, for meat, milk, skin and fur. They consume large amount of browsing plants throughout the year (Silanikove *et al*., 2010). They have strong preference and affinity for foliages from trees and shrubs. They also select forbs, flowering parts, seeds and nuts. All these plants and plant parts are rich in nutrients but often contain high levels of anti-nutritional factors. However, a collateral benefit of these materials is in reducing internal parasite infestations. Goats are, therefore, effective biological herbicides for controlling many undesirable shrubs and trees (Solaiman *et al.*, 2006). Moreover, the role of goats in enhancing nutrition of man and creating employment, income and capital storage cannot be overemphasized (Panin and Mahabile, 1997). As such, there is need for improved technologies for improved practices in keeping of goats for better output (Elmansoury *et al*., 2013).

2.5 VOLUNTARY INTAKE OF FEED IN SMALL RUMINANT NUTRITION

Voluntary intake is the amount of dry matter that a particular animal or group of animals can eat in a specified period of time (Pulina *et al*., 2013). Voluntary intake is regulated by many factors and implicitly, it was assumed that one factor acted independently and exclusively of other mechanisms. An in-depth knowledge of ecological niche and feeding behaviour of goats via their digestive anatomy unravelled that it is a function of multiple interactions. As such, to predict intake, the feedback regulators like distension, protein and energy should be considered in the context of their interacting regulatory effects (Fisher, 2002).

With the instinct of ruminants to relish and thrive on roughages, there is a lot of literature on the prediction of roughage intake so as to increase the efficiency of goat production (Fisher, 2002). Feed intake regulation in ruminants is a function of physiological and physical factors, but effects of physiology associated with high-grained diets at low dietary NDF concentrations may impede the ability of the animal to achieve maximal energy intake (Hyer *et al.*, 1991).

Animal fed roughage-based diets is limited by capacity of the reticulo-rumen and evacuation rate from this organ, which implies that the fill of the rumen and digestion cum passage rates regulate feed intake (Hyer *et al.*, 1991). Dulphy *et al*. (1994) reported that intake of hay compared to that of silage is higher and that rumen fill for hay is usually higher, likewise rumination lasted much longer with hay than silage. However, in both cases of hay and silage, animals could not use their rumen capacity to the full.

Ketelaars and Tolkamp (1992) while building comprehensive models via feed quality to simulate the processes in the rumen reported that it is most appropriate to create empirical relationship between intake and feed parameters to express rumen fill effect for prediction. Additionally, physical, chemical and morphological attributes of roughages are correlated with voluntary intake and digestibility. Until now, the prediction of intake in ruminants is a function of the mechanism regulating intake and their sensitivity to certain feed parameters, assuming that the ease of removal of organic matter of roughages from the rumen is the most important dietary attribute as rumen capacity is limited and entry rate into it cannot exceed outflow rate (Ketelaars, 1992).

Voluntary feed intake is a complex tri-dimensional system involving animal, forage and environment but not orthogonal due to existence of several interactions among them (Pulina and Bencini, 2004). Forbes (1996) Selection of feed is a function of palatability which invariably depends on certain plant and animal characteristics. Among such plants attributes are morphology, chemical composition, form and succulence. Animal factors include breed/species, physiology and experience. Aroma and taste of forage plants are also important cue for acceptability and intake by animals but irrespective of feed nutritional value, intake and palatability are altered by the presence of chemical compounds such as phenols, alkaloids and tannin (Ngwa *et al.*, 2003). Should the products of fermentation in rumen become imbalanced as a result of the inefficiency of its ecosystem, then feed intake and utilization may as well be low or affected (Chanjula and Ngampongsai, 2008).

By way of consistency, concentrate supplementation always reduce hay intake and three main factors including rumen fill, nutrients in the rumen and palatability of the feed do influence intake. In an experiment to determine the utilization of subterranean clovers by Merino sheep, McLaren & Doyle (1988) found that there was a lower consumption of mature clover than the intake of young green ones thereby resulting into drastic loss in weight of sheep fed on mature clover and gain in weight of those fed green clover. Surprisingly, the level of rumen fill in both cases were similar but a notable difference in dry matter (mature: young =8.79 g/kgBW: 9.98 g/kgBW) and NDF (mature: young =5.54 g/kgBW: 4.56 g/kgBW) of the rumen digesta load of the sheep. Comparatively, McLaren and Doyle (1988) observed a similar intake of Persian clover by sheep over mature and green subterranean clovers with greater digesta load of dry matter in the rumen. Consequent upon this aforementioned weight gain of sheep fed Persian clover was greater and significant over those fed with mature or green subterranean clover even though the feed conversion of these diets did not differ.

2.6 FORAGES AND ROUGHAGES AS SMALL RUMINANTS DIET

Forages are the prime class of feed in ruminant industry (Bohnert *et al.*, 2007). Generally, in ruminant production, forages are categorized into legumes and grasses of which over 14,000 and 6,000 of their species, respectively, are used the world over (Pond *et al*., 2005). Their quality parameters such as crude protein, palatability and DM digestibility vary markedly due to differences in variety, maturation and management practices (Bohnert *et al*., 2007). However, their NDF concentration is over 18% (Waters *et al*., 2007) and they contain huge amounts of lignin and cellulose with low level of nitrogen (Chanjula *et al*., 2004). Nonetheless, according to West (2003), the quality of forage is greatly dependent of its users i.e. the ruminants, and it is a complex interrelationship of several factors that affect intake potential, nutrient content, digestion, rumen fill, passage rate and products partitioning within the animal but in all, the chief source of energy for these animals is the latent cellulose in the plants cell walls (Solaiman, 2006). Hence, Weston (1985) concluded that lambs may be relatively at a disadvantage compared to adults when fed on lower-quality roughages because of their inability to exhibit high voluntary roughage consumption that could measure up with their nutrient need.

There is a general assumption that a constant correlation exists between forage intake and digestion, likewise between NDF and intake but often at times large differences appear among forages which can lead to poor performance if not considered. Therefore, such assumption is not uniform (West, 1998). In addition, Chiofalo *et al*. (1992) established that during feeding of silage or green forage or even hay, ruminants are always faced with deficit but often offset it by an increase in the number of small meals taken during the day.

2.7 PHENOMENA IN THE RUMEN

Preference of ruminants for feed of high nutritive value is intrinsic but even if they graze continuously over the day, they do not use their maximum rumen capacity, however, just as the fill of this rumen is important for intake, same is palatability of forage or craving for it. Hence, the initial eating rate of forage by ruminants at the start of meal can be a nice parameter to access the sensory response evoked by it and the motivation of the animal to eat it (Baumont *et al*., 1997). The major lubricant which act as buffer and provide medium for microbial access to the feed particles of these forages in the rumen is the rumen fluid or liquid (Seo *et al*., 2007). During *in situ* degradation of mixed grass, cocksfoot and lucerne hays Baumont *et al*., (1997) added that NDF and dry matter decreased and increased, respectively when voluntary intake was different among all at levels of 1000, 1484 and 1608g in the same order. Differences in the intake of each of the hays was due to size of principal meals and intake rate most especially intake rate at start of meal. Degradation is an important factor linked with space creation in the rumen and generally improves roughage intake. The *in sacco* method where particles of roughages are confined in dacron bags may, however, restrict microbial colonization rate and the actual rate of degradation may not be as well known (Nsahlai, 1991).

2.8 FACTORS AFFECTING RUMEN FILL OR CONTENT AND SIZE

Rumen fill is the amount of herbage or roughage within the rumen and it is determined by the total intake and rate at which ingested ones leave the rumen (Weston and Hogan, 1971). It is alleviated through degradation of digestible matter and evacuation of indigestible ones (Nsahlai, 1991). Furthermore, Aitchison *et al*. (1986) established that the size of rumen fill is a function of factors that do affect rate of digestion and passage. While it was found that carbohydrates in high quantity, but fermented more slowly than other substrates, led to large size of rumen fill, intake of forage by sheep was also highly correlated with the content of cell wall. Also, there were significant levels in the rate of digestion of dry matter and NDF of clover hay when fed to sheep unlike a similar relationship maintained when early cut and late cut ryegrass hays were fed to sheep.

Nsahlai and Apaloo (2007) empirically proved that rumen fill limits roughage intake. A strong positive relationship was established between intake and degradability. In the same vein, Campling (1964) in agreement with Nsahlai and Apaloo (2007) reported that rumen digesta load can be affected by diet quality, extent of maturity or proclivity of animal to use energy. DE Vega and Poppi (1997) indicated that the effect is, however, small. In the same vein, response of animals to change in diet quality could be associated with their physiological state. Besides, Weston *et al.* (1989) recorded a higher digesta load in lambs than in mature sheep, with an incremental difference from 22% to 40% for diets with crude protein of 86 and 182 g/kgDM, respectively.

Although, Baumont *et al*. (1997) reported a significantly low rumen content in sheep fed cocksfoot and lucerne hays before their meal, but after meal, the observation remain the same except that rate of dry matter disappearance of lucerne was high. Intake of low quality forage is, therefore limited by large size of un-degradable and slowly degradable materials in the rumen. Degradation, particle breakdown and passage rate of food residues are key factors contributing to the degree of rumen fill. Sheep eat to a constant rumen fill for a particular diet but not necessarily between or among diets (McLaren and Doyle, 1988). Weston (1985) argued that, digesta load in the rumen may regulate voluntary consumption of roughage but ruminants have been found not to maintain a consistent level of fill in the rumen. For example, Weston (1996) showed a higher digesta load with enhanced voluntary roughage intake in lactating cows and a lower one when roughage of low palatability was offered. In the same vein, a difference between 19 and 40% digesta load and digesta organic matter per unit wet weight of digesta in the rumen was recorded for lambs over adults when fed chopped roughage diets. In all other sections distal to the rumen, lambs had significantly less digesta load and digesta organic matter compared to adult lambs.

Stanley *et al*. (1993) opined that cows during preparturient period have changes in intake but these are not only due to factors of rumen capacity and distension but also patterns and magnitude of changes in the dry matter intake and rumen capacity. Despite this, rumen volume may be 15 litres larger than volume based on rumen evacuation, as an index for estimating rumen fill which influence feed intake (Kreikemeier *et al*., 1990). When feed particles escape rumen fermentation, feed efficiency is reduced. Moreover, DE Vega and Poppi (1997) found no significant difference in weight of rumen contents of sheep when fed with different fractions of mixture of grass and lucerne hays but the animal effect was so pronounced on all DM fractions except NDF while time for retention of dry matter and even NDF was affected by the feed mixture. Addition of roughage to concentrate diet increase passage and starch digestion rate, likewise intake of feed and consequently shift the microbial load in the rumen and end products of fermentation as associated effect on rumen fill and passage rate (Kreikemeier *et al*., 1990).

2.9 EFFECT OF TIME ON RUMEN DIGESTA LOAD

Before morning meal, rumen fill of animals fed hay was 15% greater than the fill of those fed with concentrates. This was partly due to an aversion to the associated forage (Dulphy and Demarquilly, 1994). In an experiment in which sheep were fed with hay alone and hay plus one of barley, wheat and beet pulp, wet digesta contents of the rumen were the same and consistent with a physical effect on intake. Besides rumen fill at night when animals were receiving concentrates was low.

Baumont *et al*. (1997) observed a no significant difference in rumen fill of sheep in the in the morning and evening after a 12 hour cycled eating and ruminating patterns. However, there was a close relationship between the total dry matter in the rumen and the wet digesta weight even though the wet digesta before hay distribution was negatively related with intake of dry matter. Dulphy *et al.* (1994) added that for modifications of intake and metabolic control of appetite through animal requirements with huge supply of concentrates, obvious changes in the physicochemical parameters of rumen content are accountable.

Via distension, digesta load in the rumen could act as satiety agent and rate of passage of this load from the rumen also determines roughage intake (Weston, 1985; Campling, 1970). Mechanisms that enhance roughage intake are changes in processes involved in clearance of digesta, increase in digesta load maintained in the rumen and modulation in responsiveness of the central nervous system to the sensory output evoked by the reticulo-rumen. This enhancement was concomitant to increased digesta dry matter quantities in the rumen and the rest of the compartments of the GIT. Estrada *et al*. (2004) observed no variation in his rumen fill measurement and opined it may be partly due to long time taken upon meal termination for evacuation of the rumen content. Also, there could be a transitory instant distinction of rumen filling effect at main meal termination. Faverdin (1999) established that should there be increase in rumen fill on addition of material into the rumen limiting voluntary intake, then it results in modification of meals number, size and distribution.

2.10 PASSAGE RATE AND RETENTION TIME

To describe and predict the biological mechanisms involved in digestion of feeds by ruminants, mathematical models can be useful but the models also rely heavily on accurate prediction of passage rate so as to determine ruminal digestibility of feeds and their nutrients so that different strategies for feeding and management of the animals can be allowed and adopted (Tedeschi *et al*., 2011). Nevertheless, retention of forage diets in the rumen takes a longer time in cattle than in sheep and goats even though the digestive efficiency of cattle is higher (Poppi *et al*., 1981). Campling (1964) thus, suggested that time taken for particles to be reduced to suitable size that can be transferred from rumen to omasum may be a prime factor assessment of time taken for roughage to be retained in the rumen and it possibly has effect on voluntary intake of cows. Weston (1985) also reported that the major factor that limit voluntary intake of low quality forages is digesta passage rate from the rumen into omasum.

The rate of passage of roughage in the rumen is influenced by several dietary nutrients viz; dietary concentration or intake of components such as lignin, NDF, hemicelluloses, crude protein, acid detergent fibre and body weight (Tedeschi *et al*., 2011). On another view, DE Vega and Poppi 1997 established with no added impact on digestibility, an increase in voluntary intake and a marked decrease in retention time when legume proportion was increased. Moreover, different fractions of pangola and lucerne hays had no effect on rumen digesta load or passage rate of marker but altered that of chromium ethylene diamine tetra acetate (Cr-EDTA).

Illius and Gordon (1991) modelled retention time of food in the digestive tract as a regression scale $W^{0.27}$, large fibre particles of roughage to comminute on scale $W^{0.27}$. Large ruminants retain digesta longer than small ones which explains why they can survive on lower quality food as the retention increases their digestive efficiency. Besides, a maximum intake of metabolized energy scales with $C.W^{0.87}$ while that of maintenance is $W^{0.73}$.

2.11 DIETARY SUPPLEMENTATION AND THE NEED FOR IT

Fertilized or young and succulent grasses as forage diets readily contain soluble nitrogen such that with moderate available energy, productivity is enhanced; as such no supplementation is required (Nsahlai *et al*., 1998). Contrary to this, in period of nutritional constraints, supplementation with crop by-products may be necessary as this result from high seasonal and yearly fluctuations in forage quality and feed availability. Moderate supplementation stimulates intake while biomass availability and vegetation quality is low on slightly degraded forage land (Schlecht et al., 1999). Invariably, when legumes are introduced into pastures to increase the supply of protein in the GIT, their ability to do so is largely dependent on the escape properties of legume particles within the rumen if dominated by grass particles. A strong assertion, according to Nsahlai and Apaloo (2007) counting on the recommendation of *in sacco* method of degradation, attributes of feed are mostly known in the rumen of animals whose feed is well supplemented with protein which is the first nutrient that restricts the potency of rumen microbial fermentative activity for low quality roughages. Related to this, is the double advantage of increased degradation and passage rates when forage legumes were used for supplementation as confirmed by others (Abule *et al*., 1995; Bonsi *et al*., 1995; Nsahlai *et al*., 1998).

Solaiman (2006) asserted that protein is the most high-priced portion of animal feed and it often varies between 12-16% of ration dry matter based on two main factors namely; animal physiological state (growing, pregnancy or lactating) and quality of forage. Therefore, to provide high protein supplements to ruminants when feeding with low-quality roughages tend to stimulate intake, digestion and performance (Chanjula *et al*., 2004a, 2008b). Urea and other non-protein nitrogen sources have been found useful in this aspect (Solaimon, 2006). By their use, voluntary feed intake is increased (Archibeque, 1999), microbes of the rumen produce microbial protein which is a good source of nitrogen for the host animal and nutrient digestibility and passage of feed from the rumen are improved positively. For example, when Bohnert *et al*. (2007) supplemented steers with protein in cool season and warm season forage, he established an intake increase by 47% on warm season forage compared with 7% on cool season forage. In addition, not only intake and digestibility of the two forages were different but also that the physiological response of ruminants to supplemental protein is partly dependent of the cell wall structure of the diet. Nsahlai (1991) also asserted that when increase in intake resulted from increased digestion rate of low-quality roughage, then diet digestibility rises by 4-40% depending on the quality of the basal feed.

Another cogent reason for the requirement of a supplemental nitrogen source in ruminants, is the proper functioning of the rumen most especially when the diet component is of very low quality (Hernandez and Sanchez, 2014). When straw or hay has been ammoniated with urea, ammonia gas or ammonium bicarbonate at a condition it is not needed, then only a source of by-pass nutrients is used to heighten animal performance (FAO, 2002). To buttress these assertions, Wickersham *et al.* (2004) noted that trial studies take advantage of protein supplementation since nitrogen requirements of rumen microbes may not be met and thereby resulting to poor use of roughage and poor performance. Although rumen degradable protein improves animal performance, nitrogen available for this function still include absorbed nitrogen or mobilized endogenous nitrogen from source like recycled urea. Likewise, status of nitrogen in ruminants can also be improved by providing rumen un-degradable protein as it also has potential to make nitrogen available for microbes in the rumen (Lobley *et al.* 2000), it was established that ruminally degradable protein is more efficient than un-degradable one (Bandyk *et al.* 2001). Complementary to all these, multi-nutrient blocks of molasses are also important supplements when low nitrogen basal feed are offered to ruminants (FAO, 2007).

Nsahlai *et al*. (1998) observed that the intake of roughages without supplementation is within 17 to 29 g/kg body weight and 16 to 23 g/kg body weight for sheep and cattle, respectively, and thus elicit varied levels of productivity. As such, the amount of supplement required by these animals may be a function of basal roughage quality. Ordinarily, animals on poor quality diets do mobilize their energy reserve to cater for their nutritional needs but this results in reduced body condition. With the range of body condition score of goats between 2.1 for poor and 3.8 for fair, Lengarite *et al*. (2014) observed that goats offered long grass without supplement were poor while those fed mixed grass hay with whole Acacia pods as supplement, were fair.

Tafaj (2005) observed that it is not a strategy to overcome limitation of low quality forage by feeding concentrates as supplement to ruminants, rather the quality of the roughage should be increased. A reduction of concentrate level from 50 to 20% in the diet of low fibre forage improved rumen conditions as the rumen solid passage rate and fibre digestibility increase with decrease concentration of large particles and of the mean particle size of the rumen digesta and of the faeces. Besides, Lengarite *et al*. (2014) reported that with supplementation, there was an increase in milk production of goats, similar daily weight gain of suckling goat kids, improved digestibility with milled Acacia and increased feed intake with chopped grass hay. Lengarite *et al*. (2014) highlighted that supplementation can alleviate nutritional constraints, increase milk yield and maintain body condition of pastoral goats in dry land, if included as milled Acacia or whole one in mixed grass hay.

2.12 UREA TREATMENT AND OPTIMIZATION OF LOW QUALITY ROUGHAGES

Urea treatment is done to optimize the use of poor quality roughage and in principle it involves two processes namely; ureolysis and ammonification i.e. release of ammonia by the dissolution of urea in water and ammonia effect on the cell walls of the forage. During these processes, telluric bacteria grow and release an enzyme called urease which catalyzes the production of ammonia under suitable physic-chemical conditions namely; humidity and temperature, in a hermitic condition (Chenost *et al*., 2001). Furthermore, Tesfayohannes *et al.* (2013) stated that there exist ester bonds among lignin, hemicelluloses and cellulose which physically make fibre to swell but with urea treatment, they can be broken. Hence, urea can enhance the nutritive quality of straws and other roughages fed to ruminants (Ghana et al., 1993; Got et al., 1991) while increasing their crude protein content and reducing the neutral detergent fibre cum hemicelluloses.

Chanjula and Ngampongsai (2008) found no significant difference in including urea as supplemental nitrogen at 0, 1, 2 and 3 % level to cassava chips in the diets of growing goats, but with increasing urea levels, digestible nutrient intake of crude protein was affected. In the same vein, apparent digestibility of all the nutrients was similar with unaffected intake. Besides, digestion potential and rate of plants with lignin and silica in their cell wall are limited and that metabolizable energy (Mcal/d or Mcal/kgDM) of host energy metabolism would not be affected even if urea is included with increasing levels (Merten, 1977; Chanjula and Ngampongsai, 2008). Nonetheless, according to Chenost (2001) treatment with urea is superior, simple and easy for optimization of poor quality roughages. Adding urea increased average daily gain of 200 g weight per day in cattle, 1-2.5 kg milk per day in lactating cattle and an improved efficiency of draught animals (Chenost, 2001).

2.13 SOURCES, INTAKE AND IMPORTANCE OF WATER IN RUMINANTS

Water used by animals for their body functions could be ingested as drinking water, as part of feed constituent or by catabolic process (Andreas Jenet *et al.*, 2004). Water plays an important role in food digestion, metabolic waste transport, body temperature normalization and excretion. Ability of animals to conserve water and prevent or endure deprivation differs. While some tolerate severe dehydration, others would not consume feed any longer when deprived of water for a short-while and it may eventually lead to mortality. Hence, making available adequate quantity of clean drinking water is a major requirement for reasonable growth, milk-let down and general optimum health of animals.

There are three major sources of water for ruminants. These include drinking water, water contained in feeds and metabolic water. Water contained in feed varies and this is a function of moisture content of the feed (Sileshi *et al*., 2003). It may range from as low as 5% in dry feed to as high as 90% in succulent herbages (Sirohi *et al*., 1997). In most cases water contained in dry feed is insignificant compared with the water requirement of these animals so the major source of water on which they depend is drinking water, as such its provision becomes a concern of producers. Ordinarily, ruminants may not need water when the available one in feed, most especially succulent feed, has satisfied their requirement (Sileshi *et al*., 2003). For instance, sheep drink less or no water provided that which is contained in feed is above 70% (Sirohi *et al*., 1997).

With respect to water intake in ruminants, Estrada *et al*. (2003) expounded that even though low dry matter content of fresh grass is a factor restricting ruminants voluntary intake, it's only internal water ingested with such fresh grass that limits voluntary dry matter intake in dairy cows and that nonappearance of any effect of external water in this has been a very consistent observation in several studies. In addition, it was noted that water requirements of ruminants is individualistic and highly specific depending on their ability to withstand dehydration. Hence, that of sheep, goat and camel is not as high as cattle. However, physiological state of these animals, feed quality, feed intake, environmental temperature and humidity also play key roles in their water need. For example, lactating cow would ordinarily consume more water to survive the stress posed by milk let-down than one of its similar size fed on maintenance level. Also, Maynard *et al*. (1981) demonstrated a gradual increase of water intake by a 450 kg cow eating 10 kg dry feed per day, from 28 litres to 41 litres and to 66 litres as temperature rose from 4^0C to 21^0C and to 32^0C, respectively. It could be added that dry matter digestibility affects water intake just as water intake is affected by not only quantity of feed but also the quality.

2.14 FACTORS INCREASING WATER INTAKE IN RUMINANTS

Some factors experimented to ordinarily increase water consumption of ruminants include legumes inclusion and protein supplementation in diets (Zewdu, 1991); increased level of roughage intake and its nitrogen content (Sileshi *et al.*, 2003); laxative properties of feed (Sileshi *et al.*, 2003); high salt and other minerals intake (Wilson 1970; Abdelatif and Ahmed 1992) and excretion of large volume of urine (Sirohi *et al.*, 1997). Moreover, regarding filling of the rumen, Estrada *et al.* (2004) observed that neither the total weight of fresh content nor that of dry grass varied with respect to grass dry matter content, but internal water unlike external one did affect dry matter intake without rumen fill modifications. By implication, it is either rumen fill is independent of water or on the contrary, that dry matter intake is controlled by maximum possible level of fill of rumen.

2.15 DIGESTIBILITY AND THE ASSOCIATED DEPRESSION ON ROUGHAGES

In ruminants, digestibility is a function of the rivalry between digestion and passage rate (West, 2003) while its depression is the inverse relationship between amount of lignin and rate of digestion (Van Soest, 1994). This means that digestibility depression increases with the effects of intake of forages, physical form of forages, and passage of forages and concentrate addition either with digestible or slow-digesting cell walls. Thus, increase in intake in multiples over maintenance leads to digestion of more digestible fractions and sensitivity to passage effects thereby leaving the rumen undigested

Muamba *et al.* (2014) calculated digestibility (g/kg) as: Component digestibility (g.kg-1) =

$$\frac{\text{(Component in feed - component in faeces)}}{\text{Component in feed}} \times 100.$$

There are quite a number of methods for assessing the digestible value of forages (Muamba *et al*., 2014) but erroneous conclusions may be arrived at in *in vitro* and *in sacco* methods if not supported by feeding trials which give information on health and productivity of the animals (Norton, 1998). This is so since palatability and intake of the forage cannot be predicted. It is also a function of forms in which the forages are offered. On the other hand in vivo apparent digestibility may be determined by complete collection of faecal output of animals (Muamba *et al.*, 2014).

Additionally, Minson (1990) postulated that temperature, water availability and evaporative demand does affect digestibility of dry matter and it becomes a thing of greater concern with respect to global warming. Dugmore and Nsahlai (2010) found a decrease of 4.4% and 15% in digestibility and intake respectively for every degree rise in temperature. Besides, Weston (1985) contributed that lactation also posed a small depressing effect on digestibility in the alimentary tract as agreed to by several past studies with sheep and cattle.

2.16 FACTORS AFFECTING DIGESTIBILITY

Digestibility and intake potential have to be understood via several factors and this is better done through in vitro digestion, chemical analysis and microscopic study of the major components of forages (Wilson *et al*., 1983). Faecal chemical indices tested to predict digestibility seem to be the best and attractive method so far, however faecal crude protein content is the most accurate predictor of digestibility, an assertion from the Lancaster (1949) model which based on biological relationship between digestibility and crude protein-fibre content. It permits estimation even if the animal is in confinement either tethered or on-stalled (Boval *et al*., 2003). They also noted that crude protein-fibre is a reliable index to predict organic matter digestibility in tropical condition.

Aitchison *et al*. (1986) also asserted that digestibility decreased with increasing maturity of the fed hays and by implication it was the effect of reduced crude protein and water soluble carbohydrates, likewise, corresponding increase in fibre content. Nonetheless, there existed a very high level of significance in the measure of apparent digestibility of dry matter, NDF and ADF. In addition, Baumont *et al*. (1997) found a lower digestibility of mixed grass hay and asserted that it was a resultant established effect of higher fibre content (NDF & ADF) and low crude protein. Puchala *et al*. (2001) also observed a marked decrease in nitrogen digestibility of forage in fresh and hay forms, containing high percentage of condensed tannin. This inhibitor also elicited a moderate decline in rumen methane emission and he concluded that, although it's potentially beneficial, it still needs further investigation.

Although Pasha *et al*. (1994) observed an increase in dry matter intake when sheep were fed with dehydrated grass, as to digestibility or acceptability of dehydrated grass, Estrada *et al*. (2004) affirmed reduced levels which possibly confound the effect of drying on voluntary intake. In addition, as clover or forage species mature, there is a decline in intake, decrease in digestibility and the utilization becomes poor (Hogan and Weston, 1971; Minson, 2012; Favreau *et al*., 2010).

2.17 FEEDING BEHAVIOUR OF GOATS

Goats ordinarily exhibit a wide range of behaviour but under captivity or in intensive management systems, they are encapsulated and reduced to express very little social behaviour most especially during studies. In this situation, they experienced high stock density, sexual segregation, and early separation of kids from mothers, frequent regrouping and manipulations during pregnancy and weaning (Miranda-de la Lama and Mattiello, 2010). But in relation to feed, the nutritive value and sensory properties may hold influence on behaviour most especially intake (Baumont, 1996). Also, Forbes (2007) added that taste and odour of feed are key factors to determine the feeding behaviour.

Favreau *et al*. (2010) asserted that goats do evaluate feed by associative learning of pre-ingestive attributes and post-ingestive consequences. While the former affect eating patterns and short-term choices in favour of a newly introduced feed, the later to a great extent are essential for the animals to meet their nutritional requirements, thus influencing daily intake of hay. A clear understanding of this elucidates feeding behaviour, behavioural adjustment and pattern of eating activity as essential to optimize forage utilization by ruminants. Invariably, post-ingestive consequences such as nutritive value, toxicity and most importantly rumen fill influence feeding behaviour of the animals, contribute to their satiation process and control their intake to prevent excesses (Baumont *et al*., 2000; Favreau *et al*., 2010). Somehow, goats just like sheep were found to give less regard to post-ingestive consequences and sometimes give preference to novelty seeking diverse diets just for pleasure with implication for welfare rather than functional purpose (Favreau *et al*., 2010).

Behaviourally, eating time by sheep feeding on clover hay, early and late cut ryegrass was found not significant unlike rumination time but between these two activities, the difference in total period spent was also found to be very relevant (Aitchison *et al*., 1986). A further demonstration by Weston (1985) showed that particle sizes and texture of roughages fed to ruminants of different ages and or weights do affect their feeding behaviour in terms of eating and rumination. Also, lambs spent more time eating chopped diet but their feed intake per unit metabolic body weight was not significant. All these behavioural activities have no effect on intake of adult sheep but the animals consumed more feed and digestibility in these animals was similar to that of lambs.

2.18 ARTIFICIAL NEURAL NETWORK (ANN)

Like other conventional statistical prediction and classification methods, artificial neural network (ANN) is also used (Salawu *et al*., 2014). It functions like the human brain (Gorgulu, 2012) and it surpasses the known prediction methods in its capability to generalise and handle fuzzy information (Jain *et al*., 1996). It uses the common Multi-Layered Perceptron (MLP) which consists of input, hidden and output layers of varying number of neurons depending on the complexity of the problem it is being applied to. Data input and output variables are firstly used for training in the ANN and just as humans solve a new problem based on past experience, ANN takes the previous training outcome to create patterns, learn the patterns and develop the ability to classify new patterns correctly as validation for such previous outcome (Whiteman and Kana, 2013).

However, its application in livestock production is fairly recent (Shahinfar *et al*., 2012; Fernandez *et al*., 2006), mostly using it in poultry egg production, rabbit meat production, broiler production, dairy production and breeding.

2.19 CONCLUSION AND IMPLICATIONS

This review hereby elicit the need for research on how urea could be used to improve hay quality, the effect of such use on feeding behaviour of goats, voluntary intake, degradation and digestibility, and how it impact on reticulo-rumen fill and performance of goats. The study will enable development of strategies in managing naturally available feedstuffs for these animals and culminating into improved production.

Chapter 3

RUMEN FILL PREDICTION USING ARTIFICIAL NEURAL NETWORK

ABSTRACT

This study sought to develop a predictive model for simulating the fill of the rumen. Rumen fill has complex dynamic behaviour that is influenced by both animal and diet factors. The study used 20 sources of data on rumen fill. Data comprised 140 treatment means (78 cattle and 62 sheep). Each mean rumen fill was measured by complete manual evacuation through fistulas or slaughtering. The following variables were collected: specie/type (SPT), age, physiological state (PHY), body weight (LBW), mature body weight (MBW), housing system (MGT), dietary characteristics: viz; crude protein (CP), neutral detergent fibre (NDF), acid detergent fibre (ADF) and non-fibre non-protein carbohydrate (CHO) were used as predictors of rumen fill (RFD; in kg DM). Decisions to terminate feeding activity or to begin feeding affect rumen fill. Artificial neural network can lend a hand during simulation. Artificial neural network (ANN) is a mathematical representation of the neurological functioning of the brain and its usage is new in the animal sciences. Data were separated into two: for learning (70%) and for validation (30%). The ANN model used for predicting rumen fill was a committee of five networks with a topology of 11 input layers, 5 hidden layers of neurons, and 1 output layer (11-(11-15-20-22-26)-1) structured on a multilayer perceptron. Training could explain 83% of the variation in rumen fill (R^2 = 0.83). However, for the validation, the relationship between observed and predicted could explain 92% of the variation (R^2 = 0.92). Input sensitivity analysis showed 95.4%, 69.4%, 55.3%, and 50.6% for mature body weight, physiology, crude protein and age, respectively. Validation ended up with a 5.6% prediction error for rumen fill. Manual rumen evacuation is a worthy technique to explore species variation and ANN model for prediction of rumen fill with its low prediction error, could be an efficient model to simulate fill and or intake in field situations. The use of these large datasets adapted from scientific literature and ANN model for prediction of rumen fill improves the quantification of relationships that exist among all the predictor variables and between them and the fill. With such efficient model in rumen fill prediction, the dynamics and complexity of the system is simplified for solid and quality studies aimed at improving productivity and profitability of ruminant.

Keywords: Rumen fill; Artificial Neural Network; Cattle; Sheep.

3.1 INTRODUCTION

Artificial neural network is an artificial intelligence data driven technique which mimics the biological neural network of the human brain in problem solving processes. It is a powerful tool for system modelling in a wide range of applications (Fernandez *et al.*, 2006; Nobari & Tahmoorespur, 2011; Gorgulu, 2012; Ghazanfari, 2014). However, despite the large data set analyses in the field of animal sciences, its use are still very limited (Fernandez *et al.*, 2006). Until recently, the use of ANN and other machine learning techniques is increasing in agriculture because of their speed, strength and suppleness in classification and prediction applications most especially those involving non-linear systems (Shahinfar *et al.*, 2012). Besides, a number of limitations and outcomes which are often not the best possible ones, in conventional statistical prediction and classification methods, such as linear and logistic regression (Salawu *et al.*, 2014), had driven efforts to the use of ANN which is remarkable in its information processing characteristics, non-linearity, high parallelism, robustness, fault and failure tolerance, learning ability to handle imprecise and fuzzy information and capability to generalise (Jain *et al.*, 1996; Whiteman and Kana, 2014).

In animal sciences, ANN has been used in prediction of growth performance of broiler chickens (Ghazanfari, 2014), rabbits (Salawu *et al.*, 2014), and sheep (Behzadi and Aslaminejad, 2010; Ganesan *et al.*, 2014), in prediction of breeding values of dairy cattle (Shahinfar *et al.*, 2012), weekly milk production of goats (Fernandez et al., 2006) and 305-day milk production (Lacroix *et al.*, 1995; Ghandi *et al.*, 2010; Gorgulu, 2012), in classification of meat and intramuscular fat (Kim *et al.*, 1998), in detection of mastitis (Kim and Heald, 1999), in detection of oestrus (Mitchell *et al.*, 1996), in analysis of lactation curve (Pietersma *et al.*, 2003), in identifying reasons for culling (McQueen *et al.*, 1995) and most recently, in modelling and prediction of *in vitro* rumen CH_4, CO_2 and total gas production

(Dong and Zhao, 2014). In the same vein, the current study seeks to bridge a knowledge gap in understanding reticulo-rumen fill, which governs long-term control of voluntary feed intake by ruminants (Forbes, 1977; Galyean and Oltjen, 1988). It is imperative to take into consideration predictor variables to include forage and animal characteristics (Madsen & Hvelplund, 1994). The objectives of the study were; (1) to unravel the relationship between dietary intake and rumen fill and develop a simulation model for prediction of the fill in cattle, sheep and goat using ANN, and (2) to evaluate possible similarities or differences among ruminant species with different body sizes and physiological states.

3.2 MATERIALS AND METHODS

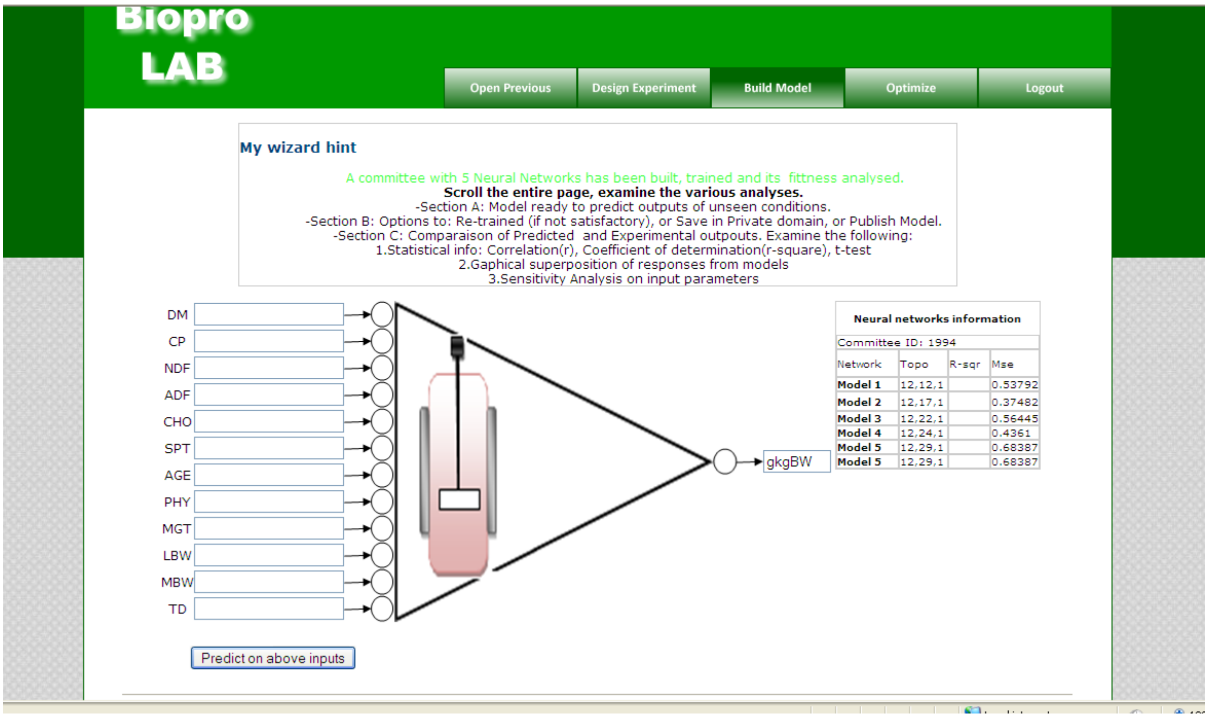
A database was created based on information obtained from several experiments in which rumen fill was measured by slaughtering (Weston *et al*., 1988; 1989) or by complete manual evacuation through the fistulas (Aitchison *et al*., 1986; Baumont *et al*., 1996; Bines et al., 1969; Boudon *et al*., 2009; Campling *et al*. 1963; Chiofalo *et al*., 1992; DE Vega and Poppi 1996; Dulphy *et al*., 1996; Estrada *et al*., 2004; Favreau *et al*., 2010; Gasa *et al*., 1991; Kimambo *et al*.,1993; McLaren and Doyle 1988; Poppi *et al*., 1980; Reynolds *et al*., 2004; Stanley *et al*., 1993; Wickersham *et al*., 2004). Two treatment means in Seo *et al*. (2007) who also developed a database were included. Experiments and treatments were selected using the following criteria: (1) Reticulo-rumen digesta must have been completely evacuated manually through the fistulas or after slaughtering. (2) Reticulo-rumen digesta must be homogenised, sub-sampled and at least analysed for dry matter. (3) Diet offered must have included roughages and the ratio of any other feed must have been specified. (4) Forage name must have been mentioned and or its composition must have been analysed and stated. Where feed composition did not state all of DM, CP, NDF and ADF, the feed composition tables www.beefmagazine.com 2012 and 2013 were used. (5) Dry matter intake or its organic matter equivalent should have been measured and not estimated. And (6) Physiological state of animals must be stated.

Treatment means in the database included 78 cattle and 62 sheep totaling 140. Thirty-five (35), seven (7), fourteen (14), eight (8) and fourteen (14) were lactating (4), pregnant (3), non-pregnant (2), maintenance (1) and growing (0) cattle respectively while one (1), zero (0), two (2), fifty-two (52) and seven (7) were for sheep respectively. Only Boudon *et al*. (2009) grazed half of his treatment animals outdoor (0) and also introduced coconut fibre as rumen inert bulk while others fed indoor (1). Animal and management information were defined with numerical values as shown above to make it easier for modelling by the ANN. All dietary information is given on dry matter basis with g/kg as the unit. Weights in pounds or metabolic values were also converted to kg. Time delay for measurement of fill was computed in hours but where no specification, an assumption of zero hour was made.

3.3 DATA COMPUTATION

Data developed were reduced to 11 inputs (SPT, AGE, PHY, MGT, LBW, MBW, DM, CP, NDF, ADF& CHO=1,000-CP-NDF) and 1 output, RFD.

Where SPT=specie/type, AGE=age, PHY=physiological state, MGT=housing system, LBW=body weight, MBW=mature body weight, DM=dry matter, CP=crude protein, NDF=neutral detergent fibre, ADF=acid detergent fibre, CHO=non-fibre non-protein carbohydrate and RFD=dry rumen fill.



My wizard hint

A committee with 5 Neural Networks has been built, trained and its fittness analysed.
Scroll the entire page, examine the various analyses.
-Section A: Model ready to predict outputs of unseen conditions.
-Section B: Options to: Re-trained (if not satisfactory), or Save in Private domain, or Publish Model.
-Section C: Comparaison of Predicted and Experimental outpouts. Examine the following:
1.Statistical info: Correlation(r), Coefficient of determination(r-square), t-test
2.Gaphical superposition of responses from models
3.Sensitivity Analysis on input parameters

Neural networks information

Committee ID: 1994

Network	Topo	R-sqr	Mse
Model 1	12,12,1		0.53792
Model 2	12,17,1		0.37482
Model 3	12,22,1		0.56445
Model 4	12,24,1		0.4361
Model 5	12,29,1		0.68387
Model 5	12,29,1		0.68387

Figure 3.1 Artificial neural network (ANN) structure with committee of 5 modellers

3.4 ARTIFICIAL NEURAL NETWORK (ANN) TRAINING

Data as shown in Table 3.1 were trained 8 different times with the ANN using back propagation algorithm (while seeking to reduce error difference i.e. Root Mean Square Error (*RMSE)* between predicted the output and the observed, to choose the modeller with the best fit. Each training was programmed a re-run for 500 or 700 times. One with 500 re-run was on the long run used and it had an arrangement of 11-(11-15-20-22-26)-1 to show its input, hidden layer of 5 neural networks consisting of varying weights of neurons and output layers. Only 70% i.e. 98 treatment means of the entire data was used for training.

Table 3.1 Artificial neural network (ANN) training data for rumen fill prediction

S/N	DM (g/kg)	CP (g/kg)	NDF (g/kg)	ADF (g/kg)	CHO (g/kg)	SPT	AGE (yrs)	PHY	MGT	LBW (kg)	MW (kg)	RF Observed (kg)
1	870	150	545	307	305	2	3	1	1	50	70	1.3
2	875	106.3	652	404	241.7	2	3	1	1	52	70	1.5
3	865	250	294	288	456	2	3	1	1	54	70	1.3
4	870	150	545	307	305	2	3	1	1	56	70	1.3
5	875	106.3	652	404	241.7	2	3	1	1	50	70	1.4
6	865	250	294	288	456	2	3	1	1	52	70	1.2
7	870	150	545	307	305	2	3	1	1	56	70	1.3
8	875	106.3	652	404	241.7	2	3	1	1	60	70	1.5
9	865	250	294	288	456	2	3	1	1	58	70	1
10	870	150	545	307	305	2	3	1	1	60	70	0.9
11	875	106.3	652	404	241.7	2	3	1	1	54	70	1.5
12	865	250	294	288	456	2	3	1	1	58	70	0.9
13	884	85	684	396	231	2	3	1	1	60	90	0.9
14	878	196	637	298	167	2	3	1	1	61	90	0.8
15	855	198	447	312	355	2	3	1	1	63	90	0.7
16	843	27	730	480	243	7	6	2	1	396	750	8.7
17	850	75	630	390	295	7	6	2	1	415	750	13.9
18	863	164	650	380	186	7	6	2	1	487	750	11.3
19	843	27	730	480	243	7	6	2	1	573	750	9.2
20	850	75	630	390	295	7	6	2	1	615	750	10.8
21	863	164	650	380	186	7	6	2	1	642	750	10.8
22	154	198	455	231	347	7	6	4	1	683	750	16.5
23	176	210	441	220	349	7	6	4	0	683	750	11.1
24	154	198	455	231	347	7	6	4	1	683	750	11.8
25	176	210	441	220	349	7	6	4	0	683	750	9.6
26	154	198	455	231	347	7	4	4	1	594	750	11
27	176	210	441	220	349	7	4	4	0	594	750	9.3
28	154	198	455	231	347	7	4	4	1	594	750	8.9
29	176	210	441	220	349	7	4	4	0	594	750	6.5
30	154	198	455	231	347	7	6	4	1	683	750	17.3
31	176	210	441	220	349	7	6	4	0	683	750	17.1
32	154	198	455	231	347	7	6	4	1	683	750	15.7
33	176	210	441	220	349	7	6	4	0	683	750	14.4
34	154	198	455	231	347	7	4	4	1	594	750	13.5
35	176	210	441	220	349	7	4	4	0	594	750	12.7
36	154	198	455	231	347	7	4	4	1	594	750	10.7
37	176	210	441	220	349	7	4	4	0	594	750	11.8
38	852	78	650	380	272	7	4	2	1	522	750	13.7
39	852	78	650	380	272	7	4	2	1	522	750	15.9
40	852	78	650	380	272	7	4	2	1	522	750	16.5
41	852	78	650	380	272	7	4	2	1	522	750	15.7
42	911	68	650	380	282	7	4	2	1	522	750	9.6

43	911	68	650	380	282	7	4	2	1	522	750	17.4
44	911	68	650	380	282	7	4	2	1	522	750	15.3
45	911	68	650	380	282	7	4	2	1	522	750	14.3
46	157	125	597	312	278	4	4	1	1	60	90	0.9
47	170	119	587	328	294	4	4	1	1	61	90	1
48	80	103	697	376	200	4	4	1	1	63	90	1.1
49	157	125	597	312	278	4	4	1	1	60	90	1.4
50	170	119	587	328	294	4	4	1	1	61	90	1.4
51	80	103	697	376	200	4	4	1	1	63	90	1.6
52	157	125	597	312	278	4	4	1	1	60	90	1.3
53	170	119	587	328	294	4	4	1	1	61	90	1.4
54	80	103	697	376	200	4	4	1	1	63	90	1.9
55	157	125	597	312	278	4	4	1	1	60	90	1.8
56	170	119	587	328	294	4	4	1	1	61	90	1.9
57	80	103	697	376	200	4	4	1	1	63	90	2.3
58	900	88	663	380	249	4	4	1	1	68.6	90	1.2
59	895.2	100	431.6	231.2	468.4	4	4	1	1	69.6	90	1.1
60	895.8	101.4	425.7	237.2	472.9	4	4	1	1	70.8	90	1
61	906.3	90.5	547.7	304.4	361.8	4	4	1	1	71	90	1
62	900	88	663	380	249	4	4	1	1	68.6	90	1.8
63	895.2	100	431.6	231.2	468.4	4	4	1	1	69.6	90	1.8
64	895.8	101.4	425.7	237.2	472.9	4	4	1	1	70.8	90	1.8
65	906.3	90.5	547.7	304.4	361.8	4	4	1	1	71	90	1.8
66	121	255	460	246	285	7	6	4	1	688	750	11.2
67	128	255	459	244	286	7	6	4	1	688	750	12.1
68	134	259	458	248	283	7	6	4	1	688	750	11.1
69	162	256	468	245	276	7	6	4	1	688	750	11.6
70	218	142	452	235	406	7	6	4	1	672	750	20.7
71	302	144	452	229	404	7	6	4	1	672	750	21.1
72	164	142	452	235	406	7	6	4	1	672	750	21.1
73	227	144	452	229	404	7	6	4	1	672	750	21.9
74	914	72	667	368	261	2	2	1	1	60.9	90	2
75	917	113	600	365	287	2	2	1	1	61.3	90	2.1
76	917	113	600	365	287	2	2	1	1	62.3	90	2.3
77	921	156	531	362	313	2	2	1	1	62.7	90	2.1
78	377	168	404	286	428	7	5	4	1	700	750	10.3
79	546	177	339	211	484	7	5	4	1	700	750	11.8
80	414	139	483	292	378	7	5	4	1	700	750	11.5
81	569	158	391	214	451	7	5	4	1	700	750	12.6
82	194	43	752	460	205	3	1	0	1	316	750	7.7
83	621	54	778	470	168	3	1	0	1	316	750	6.7
84	900	102	640	530	258	2	2	1	1	41	70	0.4
85	910	179	420	300	401	2	2	1	1	41	70	0.4
86	880	144	400	330	456	2	2	1	1	41	70	0.5
87	889	87.5	657	400.5	255.5	3	2	1	1	483	900	9.9
88	889	62.5	694	431.7	243.5	3	2	1	1	483	900	8.7

89	889	75	622	400.5	303	3	2	1	1	483	900	10.6
90	889	56.3	681	431.7	262.7	3	2	1	1	483	900	9.9
91	502	87.5	700	219	212.5	3	2	1	1	483	900	10.3
92	566	62.5	721	219	216.5	3	2	1	1	483	900	10.5
93	502	62.5	730	219	207.5	3	2	1	1	483	900	11.5
94	566	45	768	219	187	3	2	1	1	483	900	11.3
95	889	87.5	657	400.5	255.5	2	2	1	1	44.5	70	0.9
96	889	62.5	694	431.7	243.5	2	2	1	1	44.5	70	0.9
97	889	75	622	400.5	303	2	2	1	1	44.5	70	1
98	889	56.3	681	431.7	262.7	2	2	1	1	44.5	70	1

DM=dry matter, CP=crude protein, NDF=neutral detergent fibre, ADF=acid detergent fibre, CHO=non-fibre, non-protein carbohydrate, SPT=specie/type, AGE, PHY=physiological state, MGT=housing system, LBW=body weight, MBW=mature body weight, RF=rumen fill

There was no rearrangement to avoid bias. The structure of the ANN in use has multilayer perceptron (MLP) with a feed forward nature by means of which input data were sent to hidden layer in which a sigmoid transfer function was adopted to sum up the weighted input along with associated bias, thereafter shift data into a more nonlinear form as expressed by the following respective equations described by Desai *et al*. (2008):

1. $\mathbf{Sum=} \sum^{n}\mathbf{i=1xiwi+\Theta}$ where wi(i=1, n) are the connection weights, Θ is the bias and xi is the input variable.
2. $\boldsymbol{f}(\mathbf{sum}) = \mathbf{1}/(\mathbf{1} + \mathbf{exp}(\mathbf{sum}))$

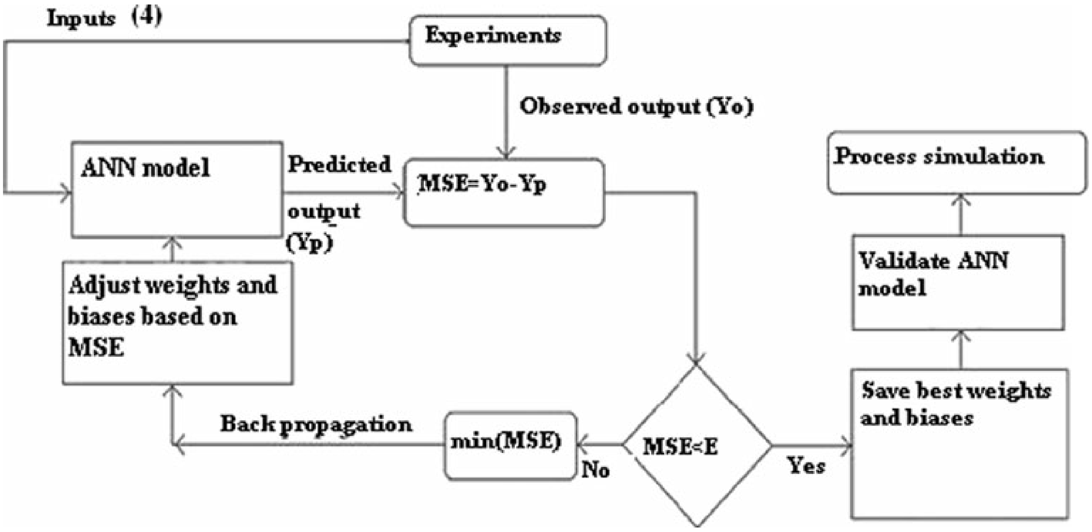


Figure 3.2 Training flow chart for the Artificial Neural Network (ANN)

3.5 ARTIFICIAL NEURAL NETWORK (ANN) VALIDATION

Forty-two treatment means were used for validation of the ANN training model outcome using the same topology (i.e. input-hidden-output layer arrangement), and same epoch (i.e. re-run).

Table 3.2 Artificial neural network (ANN) validation output for rumen fill prediction

S/N	DM (g/kg)	CP (g/kg)	NDF (g/kg)	ADF (g/kg)	CHO (g/kg)	SPT	AGE (yrs)	PHY	MGT	LBW (kg)	MBW (kg)	RF Obs (kg)	RF Pred (kg)
1	502	87.5	700.0	219.0	212.5	2.0	2.0	1.0	1.0	44.5	70	0.9	3.6
2	566	62.5	721.0	219.0	216.5	2.0	2.0	1.0	1.0	44.5	70	0.9	4.4
3	502	62.5	730.0	219.0	207.5	2.0	2.0	1.0	1.0	44.5	70	1.0	4.7
4	566	45.0	768.0	219.0	187.0	2.0	2.0	1.0	1.0	44.5	70	1.0	4.7
5	476	186.0	325.0	203.0	489.0	7.0	5.0	4.0	1.0	659	750	9.6	13.3
6	476	186.0	325.0	203.0	489.0	7.0	5.0	4.0	1.0	658	750	11.0	13.2
7	476	186.0	325.0	203.0	489.0	7.0	5.0	4.0	1.0	651	750	11.9	13.2
8	445	118.0	526.0	316.0	356.0	7.0	5.0	3.0	1.0	745	750	8.2	14.3
9	445	118.0	526.0	316.0	356.0	7.0	5.0	3.0	1.0	749	750	8.1	14.4
10	806	135.0	476.0	270.0	389.0	7.0	5.0	4.0	1.0	576	750	9.4	12.2
11	1055	176.7	623.1	353.4	200.2	7.0	6.0	4.0	1.0	703	750	11.3	11.9
12	880	160.0	513.0	400.0	327.0	7.0	4.0	4.0	1.0	580	750	8.9	11.6
13	880	160.0	513.0	400.0	327.0	7.0	4.0	4.0	1.0	580	750	9.4	11.6
14	880	160.0	513.0	400.0	327.0	7.0	4.0	3.0	1.0	580	750	8.3	11.4
15	880	160.0	513.0	400.0	327.0	7.0	4.0	3.0	1.0	580	750	7.3	11.4
16	880	160.0	513.0	400.0	327.0	7.0	4.0	3.0	1.0	580	750	7.0	11.4
17	880	160.0	513.0	400.0	327.0	7.0	4.0	3.0	1.0	580	750	6.3	11.4
18	880	160.0	513.0	400.0	327.0	7.0	4.0	3.0	1.0	580	750	6.1	11.4
19	882	53.0	716.0	351.0	231.0	2.0	1.0	0.0	1.0	32.1	70	0.7	0.4
20	872	110.0	613.0	450.0	277.0	2.0	1.0	0.0	1.0	33.1	70	0.8	-0.1
21	861	170.0	506.0	383.7	324.0	2.0	1.0	0.0	1.0	34.2	70	0.8	-0.1
22	851	227.0	403.0	417.3	370.0	2.0	1.0	0.0	1.0	36.3	70	0.6	-0.2
23	145	145.0	145.0	324.0	710.0	6.0	3.0	4.0	1.0	58.2	70	1.0	7.5
24	145	145.0	145.0	324.0	710.0	6.0	3.0	2.0	1.0	59.6	70	0.8	7.4
25	890	345.6	340.0	280.0	314.4	5.0	5.0	2.0	1.0	57.9	70	1.0	2.4
26	850	86.3	760.0	530.0	153.7	5.0	4.0	1.0	1.0	48.2	70	0.8	3.6
27	890	314.6	470.0	371.0	215.4	5.0	4.0	1.0	1.0	52.7	70	0.9	0.2
28	850	45.7	760.0	530.0	194.3	0.0	1.0	0.0	1.0	22.5	70	0.4	-0.2
29	890	158.2	470.0	371.0	371.8	0.0	1.0	0.0	1.0	22.9	70	0.4	-0.2
30	890	221.2	340.0	280.0	438.8	0.0	1.0	0.0	1.0	24.6	70	0.4	-0.2
31	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	361	900	13.0	7.2
32	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	367	900	12.1	7.2
33	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	362	900	13.1	7.2
34	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	369	900	12.0	7.2
35	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	361	900	12.9	7.2
36	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	364	900	10.4	7.2
37	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	365	900	13.6	7.2
38	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	363	900	10.9	7.2
39	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	366	900	13.5	7.2
40	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	361	900	11.0	7.2
41	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	363	900	12.6	7.2
42	859	53.0	717.0	469.0	230.0	3.0	1.0	0.0	1.0	361	900	11.0	7.2

DM=dry matter, CP=crude protein, NDF=neutral detergent fibre, ADF=acid detergent fibre, CHO=non-fibre, non-protein carbohydrate, SPT=specie/type, AGE, PHY=physiological state, MGT=housing system, LBW=body weight, MBW=mature body weight, RF=rumen fill

3.5.1 Modification of Datasets

Further efforts were made to modify the datasets used for ANN model. This was in a bid to eliminate negative predictions in the model. Cattle and sheep, when allowed to feed *ad-libitum* either on grazing or indoor, decide when to terminate feeding activity or when to begin it. However, as intake of roughage continues, spontaneous degradation due to microbial activities in the rumen continues. Hence, passage and digestion rates are affected. Invariably, it was considered that time delay (TD) before the measurement of rumen fill, either by complete evacuation through the fistula or slaughtering of the animals, could be an essential factor to be taken as predictor variable. Besides, RF (kg) for the datasets was scaled or converted to g/kg body weight. After this computation, all the variables were subjected to Pearson's correlation analysis to evaluate the linearity that exists between variables and the strength of such linearity. The modified datasets were then trained and validated in ANN.

3.6 RESULTS

Table 3.3 Diet quality and animal attributes used in the database for rumen fill dry matter measurement

Animal		DM (g/kg)	CP (g/kg)	NDF (g/kg)	ADF (g/kg)	CHO (g/kg)	SPT	AGE	PHY	MGT	LBW (kg)	MBW (kg)	RF (kg)
Cattle	N	78	78	78	78	78	78	78	78	78	78	78	78
	Minimum	121	27	325	203	168	3	1	0	0	316	750	6.1
	Maximum	1055	259	778	480	489	7	6	4	1	749	900	21.9
	Mean	581.0	129.7	565.2	331.1	305.1	5.9	4.0	2.5	0.9	556.7	788.5	11.8
	S.D	317.4	67.3	128.9	101.0	77.3	1.8	1.8	1.6	0.3	122.2	65.9	3.4
Sheep	N	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0
	Minimum	80	45	145	219	153.7	0	1	0	1	22.5	70	0.4
	Maximum	921	345.6	768	530	710	6	5	4	1	71	90	2.3
	Mean	692.7	130.5	556.3	341.0	313.2	2.8	2.9	1.0	1.0	54.0	78.7	1.2
	S.D	315.5	63.2	148.6	72.6	113.8	1.3	1.1	0.5	0.0	12.2	10.0	0.5
Total	N	140	140	140	140	140	140	140	140	140	140	140	140
	Minimum	80	27	145	203	153.7	0	1	0	0	22.5	70	0.4
	Maximum	1055	345.6	778	530	710	7	6	4	1	749	900	21.9
	Mean	630.5	130.1	561.2	335.5	308.7	4.5	3.5	1.8	0.9	334.1	474.1	7.1
	S.D	320.3	65.3	137.6	89.4	94.9	2.2	1.6	1.4	0.2	266.7	357.3	5.9

DM=dry matter, CP=crude protein, NDF=neutral detergent fibre, ADF=acid detergent fibre, CHO=non-fibre, non-protein carbohydrate, SPT=specie/type, AGE, PHY=physiological state, MGT=housing system, LBW=body weight, MBW=mature body weight, RF=rumen fill, N=number, SD=standard deviation

3.6.1 Data variations

The database was characterized by large variations in both dietary and animal variables. The diet composition for the 140 treatments was solely on roughages except in few cases where some other complementary feeds were used. There were four-fold and five-fold differences in level of rumen fill among cattle and sheep treatment means respectively, when minimum and maximum values were compared, but when comparing specie, cattle surpassed sheep 10 and 15 times in minimum and maximum values of the fill of rumen, respectively. Likewise when minimum and maximum values of live body weight were compared, it was a two-fold difference in cattle and was five-fold difference in sheep, but a similar variation to that of inter-specie fill of rumen was observed in the body weight. Between the two species and among all treatments, there were significant values for animal variables (SPT, AGE, PHY and LBW) and dry matter of the dietary variables.

3.6.2 ANN training model (I) of rumen fill (kg)

ANN committee when assessed on training data pool learnt by seeking to minimise the error difference (*RMSE)* between the predicted output and the observed output values using the equation:

$$\mathbf{RMSE} = \surd\ \frac{\sum_{i=1}^{n}\sum_{n=}^{m}1(Y_{n}^{i} - y_{n}^{\wedge i})^{2}\ ;}{NM}$$

Where N is patterns number used in the training; M is number output nodes; i is index of input pattern (vector) and Y^{i}_{n} and $\hat{y}^{i}_{n}$ are the observed and predicted outputs, respectively. Root Mean Square Error (*RMSE)* was 0.138 as shown in the training output when R^2 was 0.83.

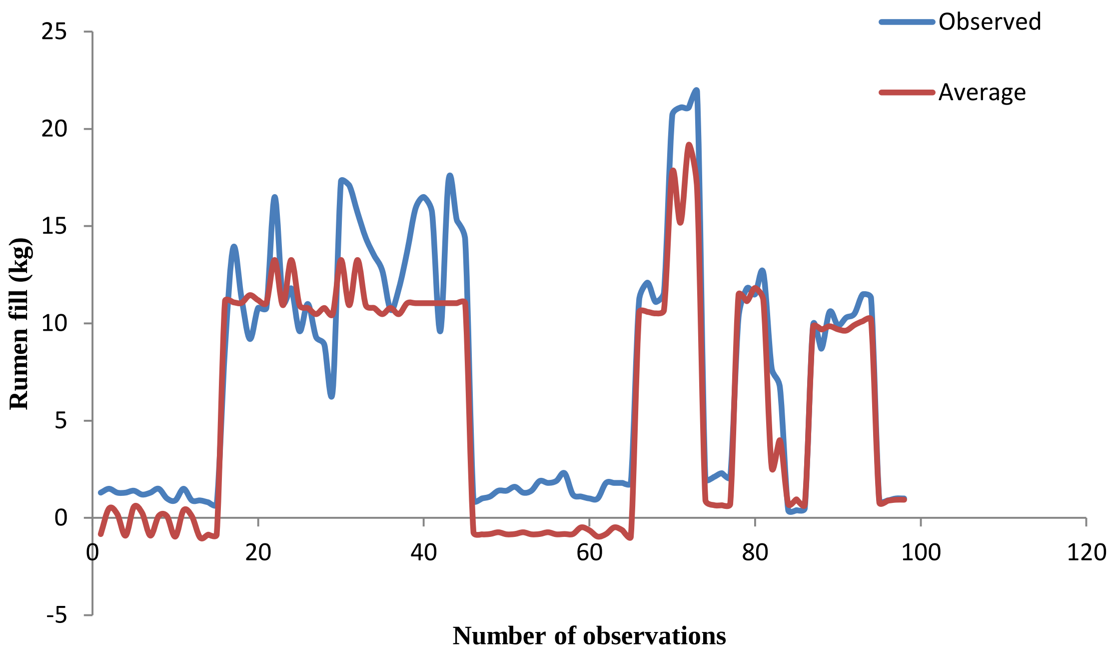


Figure 3.3 Training data output curve showing ANN average predicted and observed rumen fill

3.6.3 ANN validation model (I) of rumen fill (kg)

On validation, data pool gave R^2 of 0.92. The general output of predicted values is shown in Table 3.2.

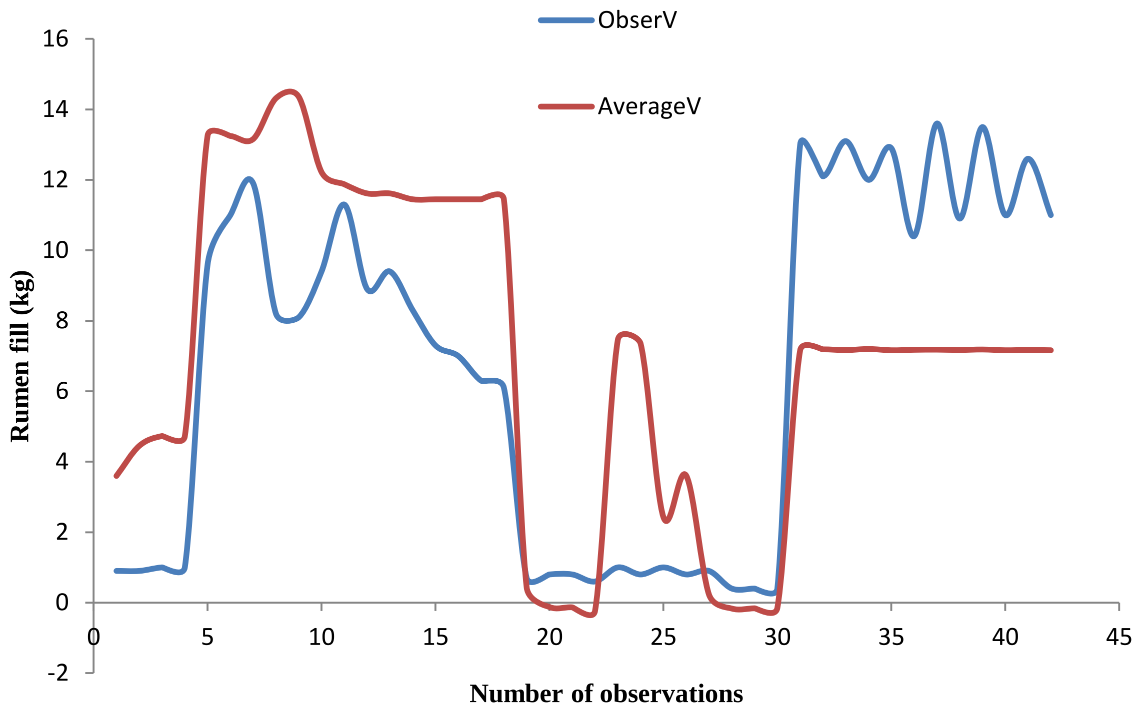


Figure 3.4 Validation data output showing ANN average predicted and observed rumen fill

Both training and validation outputs of the ANN followed the same pattern for the observed and predicted rumen fill and this is a signal for a fair prediction more importantly that the error of prediction is 5.6%.

Table 3.4 Correlation coefficient of rumen fill (g/kgBW) with other variables

Variables	r	P-value
DM	0.137	0.107
CP	-0.502	0.000
NDF	0.469	0.000
ADF	0.290	0.001
CHO	-0.335	0.000
SPT	-0.131	0.123
AGE	-0.267	0.001
PHY	-0.328	0.000
MGT	0.117	0.165
LBW	-0.040	0.639
MBW	0.194	0.022
TD	-0.034	0.687

DM=dry matter, CP=crude protein, NDF=neutral detergent fibre, ADF=acid detergent fibre, CHO=non-fibre, non-protein carbohydrate, SPT=specie/type, AGE, PHY=physiological state, MGT=housing system, LBW=body weight, MBW=mature body weight, TD=time delay

Rumen fill (g/kgBW) was positively correlated with NDF (P<0.0001), ADF (P<0.001) and MBW (P<0.05) but negatively correlated with CP (P<0.0001), CHO (P<0.0001), AGE (P<0.001) and PHY (P<0.0001).

3.6.4 ANN training and validation model (II) of rumen fill (g/kgBW)

The modified datasets on training and validation in the ANN has *RMSE* of 0.54 with R^2 of 0.37and 0.22, respectively.

Table 3.5 Artificial neural network (ANN) validation model (II) outputs for rumen fill prediction

DM (g/kg)	CP (g/kg)	NDF (g/kg)	ADF (g/kg)	CHO (g/kg)	SPT	AGE (yr)	PHY	MGT	LBW (kg)	MBW (kg)	TD (hr)	RF Predicted (g/kgBW)	RF Observed (g/kgBW)
502	87.5	700	219	212.5	2	2	1	1	44.5	70	0.5	19.122	20.22472
566	62.5	721	219	216.5	2	2	1	1	44.5	70	0.5	20.389	20.22472
502	62.5	730	219	207.5	2	2	1	1	44.5	70	0.5	20.211	22.47191
566	45	768	219	187	2	2	1	1	44.5	70	0.5	20.651	22.47191
476	186	325	203	489	7	5	4	1	659	750	6	19.16	12.59484
476	186	325	203	489	7	5	4	1	658	750	6	19.165	14.43769
476	186	325	203	489	7	5	4	1	651	750	6	19.196	15.82181
445	118	526	316	356	7	5	3	1	745	750	6	20.032	9.530201
445	118	526	316	356	7	5	3	1	749	750	6	20.015	9.345794
806	135	476	270	389	7	5	4	1	576	750	0	19.033	16.31944
1055	176.7	623.1	353.4	200.2	7	6	4	1	703	750	0	19.635	16.07397
880	160	513	400	327	7	4	4	1	580	750	0	21.171	15.34483
880	160	513	400	327	7	4	4	1	580	750	0	21.171	16.2069
880	160	513	400	327	7	4	3	1	580	750	0	25.145	14.31034
880	160	513	400	327	7	4	3	1	580	750	0	25.145	12.58621
880	160	513	400	327	7	4	3	1	580	750	0	25.145	12.06897
880	160	513	400	327	7	4	3	1	580	750	0	25.145	10.86207
880	160	513	400	327	7	4	3	1	580	750	0	25.145	10.51724
882	53	716	351	231	2	1	0	1	32.1	70	0	19.001	21.80685
872	110	613	450	277	2	1	0	1	33.1	70	0	17.225	24.16918
861	170	506	383.7	324	2	1	0	1	34.2	70	0	16.487	23.39181
851	227	403	417.3	370	2	1	0	1	36.3	70	0	16.084	16.52893
145	145	145	324	710	6	3	4	1	58.2	70	0	25.377	17.18213
145	145	145	324	710	6	3	2	1	59.6	70	0	22.501	13.42282
890	345.6	340	280	314.4	5	5	2	1	57.9	70	0	18.952	17.27116
850	86.3	760	530	153.7	5	4	1	1	48.2	70	0	22.071	16.59751
890	314.6	470	371	215.4	5	4	1	1	52.7	70	0	19.877	17.0778
850	45.7	760	530	194.3	0	1	0	1	22.5	70	0	17.718	17.77778
890	158.2	470	371	371.8	0	1	0	1	22.9	70	0	16.044	17.46725
890	221.2	340	280	438.8	0	1	0	1	24.6	70	0	14.754	16.26016
859	53	717	469	230	3	1	0	1	361	900	4	21.362	32.68698
859	53	717	469	230	3	1	0	1	367	900	4	21.366	29.97275
859	53	717	469	230	3	1	0	1	362	900	4	21.362	32.87293
859	53	717	469	230	3	1	0	1	369	900	4	21.368	29.5393
859	53	717	469	230	3	1	0	1	361	900	4	21.362	32.40997
859	53	717	469	230	3	1	0	1	364	900	4	21.364	25.82418
859	53	717	469	230	3	1	0	1	365	900	4	21.365	33.69863
859	53	717	469	230	3	1	0	1	363	900	4	21.363	27.27273

859	53	717	469	230	3	1	0	1	366	900	4	21.365	33.33333
859	53	717	469	230	3	1	0	1	361	900	4	21.362	27.70083
859	53	717	469	230	3	1	0	1	363	900	4	21.363	31.40496
859	53	717	469	230	3	1	0	1	361	900	4	21.362	27.70083

DM=dry matter, CP=crude protein, NDF=neutral detergent fibre, ADF=acid detergent fibre, CHO=non-fibre, non-protein carbohydrate, SPT=specie/type, AGE, PHY=physiological state, MGT=housing system, LBW=body weight, MBW=mature body weight, RF=rumen fill

All predictions in the ANN validation model built apparently on the training model and none of them was negative even though the coefficient of determination (R^2) was less and explained little of the variability in the datasets.

3.6.5 Pattern of RF (g/kgBW) between observed and predicted values in validation model (II)

The patterns of rumen fill (g/kgBW) observed and predicted though had significant variation but remained parallel and consistent in the rises and falls and trend of the curves as shown in Figure 3.5.

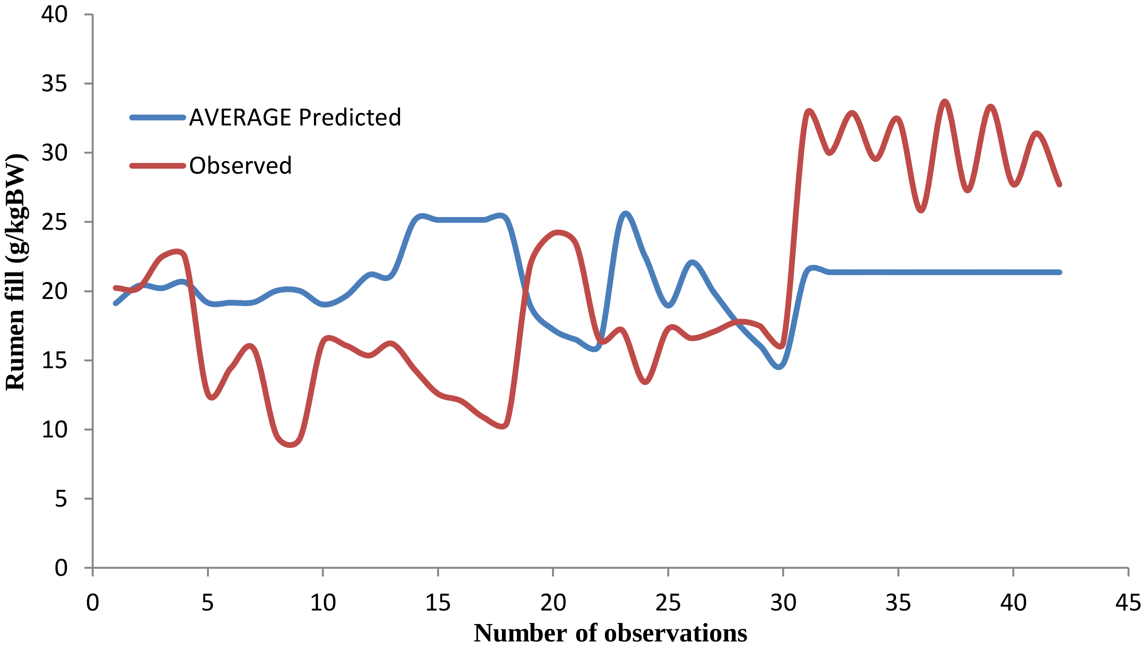


Figure 3.5 ANN Validation model (II) data output curve for average predicted and observed rumen fill

3.7 DISCUSSION

3.7.1 Dietary characteristics

Crude protein, NDF, ADF and non-fibre non-protein carbohydrate of all diets used on DM basis significantly varied from one another. However, the mean values of crude protein used for cattle, sheep and total treatments were 129.7±67.3, 130.5±63.2 and 130.1±65.3 respectively with corresponding mean values of NDF as 565.2±128.9, 556.3±148.6 and 561.2±137.6, respectively. This shows that the higher the value of crude protein in these diets, the less the value of NDF and a corresponding effect on the value of non-fibre non-protein carbohydrate of the diets. It agrees with previous studies (Got *et al*., 1991, Ghana *et al*. 1993).

3.7.2 Animal characteristics

The mean body weight for cattle was 10 times larger than that of sheep and this is empirically evident by various studies. However, cattle were mostly used for dairy experiments rather than sheep and by implication; physiology is 2.5 times greater than that of sheep as well.

3.7.3 Artificial neural network (ANN) Model (I) for rumen fill (kg)

The ANN model accounted for 83 to 92% of the variability observed in the fill of the rumen. This can be attributed to the ability of ANN to approximate non-linear processes (Shahinfar *et al*., 2012; Jain *et al*., 1996). Although, it appeared that data with higher CHO, LBW and MBW had higher observed and predicted rumen fills, typical for lactating cows, these predictions still had a calculated error of 5.6% and negative values. These are pointers to weaknesses of relationship between input parameters and corresponding output of some of data unlike the accolades given to ANN model in other fields. With the input sensitivity analysis showing 95.4%, 69.4%, 55.3%, and 50.6% for mature body weight, physiology, crude protein and age, respectively, it is plausible that rumen fill is better predicted limiting input parameters to these highly sensitive ones. Nonetheless, the modelling accuracy of ANN over response surface methodology (RSM), One Variable at a Time (OVAT) (Whiteman and Kana, 2014) and conventional statistical prediction and classification methods such as linear regression, logistic regression (Salawu *et al*., 2014) can still be further tested and confirmed with rumen fill as well.

3.7.4 Modified rumen fill (g/kgBW) and the predictors

Although competing activities in the rumen i.e. degradation and passage, and their rates may apparently affect the rumen fill (Nsahlai, 1991), the time delay (TD) before fill measurement was not significant ($P>0.05$). However, NDF ($P<0.0001$), ADF ($P<0.001$) and MBW ($P<0.05$) were positively correlated with rumen fill ($r=0.469$, $r=0.290$ and $r=0.194$ respectively) and it is an indication to increasing rumen fill with increase in fibre content of feed. Several previous studies supported this (Aitchison *et al*., 1986; Baumont *et al*., 1997; Nsahlai 1991; Weston 1996). Conversely, CP ($P<0.0001$), CHO ($P<0.0001$), AGE ($P<0.001$) and PHY ($P<0.0001$) were negatively correlated with rumen fill. This implies that a decrease in either of these parameters would lead to a corresponding increase in the fill of the rumen. For example, availability of CP most especially in feed enhances rate of degradation (Baumont *et al*., 1997). Besides, for every increase in input parameters, rumen fill increases with 0.90.

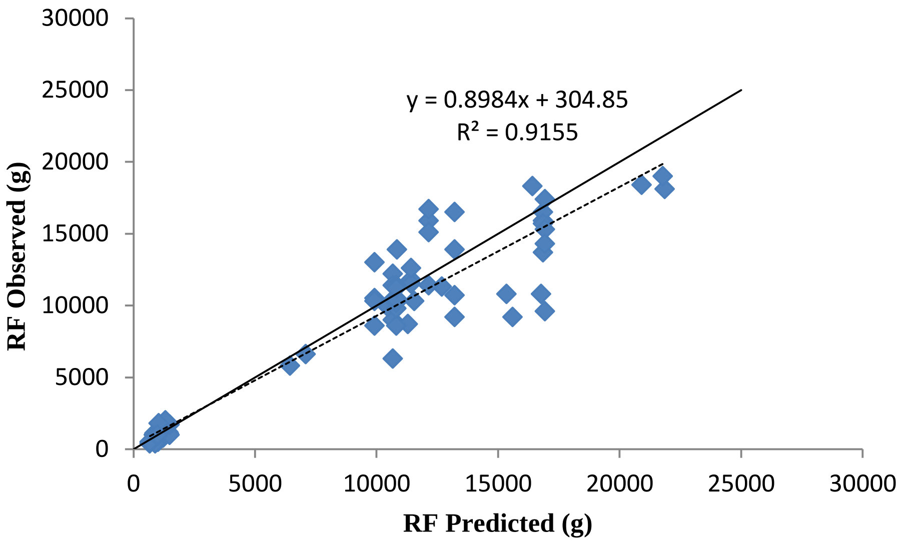


Figure 3.6 Relationship between the predicted (ANN training model II) and observed values of rumen fill

In the same vein, ANN validation model (II) in Figure 3.7 shows that rumen fill increases by 0.608 for every increase in input.

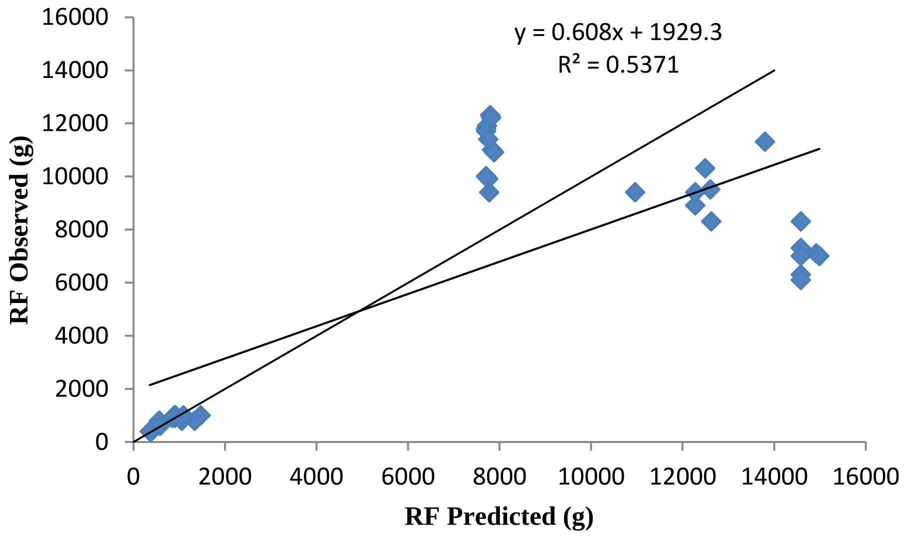


Figure 3.7 Relationship between the predicted (ANN validation model II) and observed values of rumen fill

This study is the first in ruminants that seeks to establish prediction of rumen fill via ANN using predictors from animal and plant attributes. The only previous study in ruminant particularly that used ANN, has only explored this modelling technique in prediction of *in vitro* rumen CH_4, CO_2 and total gas (Dong and Zhao, 2014). Besides, the dynamics in the parallelization and linearity between the ANN predicted values and the observed values were unequivocal and it is a signal to the worthiness of the accolades given to the technique (Jain *et al*., 1996; Whiteman and Kana, 2014).

3.8 CONCLUSION

With the prediction error of 5.6% amidst variability of 83% in the training and 92% in that of validation models, it is therefore suggested that artificial neural network (ANN) could also be an efficient model to simulate rumen fill or even feed intake in field situations. The success of elimination of negative predictions achieved when datasets were modified, though ANN could only explain 37% and 22% variability of in training and validation data. However, further investigation into input parameters and ANN models, especially what goes on in the hidden layers and specific inbuilt functions establishing the relationship, still need to be done to reduce noise in the datasets and achieve the best possible relationships between input variables and rumen fill.

Chapter 4

EFFECT OF ROUGHAGE QUALITY ON DIGESTION, INTAKE AND LIVE WEIGHT CHANGES

ABSTRACT

The objective of the current study was to evaluate the effect of diet quality on nutrients intake, dry matter degradation, digestibility of nutrients, intake of digestible organic matter, metabolizable energy and live weight changes. The treatment diets were urea-treated hay (UTH), urea-sprayed hay (USH) and non-treated hay (NTH). An *in sacco* degradation trial on treatment diets was carried out at 0, 3, 6, 9, 24, 48, 72 and 96 hours using two fistulated cattle. These treatments were fed to 18 goats which were blocked in two weight groups before randomly assigning them to treatments. At the 7th week of the feeding trial, an *in vivo* digestibility trial was carried out using all the 18 goats. Faecal bags were fitted on the goats and a 4-day adaptation to the bags was allowed. Total faeces voided by each goat were collected for seven consecutive days. Data of total feed intake and total faeces voided were recorded. Treatment diets (UTH, USH and NTH) and faeces were analysed for dry matter, organic matter, neutral detergent fibre and acid detergent fibre concentrations. Thereafter, calculations were made for nutrients intake per day, apparent digestibility of nutrients, intake of digestible hay organic matter, metabolizable energy and MEIWT. Live weight of goats was recorded from the beginning and every week later until day 63. All the data were analysed using GLM procedure of SAS. Urea treatment increase solubility (*a*), rate constant of degradation (*c*), potential degradability (PD) and effective degradability (ED) followed in order by UTH>USH>NTH. Intakes of nutrients of each of UTH, USH and NTH were different from one another and the nutritional quality of the roughages have significant effect on DMI ($P<0.001$), OMI ($P<0.001$), NDFI ($P<0.001$) and ADFI ($P<0.001$). Diet quality on the other hand had no effect on ADMD ($P>0.05$) but effect was significant on AOMD ($P<0.05$), ANDFD ($P<0.01$) and AADFD ($P<0.01$). Also, the effect of treatment feed was significant on the intake of DOM ($P<0.001$), and ME ($P<0.001$); resulting to better live weight change with UTH for by USH, and NTH. In conclusion, nutrients intake, dry matter degradation, nutrients apparent digestibility, intake of digestible hay organic matter, metabolizable energy and live weight change were greatly affected by improved quality of hay with urea.

Key words: *in vivo* digestibility; *in sacco* degradation; weight; goats.

4.1 INTRODUCTION

The in sacco method is a procedure routinely used to measure degradation parameters of nutrients in feeds within the rumen (Čerešňáková *et al*., 2007; Homolka *et al*., 2007). Although it is considered a time consuming and expensive method since it involves the use of cannulated animals (Jančík *et al*., 2009), it still gives relatively accurate results (Ørskov and McDonald, 1979). When using this technique for evaluation of the nutritive value of feedstuffs, caution must also be observed to use the result as qualitative indicator of general principles since the method is faced with some limitations. Among the limitations are; feed samples are confined in dacron bag and not exposed to breakdown due to chewing and rumination; feed would be able to leave the bag and even the rumen once broken down to apposite particle size; what is really determined is exactingly breakdown of feed materials to size just small enough to leave the bag (Ørskov *et al*., 1980).

Digestibility is positively related to nutrients concentration in feed and its intake. Therefore, digestion of feed is high with high amount of nutrients (Sanon *et al*., 2008). Roughages are major parts of ruminant rations (Anil *et al*., 2000) which function to optimize the efficiency of their GIT (Reynold *et al*., 2004) and provide energy but most of them cannot meet the supply of required crude protein for production (Anil *et al*., 2000). Consequently, potential intake of any roughage diet consumed by these animals differs because of their nutritional quality and effects. Urea treatment is a superior and effective means of optimizing the use of these poor quality essential feeds of ruminants, as it increases the nitrogen content of roughages (hay, straws and the likes), increases their voluntary intake, degradation in the rumen and also increases digestibility, all usually by 25 to 50% compared to non-treated ones (Preston, 1995).

Reticulo-rumen fill is a key factor to ruminant productivity and the extent of dry matter intake is the dominant process for assessing it. In forage-fed animals, processes that occur in the rumen determine the amount and types of nutrients absorbed and control dry matter intake (Forbes *et al*., 1995).

In the current study, three different quality diets have been achieved with the use of urea; urea-treated hay (UTH), urea-sprayed hay (USH) and non-treated hay (NTH). One objective of the study was to determine the effect of these dietary roughages on dry matter degradation, apparent nutrient digestibility and available nutrients intake in goats, water intake and live weight change.

4.2 MATERIALS AND METHODS

4.2.1 EXPERIMENTAL SITE

The study was carried out at Ukulinga Agricultural Research Unit of the University of KwaZulu-Natal, Pietermaritzburg. The location is a subtropical hinterland that lies between 29^0 $40^{'}$S and 30^0 24’ E with an elevation of about 700 m above sea level. It is characterized by 735 mm average annual rainfall, 8.9^0C and 25.7^0C mean minimum and maximum temperatures respectively. The area experiences moderate frost around May to September and summer usually between October and April.

4.2.2 EXPERIMENTAL ANIMALS AND HOUSING MANAGEMENT

Two fistulated Jersey cattle, one was a cow with live weight 324 kg and the other was a bull with live weight 280 kg, were housed in individual feedlot pen under roofed shed of 48 m^2 in diameter. The two were separated to avoid mating which may lead to removal of cannula and could eventually lead to loss of samples in the rumen.

Eighteen live goats comprising of 9 young ones between ages 6 months to 1 year with light weight between 12 to 23 kg, and 9 adult goats between 2 to 3 years weighing between 25 to 40 kg were used. Each goat was kept individually reared in a pen under same temperature, lighting and ventilation condition for 10 days adaptation, 63 days feeding trial and 6 days measurement periods.

4.2.4 EXPERIMENTAL FEED

One hundred and five bales of hay were harvested, chopped and bagged. Hay equivalent to 35 bales was treated with urea (Urea-Treated Hay UTH), 35 bales were always sprayed with urea (Urea-Sprayed Hay USH) while remaining 35 bales were not treated (Non-Treated Hay NTH) to make three different feed treatments.

4.2.5 UREA TREATMENT OF HAY

Using FAO (1997) recommendation of 5 kg Urea to 50 litres of water to be incorporated in 100 kg straw, a general approximation of 1 bale of hay equals to 15 kg was made and a total of 25 kg urea was dissolved in 300 litres of water to homogenously mix the whole 35 bales of chopped hay. Mixing was done using spades and rakes.

Procedurally, 25 kg urea was weighed, dissolved and mixed thoroughly in a measured quantity of 300 litres water for total dissolution. Thereafter, urea solution was put in watering can or sprinkler and sprinkled all over the 35 bales of milled hay displayed with a large surface area to ensure proper and uniform solution-watering. The hay was turned severally with spades and rakes for homogenization and then packed into hermitic sealed-bags to prevent losses of urea solution and ammonia generated. Likewise, to ensure an anaerobic environment as a guarantee against mould development within the damp sealed UTH mass.

This treated hay was left for 40 days before use, to hydrolyze and generate ammonia that solubilizes nutrients in hay, as indicated in the following equation.

$$CO\ (NH_2)2\ +\ H_2O\ \rightarrow\ 2\ NH_3\ +\ CO_2$$

(Urea) (water) (ammonia) (carbonic gas)

Hydrolysis occurs in the presence of heat and urease and once it is completed, one molecule of urea (60g) generates 2 molecules of ammonia (34g).

4.2.6 SPRAYING OF HAY WITH UREA

With recommendation of urea equal to 2.5% of quantity of hay to be sprayed, 2.5 kg of urea was dissolved in 60 litres of water to spray every 100 kg of hay used in this research. After dissolution, the solution was put in watering can or sprinkler and sprinkled all over the hay which was displayed with very large surface area to ensure proper and uniform solution-watering. The hay was turned severally with spades and rakes for homogenization but unlike in urea treatment, it was only left for sun drying and air-drying in part a day and after this, it was packed and used as USH.

4.2.7 FEED PREPARATION AND DEGRADATION IN THE RUMEN

Three different quality hay diets viz; UTH, USH and NTH were collected, chopped and ground to pass through a 2 mm sieve in the farm mill (Scientec RSA hammer mill Serial Number 400, Lab World PTY LTD., Sloane Park 2152, JHB). Fistulated cattle were fed for seven days with supplemental lucerne hay (LH) of 1.5 kg per animal and *ad-libitum* veld grass hay (VGH), prior to degradation period of five consecutive days. This feeding regime still continued throughout the incubation period. Lucerne hay was ordered (TWK Agric. PTY

LTD., Victoria Road, Pietermaritzburg), and milled while the VGH was harvested from the farm.

4.2.8 DEGRADATION PROCEDURE

The degradation of DM of feeds was measured using the nylon bag method as described by Ørskov *et al*. (1980). This method was adopted to measure the disappearance of DM component of feed from synthetic nylon bags following incubation in the rumen at varying periods of time (0, 3, 6, 9, 24, 48, 72 and 96 hours). A sample (2 g) of each ground feed (UTH, USH or NTH) was weighed into nylon bags with duplicates such that one bag of each of the treatment feed samples was allowed in each of the two cattle. Bags were tied to a suspender and secured with a fishing line, then suspended into the rumen for incubation. The sequential addition method was used to incubate the samples. Thereafter, bags were withdrawn and immediately rinsed and washed with running water to remove excess ruminal contents and micro-organisms from surfaces of bags. Bags for zero time were not incubated. All bags collected were washed six times in a domestic semi-automatic washing machine together with the zero time bags until the water was completely clear. Washing took 30 minutes as the water was changed for every wash cycle with each cycle lasting for 5 minutes.

After washing, bags were oven-dried at 60 ^{0}C for 48 hrs, cooled in a desicator and weighed. Hence, DM loss was calculated and expressed as percentage degradability of the original dry matter incubated. Percentages of disappearance of DM were calculated from the proportion remaining after incubation in the rumen using the equation from Ørskov and McDonald (1979); $p = a+b\ (1-e^{-ct})$, where p = disappearance rate at time t, a = soluble fraction of DM at initiation of incubation (time 0), b = insoluble fraction of DM which is potentially degradable in the rumen, c = a rate constant of disappearance of b-fraction, and t = time of incubation. Also, potential degradability (PD) and effective degradability (ED) of dry matter were calculated using the following equations: PD= a+b; and ED= a+ (bc/(c+k)) where k is the estimated rate ($0.03h^{-1}$) of out flow of degraded particles from the rumen (Nsahlai *et al*., 1998).

4.2.9 EXPERIMENTAL DESIGN AND FEEDING MANAGEMENT

All the 18 experimental goats were divided into two groups comprising of nine heavy weight goats (25 to 40 kg) and nine light weight goats (12 to 23 kg). Each group was randomly allotted to three treatment feeds, which were UTH, USH and NTH. Fresh water and salt licks containing trace minerals (calcium=120 g/kg, manganese=1200 mg/kg, copper=200 mg/kg, cobalt=1 mg/kg, sodium=10 g/kg, zinc=1200 mg/kg) were made available at all time. Feed was dispensed to these goats *ad-libitum* at 0800 h (morning) and at 1500 h (afternoon). An adaptation of 10 days was allowed to familiarize animals with the new feeding system and feed, to observe any side effect from possibly the UTH or USH. Thereafter, 63 days feeding trial was done.

4.3 *IN VIVO* DIGESTIBILITY TRIAL

Goats were weighed at the commencement of this trial At the end of the 7th week of the experiment, 18 goats comprising nine young ones (1-2yrs) with light weight (12-23kg) and nine adults (2-3yrs) with heavy weight (25-40kg), were fitted with faecal bags in their individual standing pens and were allowed a 4-day adaptation before *in vivo* digestibility trial was done. During the adaptation, animals also got used to the management of emptying faeces from bags. Faeces in bags were always emptied at mid-day and early morning before fresh feed and water were offered to goats. This was to avoid stress of faecal heavy weight on animals, to make it comfortable while resting and assist in total collection of faeces. Following the adaptation, VFI was determined at the end of the week, by collecting, weighing and subtracting orts from the total feed dispensed for the week. This was used to calculate the dry matter intake of goats. The technique described by Juko *et al*. (1961) was used for the digestion trials. After adaptation to bags, faeces were collected and weighed for seven days and daily faeces voided were recorded. All faecal samples collected from each animal were bulked to make a whole mass of faeces for each animal. Samples of feeds offered and total faeces were collected and dried in a forced-air oven at 70^0C for four days which was enough to achieve constant mass. Then faecal samples were instantly weighed, sub-sampled to 1/10th of the total faeces mass and ground to pass through a 1-mm sieve and stored in airtight containers.

4.4 MEASUREMENTS AND DATA COLLECTION

Throughout the experiment, feed intake and water intake for each goat were measured weekly. For convenience, each feed was bagged in 7 kg and two bags were allotted to each animal. At the end of every week, leftover feed in feeders were removed 30 minutes before fresh feed was offered in the morning, weighed with the leftover feed in bag, and then subtracted from the total dispensed weight of feed. Thereafter, daily intake was determined. Also, for water intake determination, five litres of fresh water was offered in the morning to each goat in individual plastic bucket and leftovers were always measured to record the daily water intake which was thereafter summed up at the end of the week. Live body weight of each goat was measured before the start of the experiment as initial body weight and thereafter weekly, till the end of the experiment.

4.5 CHEMICAL ANALYSES

All samples of feed and faeces were ground to pass through 1 mm sieve. Duplicate samples of each of the three treatment feeds UTH, USH and NTH fed to goats and faeces were analyzed for dry matter (DM), organic matter (OM), crude protein (CP) (AOAC, 1991), neutral detergent fibre (NDF), acid detergent fibre (ADF) (Van Soest *et al*., 1991) and dry matter degradation (DMD) (Ørskov *et al*., 1980), all in the laboratory of the Department of Animal and Poultry Science, University of KwaZulu-Natal, Pietermaritzburg except CP which was analysed in the laboratory of the Department of Chemistry, Faculty of Science and Agriculture, University of Zululand, KwaDlangezwa. Also, intake of digestible organic matter (DOM) and metabolizable energy (15.06 x DOM) intake in MJ/day (MEI) or MJ/kg $BW^{0.75}$ (MEIWT) were calculated. Also, ANKOM fibre analyzer was used to determine NDF and ADF. The NDF content was determined without a heat stable alpha amylase. For apparent digestibility of nutrients, the same procedure was used to analyze faecal samples of goats for dry matter (ADMD), organic matter (AOMD), neutral detergent fibre (ANDFD) and acid detergent fibre (AADFD) (Van Soest *et al*., 1991).

4.6 STATISTICAL ANALYSES

All data were analysed using SAS system 9.1 (SAS, 2013). Data were subjected to analyses of variance using the general linear models (GLM) procedure of SAS (2013) to determine the effect of roughage or treatment feeds quality on intake, digestibility, and live weight change. The model used was:

$$\boldsymbol{Y_{ijk} = \mu + S_i + P_j + (SP)_{ij} + \varepsilon_{ijk};}$$

where Y_{ijk} is the observation, μ is the overall mean common to all observation, S_i is the effect of diet, P_j is the effect of body weight $(SP)_{ij}$ is the interaction between diet and body weight and ε_{ijk} is the residual error.

4.7 RESULTS

4.7.1 Feed quality

Table 4.1 shows the diet composition and degradability properties of all feeds in the following order; UTH, USH and NTH. While DM, OM and NDF increased down this order, CP and ADF decreased. Impliedly, UTH had the highest values of CP and the lowest of DM. A bit of disparity exists in the stated order between NDF of UTH and USH but considering the ratio of NDF to ADF in the two diets, UTH had a lesser fibre content. Also, UTH had the highest solubility, rate of degradation, potential and effective degradability followed in descending order: UTH>USH>NTH.

Table 4.1 Chemical composition (g/kg) of urea-treated hay (UTH), urea-sprayed hay (USH) and non-treated hay (NTH) and diets dry matter disappearance (g/kg) in the rumen of cattle

Diets	**UTH**	**USH**	**NTH**
DM	904	920	923
OM	70	83	89
CP	75.6	47.5	20.0
NDF	723	723	735
ADF	632	592	581
Degradability of DM			
a	369	281	229
b	431(±4.8)	481(±3.7)	516(±2.7)
c	0.048 (±0.019)	0.038(±0.010)	0.036(±0.006)
tl	4.5(±1.71)	3.7(±1.29)	1.9 (±1.04)
a+b	800	762	744
ED	639	468	429

a is solubility, b is slowly degradable fraction, c is the rate of degradation, tl is the lag phase, a+b is the potential degradability and ED is the effective degradability

4.7.2 *In vivo* digestibility

Roughage quality influenced intake such that diets UTH and USH were similar but higher ($P<0.01$, $P<0.001$) than NTH for DM, OM, NDF and ADF by goats. Roughage quality affected dry matter digestibility ($P>0.05$) for AOMD ($P<0.05$), NDF ($P<0.01$) and ADF ($P<0.01$). The dry matter digestibility of UTH was larger than that of NTH but similar to that of USH. ANDFD of NTH was significantly less than USH ($P<0.05$) and UTH ($P<0.01$). Roughage quality influenced the intake digestible organic matter ($P<0.001$), metabolizable energy intake ($P<0.001$) and MEIWT ($P<0.001$). Of importance is that IDOM, MEI and MEIWT of NTH were less ($P<0.001$) than USH and UTH.

Table 4.2 Effect of diet quality on nutrients intakes (g/d), apparent digestibility (g/kg) and available nutrient intake

Variables		**Diets**		***RMSE***	**Treatment Effects**
	UTH	**USH**	**NTH**		
Nutrients intakes					
DMI	0.7721	0.8068	0.5530	0.0951	0.0008
OMI	0.7782	0.8040	0.5151	0.0962	0.0002
NDFI	0.6172	0.6334	0.4405	0.0754	0.0009
ADFI	0.4384	0.3956	0.2562	0.0521	<0.0001
Apparent digestibility of nutrients					
DMD	656.08	640.74	567.39	67.33	0.0844
OMD	688.95	669.29	567.28	63.59	0.0111
NDFD	755.52	722.40	645.92	53.42	0.0094
DFD	753.17	708.88	616.71	58.59	0.0039
Available nutrient intake					
DOM	0.5420	0.5404	0.3003	0.0806	0.0001
MEI (MJ/d)	8.1622	8.1377	4.5230	1.2137	0.0001
MEIWT(MJ/kg $BW^{0.75}$)	0.3155	0.3178	0.1730	0.0389	0.0001

DMI=dry matter intake, OMI=organic matter intake, NDFI=neutral detergent fibre intake, ADFI=acid detergent fibre intake, DMD=dry matter digestibility, OMD=organic matter digestibility, NDFD=neutral detergent fibre digestibility, ADFD=acid detergent fibre digestibility, DOM= digestible organic matter, MEI=metabolizable energy intake

Table 4.3 Average feed intake (g/d), water intake (l/d), initial weight (kg) and final weight (kg) of goats

Diets	**UTH**	**USH**	**NTH**
Number of animals	6	6	6
Feed intake	910 ±0.300	880 ±0.252	660 ±0.188
Water intake	1.02 ±0.246	1.11 ±0.119	1.25 ±0.280
Initial body weight	26.56 ±10.39	27.25 ±10.18	27.50 ±10.12
Final body weight	26.25 ±10.49	26.92 ±9.86	23.83 ±9.31
Live weight change (kg)	-0.31	-0.33	-3.67

4.7.3 Dry matter intake of goats

Although the patterns of dry matter intake of goats on UTH, USH and NTH appeared to be similar in figure (4.1), a consistent downward trend was obvious for NTH while UTH and USH initially rose within the first 14 days and thereafter fluctuate till the end of the collection period.

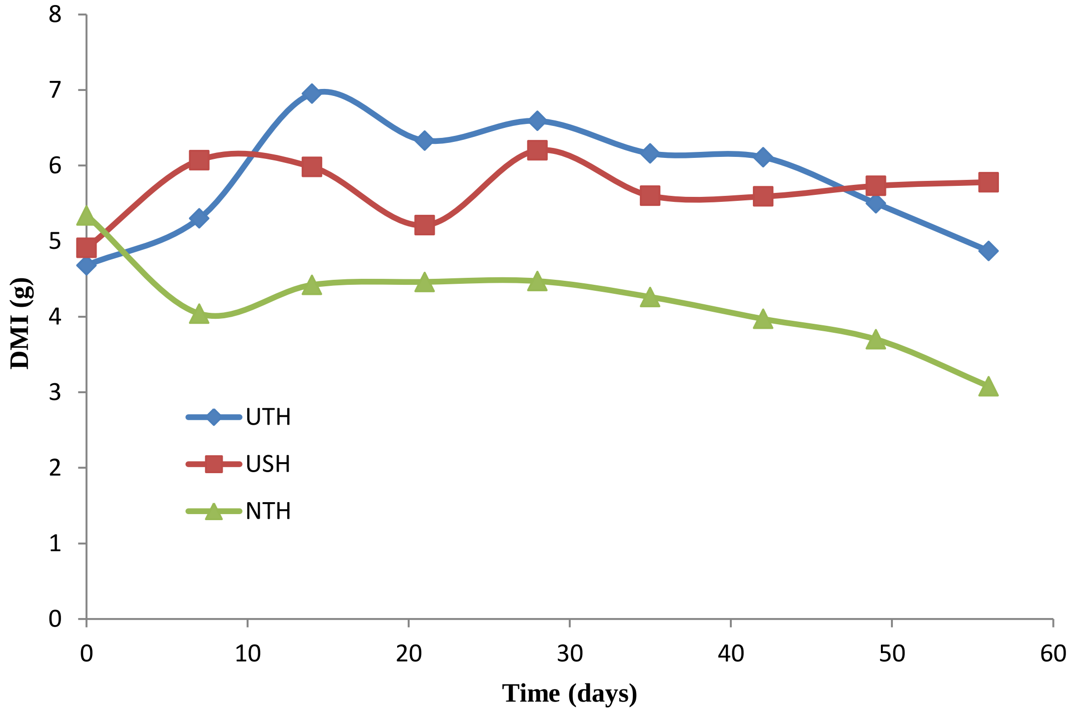


Figure 4.1 Dry matter Intake per day of goats fed urea-treated hay, urea-sprayed hay and non-treated hay

The DMI of UTH and USH were similar (P>0.05) and higher than NTH (P<0.001 or P<0.01) throughout from 7th day till 49th day. On the 56th day only USH was higher than NTH (P<0.05) while both UTH and NTH were similar.

4.7.4 Water intake of goats

Changes in water intake of goats over the experimental period, as shown in Figure 4.2, were quite small. There existed an undulating rise to the peak 40 days later for all goats. Water intake throughout the collection period for goats fed UTH, USH and UTH were similar (P>0.05) until the 6th and 7th week when water intake of goats fed NTH was similar (P>0.05) with that of USH but higher (P< 0.05) than UTH. Likewise, at the 8th week, water intake of goats fed UTH and USH were similar (P>0.05) but UTH was less (P<0.05) than NTH.

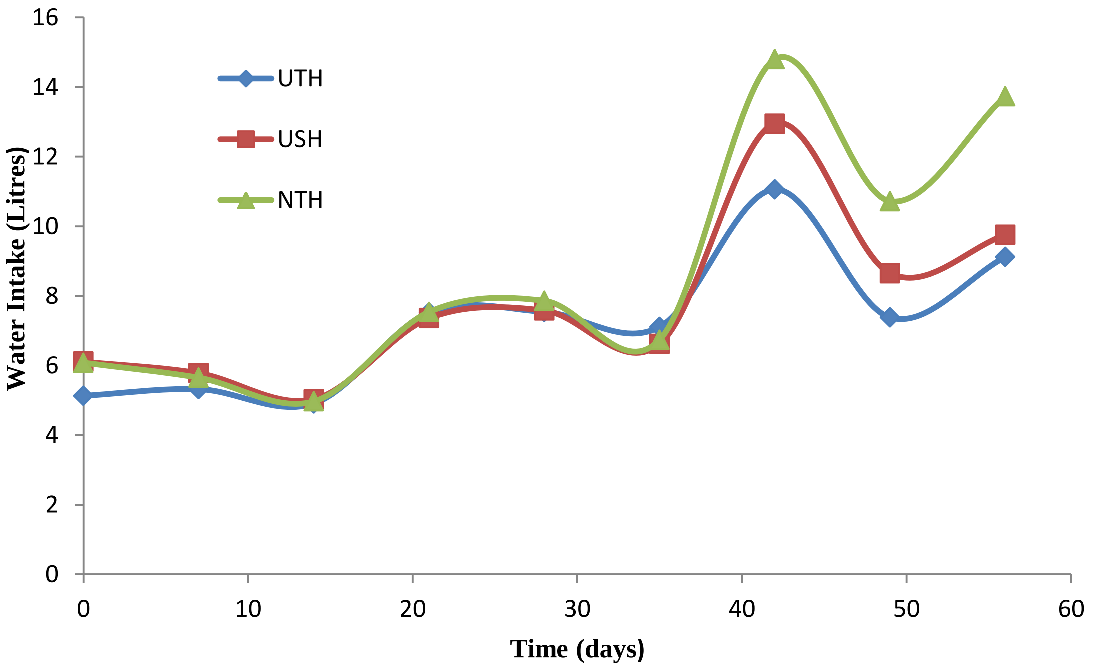


Figure 4.2 Water intake per day of goats fed urea-treated hay, urea-sprayed hay and non-treated hay

4.7.5 Body weight changes in goats

The weight changes of goats as shown in Figure 4.3 for UTH, USH and NTH over collection days was generally fluttered and the patterns appeared to be similar. Of note is that at the beginning of the experiment, there was a spectacular fall in the weight of all goats within the first seven days. Complementarily in the next seven days following such fall, there was also a surge of dramatic rise in weight of goats even to a maximum most especially for goats fed NTH. The peak attained was seen not to be maintained as there was a decline such that weight of goats fed NTH plummeted so low within the fourteen days that followed. Although the weight of goats fed UTH and USH also fell but slightly and almost steady. Worthy of note is that the level of significance of weight changes of UTH and USH over NTH at the 63rd day of data collection was higher (P<0.01).

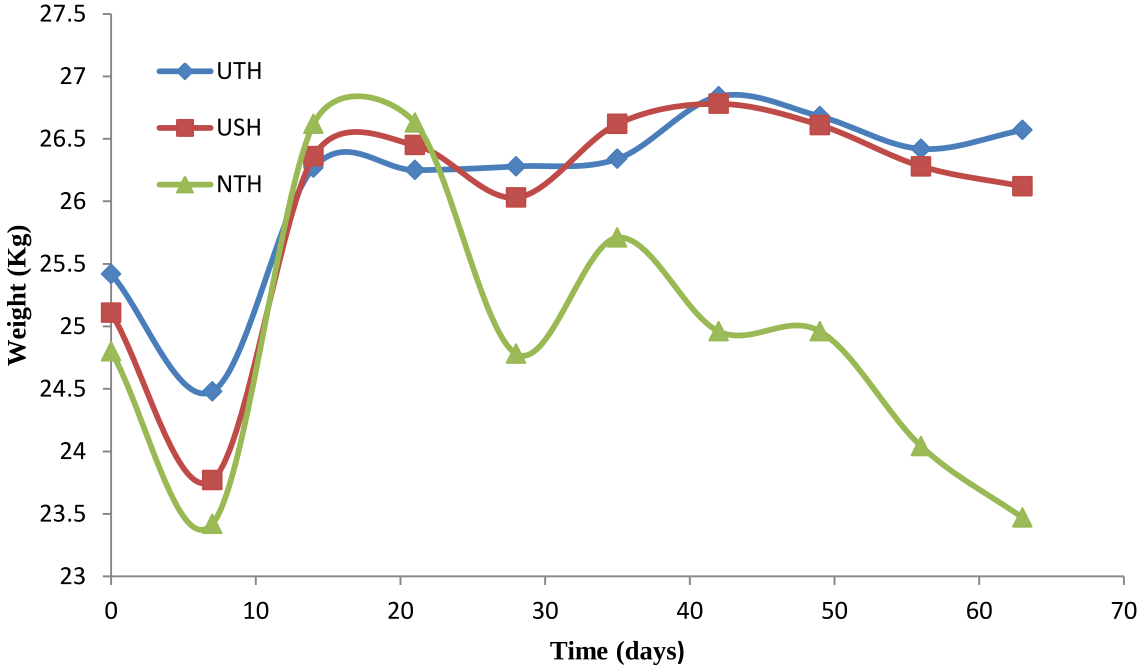


Figure 4.3 Weight changes of goats over time when fed urea-treated hay, urea-sprayed hay and non-treated hay

4.8 DISCUSSION

4.8.1 Diet quality

Quality of diets UTH, USH and NTH varied markedly (Bohnert *et al.*, 2007). The crude protein and ADF of UTH were highest followed by USH due to the beneficial effects of urea

(Got *et al*., 1991). Urea also reduced the DM, OM and NDF in UTH and USH, thereby leaving the non-treated hay with the highest values of these attributes (Ghana *et al*., 1993; Bohnert *et al*., 2007). Hence, with urea treatment or spraying, hay nutritive quality is improved.

4.8.2 Degradation, nutrients intake and digestibility

The intake of dry matter, organic matter, neutral detergent fibre and acid detergent fibre were all high in goats fed UTH and USH compared to goats fed non treated hay. This, no doubt, still buttresses the beneficial effect of urea in low quality roughage optimization and utilization (Got *et al*., 1991; Tesfayohannes *et al*., 2013).

It appeared that urea increased solubility of dry matter of hay as UTH has the highest value 369 g/kg followed by USH with 281 g/kg while that of NTH was lowest with 229 g/kg and it is probably due to the increase in nitrogen content of the hay and corresponding decrease in the fibre content (Preston, 1995; Ghana *et al*., 1993; Got *et al*., 1991). This increase was correspondingly effected on the potential degradability of the diets (UTH>USH>NTH). However, UTH was superior to USH in its difference from NTH. UTH has a difference of 140 g/kg when USH has 53 g/kg and by inference it simply shows that treating hay with urea is almost three times superior to spraying. These outcomes still agree with previous reports by Chenost *et al.* (2001) and Chanjula (2008) and emphasize the positive effects of urea in the use of poor quality roughages (Tesfayohannes *et al*., 2013). The insoluble fraction of dry matter appeared to increase with decreasing nutritional quality of hay such that NTH (with high NDF-735 g/kg and low CP-20 g/kg) had the highest value. It could also be inferred that the higher the quantity of fibre content of a feedstuff relative to a low CP, the higher its insoluble fraction and the less the rate degradation, and vice versa.

Just as the consumption of UTH and USH were fairly improved compared to that of NTH, digestibility of dry matter digestibility in these roughages were also improved for UTH and USH compared to NTH by 1.2 and 1.1 times, respectively, while the organic matter digestibility for both increased by 1.2 (Preston, 1995; Baumont *et al*., 1997) This increased roughage DM and OM digestibility when urea is included in low quality roughage for goats or ruminants is inconsistence with the reports of Archibeque (1999), Puchala *et al*. (2001) and Lengarite *et al*. (2014). However, DE Vega and Poppi (1997) and Baumont *et al*. (1997) observe negligible responses to supplemental protein via lucerne. In the same vein digestibility of neutral detergent fibre of UTH and USH were improved 1.2 and 1.1 times, respectively, while acid detergent fibre for both increased 1.2 times. This tendency agrees with Aitchison *et al*. (1986) measured with sheep. Nonetheless, it suffices to say that the variation in the nutrient digestibility of UTH, USH and NTH was due to the effect of varying quality or nutritional composition (Bohnert *et al*., 2007).

4.8.3 Dry matter intake

The UTH was readily consumed by goats than either USH and NTH. This could be a resultant effect of the urea treatment which is known to optimize the use of low quality roughage (Chenost, 2001), increase the crude protein content (Ghana *et al*., 1993), improve palatability and eventually stimulate and increase intake (Bohnert *et al*., 2007). In the same vein, intake differences among feeds for some periods of the experiment also indicate the positive effect of urea on intake of hay. This outcome is in contrary to the report of Chanjula and Ngampongsai (2008) who found no significant effect in the use of urea. Also, unlike the inconsistencies relating to the increase in intake of poor roughage when crude protein supplementation like urea is used, this outcome was specific. Hence, the use of urea to improve roughage quality has stimulated intake, digestion and performance (Solaimon, 2006) as these have been affected in experimental goats.

4.8.4 Water intake

Water was generally less readily consumed by goats in this study. This could be a consequence of environmental condition as the research was conducted in winter, a period in which house temperatures are low. To this situation, water intake is expected to reduce with decreasing environmental temperature or increasing humidity and increase with increasing temperature or decreasing humidity as demonstrated by Maynard *et al.* (1981). A sudden significant rise in water intake at a particular period towards the end of the experimental period may also be due to the same reason of temperature or other reasons like high mineral salt intake (Wilson 1970; Abdelatif and Ahmed 1992) and frequent urination resulting into excretion of large volume of urine (Sirohi *et al.*, 1997).

Unlike the expected increased level of water intake due to the effect of urea inclusion for goats fed UTH and USH (Sileshi *et al.*, 2007), water intake of goats fed non-treated hay was higher ($P < 0.05$) at certain times during the collection period. On the other hand, it may signal to the fact that water contained in NTH is markedly low and probably intolerable to the goats except that they compensate for the inadequacy by drinking water (Andreas Jenet *et al.*, 2004; Sirohi *et al.*, 1997). However, chemical composition of these diets invariably revealed that water or moisture content of the feeds are in the following descending order: UTH > USH > NTH or 9.56, 7.96 and 7.71% respectively, all within the range of 5% to 90% reported by Sirohi *et al.* (1997). Water intake of goats in this experiment varied also with varying diet quality in accordance with Maynard *et al.* (1981).

4.8.5 Live weight change

The small and inconsistent gain or loss in weight achieved over the collection period with UTH, USH and NTH was not significant for the first 35 days probably due to small number of goats used, change in feed or environment and short period of measurement. However, the superior and significant response with urea inclusion (in UTH and USH) in the 42nd day and 63rd day of data collection agrees with previous findings (Chenost, 2001; Wickersham *et al*., 2004; Solaiman, 2006; Chanjula *et al*., 2008). Live weight increase slightly due to the effect of urea agrees with the recent findings of Legarite *et al*. (2014) in goats. However, the loss in weight of goats fed NTH also conform to previous findings (Nsahlai *et al*., 1998; Lengarite *et al*., 2014). The loss in weight of goats fed UTH and USH could be due to nutritional need of goats which probably made them to mobilize their energy reserves and thereby affecting their body condition (Nsahlai *et al*., 1998).

4.9 CONCLUSION

Improved diet quality achieved on poor roughages with urea treatment or sprayed; (1) had significant effect on dry matter, organic matter, neutral detergent fibre and acid detergent fibre intake due to improved degradation of dry matter of hay in the rumen. There was improved digestibility of hay DM, OM, ADF coupled with an enhanced intake of digestible hay organic matter and metabolizable energy. The use of urea to improve the quality of roughage either by treatment or even spraying proved to be of tremendous benefits mostly because: (1) improved dry matter intake of hay; (2) had little or no effect on water intake; but (3) affected the body weight change of goats.

Chapter 5

EFFECT OF ROUGHAGE QUALITY AND PERIOD OF MEAL TERMINATION ON FEEDING BEHAVIOUR AND DIGESTA LOAD IN THE RUMEN AND OTHER DISTAL COMPARTMENTS

ABSTRACT

The current study aimed at determining the effect of (a) diet quality on feeding behaviour and digesta load in digestive organs of goats, and (b) period of meal termination on the reticulo-rumen fill and digesta load. It also predict reticulo-rumen fill of goats using artificial neural network (ANN). Goats were fed with urea-treated hay (UTH), urea-sprayed hay (USH) and non-treated hay (NTH). At the end of the 8th week of the experimental feeding trial, behavioural observation was made on 18 goats for four consecutive days using five motorized indoor CCTV cameras fixed at different locations of the pen in such a way that each conveniently captured activities of at least five goats at a time. Data were saved and adapted for 11 different behaviours (feeding or eating, rumination while lying down and standing, idling while lying down, standing and sleeping, recreation or play, fighting, drinking, mineral licking and body scratching). Time spent for each of this behavioural activities was captured with Microsoft excel and analysed with GLM procedure of the SAS system (SAS, 2013). Time spent for these different behavioural activities was not significant ($P>0.05$) except for eating and ruminating at certain times of the day ($P<0.05$). However, it was concluded that diet quality influenced the behaviour of goats, and their major activities throughout the day were eating, ruminating and recreation.

After feeding trial period and behaviour study, upon termination of meal in the morning, afternoon or evening, all goats were slaughtered in random groups of three per day to measure reticulo-rumen fill and digesta loads in other distal compartments of the digestive tract. Both diet quality and period affected ($P<0.05$) the measure of reticulo-rumen fill.

However, reticulo-rumen fill in the evening was larger ($P<0.05$) than afternoon while afternoon was similar ($P>0.05$) to morning. Also, diet quality affected ($P<0.05$) wet omasal digesta load, wet abomasum, dry abomasum and dry caecum digesta loads but did not affect ($P>0.05$) in both wet and dry digesta loads in other compartments of the digestive tract. Period of measurement did not affect ($P>0.05$) the wet omasal digesta load, and both wet and dry digesta loads in other compartments of the digestive tract except wet abomasum digesta load ($P<0.05$) and dry caecum digesta load ($P<0.05$). Both wet and dry reticulo-rumen fill were correlated ($P<0.05$) with omasum ($r=0.623$) and ($r=0.723$), respectively. ANN predicted reticulo-rumen fill of goats with $R^2 = 0.22$ and significant level of $P<0.001$ between predicted and observed values. In conclusion, reticulo-rumen fill of goats decreased by improving the roughage quality; and the period of meal termination and measurement of the fill is a key factor to the quantity of digesta load. ANN also could be used for RF prediction.

Key words: reticulo-rumen fill; CCTV camera; behaviour; meal termination; digesta; goats.

5.1 INTRODUCTION

Feeding behaviour among other behavioural types in ruminants is described in terms of satiation process and motivation of animals to eat (Baumont *et al.*, 2000). It is also a reflection of biological and physiological status of animals (Abdelsalam and Al-Seaf, 2012). However, hunger is a distressing factor that primarily influences the intake of feed and time spent eating by animals (Forbes *et al.,* 1995). Feeds with good colour, nice aroma and pleasant taste (pre-ingestive attributes) evoke more consumption and makes intake to be pleasurable. Likewise, nutritive value, rumen fill and toxicity (post-ingestive consequences) on the other hands determines when animals stop eating. Goats and sheep fed *ad-libitum* eat for 5 to 10 hours per day and ruminate also for 5 to 10 hours per day usually when feeding schedule indoor or in confinement is twice per day (Baumont *et al.*, 2000). Aside other activities that these animals may engage in ordinarily when they are on free range and even in confinement, lying down are also crucial in their behaviour. The time spent for lying down has an important value for goats because rumination occurs most during it (Abdelsalam and Al-Seaf, 2012).

Hunger may stimulate the animal's desire to eat more, thus filling the rumen. Reticulo-rumen fill is a key factor to ruminant productivity and the extent of dry matter intake is the dominant process for assessing it. In forage-fed animals, processes that occur in the rumen play a determinant role in the amount and types of nutrients absorbed and in the control of dry matter intake (Forbes *et al*., 1995). Even water intake of animals is essential for digestion, materials transport and excretion but while some studies revealed its need in the fill of rumen others were silent. However, sources of water available for functional purposes in ruminant is not limited to drinking water, it also include water in the roughage and metabolic water in their body. Besides, reticulo-rumen size of most herbivores increases isometrically with their body size and its maximum capacity in concert with metabolic demand determines the fill and retention time with a particular diet (Demment, 1982). Hence, body size or maturity of ruminant (Boudon *et al*., 2009) and some other factors such as availability of essential nutrients in feed (McLaren & Doyle, 1988) and time of feeding (Boudon *et al.,* 2009), determine the reticulo-rumen fill.

This objectives of this study were: to determine the effect of feed quality on feeding behaviour and rumen fill in goats under confinement; to evaluate the effects of the nutritional quality of roughages and period of meal termination on the reticulo-rumen fill. The hypotheses were that rumen fill will increase with increasing nutritional quality and that rumen fill will be similar upon meal termination, irrespective of period of meal termination: morning, afternoon or evening. ANN can predict rumen fill in goats.

5.2 EXPERIMENTAL DESIGN AND FEEDING MANAGEMENT

Eighteen experimental goats were randomly divided into two groups comprising of nine heavy weight goats (12 - 23 kg) and nine light weight goats (25 - 40 kg). Each group was randomly allotted to three treatment feeds, which were UTH, USH and NTH. Fresh water and salt licks containing trace minerals (calcium=120 g/kg, manganese=1200 mg/kg, copper=200 mg/kg, cobalt=1 mg/kg, sodium=10 g/kg, zinc= 1200 mg/kg) were made available at all time. Feed was dispensed to these goats *ad-libitum* at 0800 h and at 1500 h. An adaptation of 10 days was allowed to familiarize animals with the new feeding system and feed, to observe any side effect from possibly the UTH or USH. Thereafter, 63 days feeding trial was done, a feeding behavior study was carried out. Meal termination times in morning and afternoon were noted so as to establish the likely time the reticulo-rumen fill (RF) would be measured. Live body weight of each goat was measured the last time before slaughter. Fill measurement of organs of the digestive tract were recorded six days following the end of the feeding behaviour study. Three goats, randomly selected from one of three treatments, were slaughtered during the morning, afternoon or evening.

5.3 BEHAVIOURAL OBSERVATIONS

At the end of the 8th week, all the goats were observed for behavioural studies. Behavioural observations were recorded using five motorized indoor CCTV cameras installed strategically in different locations in the housing pen in such a way that each conveniently captured activities of at least five goats at a time, while rear, side or front views of some others could also be viewed. All cameras were attached to a digital video recorder (dvr) control unit and a computer to record and save all observations for each goat throughout 24 hours period for four consecutive days. In the behavioural observation, the duration of feeding, rumination, idling, social and drinking activities were recorded at 2-min interval during the 24 hours for four days. Times per hour spent in each of the behavioural activities was calculated using Microsoft excel package and analyzed using SAS system.

Table 5.1 Behaviour definitions

Behaviour	Acronym	Description
Feeding	FED	Animal standing in with its head deepened downward into the feeder.
Ruminating (Standing)	RST	Animal chewing without any visible foodstuff in the mouth when standing.
Ruminating (Lying down)	RLD	Animal chewing without any visible foodstuff in the mouth when lying down.
Idling (Standing)	IDT	Animal standing without performing any other visible activity.
Idling (Lying down)	ILD	Animal lying down without performing any other visible activity.
Idling (Sleeping)	IDL	Animal curdling head into its body while lying down or lying, with eyes visibly closed and or without performing any other visible activity.
Social (Play)	SPL	Animal engaging in any form of recreation on its own or with others displaying excitement.
Social (Fight)	SFI	Animal engaging in any form of tussle or brawl with others even though the individual pen was demarcated.
Social (Scratching)	SSC	Animal using horns, or legs or mouth to scratch any part of its body.
Drinking	DRI	Animal standing or lying down with its head deepened downward into the drinker.
Mineral Licking	MLI	Animal standing or lying down with its head deepened downward into the mineral-salt lick container.

5.4 SLAUGHTERING PROCEDURE

Slaughtering was carried out during week 9 and week 10. At the end of the experimental trial, goats were randomly selected from one of each treatment for slaughtering in batch of three goats/day in the morning, afternoon or evening for reticulo-rumen fill measurement. The fill of other digestive organs was also assessed. The animals were transported in the farm's vehicle from livestock section to the abattoir at the Ukulinga Research farm each day between 1000 and 1100 h in the morning, between 1400 and 1530 h in the afternoon or between 1930 and 2100 h in the evening following pre-slaughtering weight measurement of the selected animal on an electronic weigh-scale. Immediately afterwards, animals were slaughtered by stunning with electrical stunning machine and then severed with a knife to let out blood. The entire gut was removed from the carcass, and ends of reticulo-rumen, omasum, abomasum, small intestine, large intestine, caecum and colon were identified and tied to avoid mixing of digesta contents. Each compartment was then emptied completely by scraping the contents into a foil container. The RF and other digesta contents were weighed to the nearest gram on a portable electronic scale (Mettler Toledo Spider 2, 1-15 kg). The fill of every compartment were pre-dried in a forced-air oven at 70^0C until their mass was constant.

5.5 CHEMICAL ANALYSES

After pre-drying samples of rumen fill (RF) and other digesta contents were instantly weighed, sub-sampled (200 to 300 g) and ground to pass through 1 mm sieve and stored in airtight containers. All samples of feed were ground to pass through 1 mm sieve. Duplicate samples of each of 3 treatment feeds UTH, USH and NTH fed to the goats were analyzed for dry matter (DM), organic matter (OM), crude protein (CP) (AOAC, 1991), neutral detergent fibre (NDF), acid detergent fibre (ADF) (Van Soest *et al*., 1991). Likewise, duplicate samples of RF and omasal digesta load (ODL) were also analyzed for DM, NDF and ADF. DM was determined using oven at 60^0C for 48 hrs while OM was determined using ash furnace at 550^0C for 5 hrs. PerkinElmer series 11 CHNS/O analyzer was used to determine nitrogen content according to AOAC, 1991, and a conversion factor 6.25 was used to calculate CP to standard Kjeldahl value (Nx6.25). Also, ANKOM fibre analyzer was used to determine NDF and ADF. The NDF content was determined without a heat stable alpha amylase.

5.6 STATISTICAL ANALYSIS

All data were analyzed using SAS system 9.1 (SAS, 2013). Collected behavioural data were compiled in Microsoft Excel and the GLM of SAS (2013) was used to perform the analysis. All results were presented as mean ± SE. The model used was;

$\boldsymbol{Y_{ijkl} = \mu + S_i + BW_j + (P)_k + \varepsilon_{ijkl}}$; where Y_{ijkl} is the observation, μ is the overall mean common to all observation, S_i is the effect of diet, P_j is the effect of time, $(BW)_j$ is the co-variate effect of body weight and ε_{ijkl} is the residual error. Fill data were subjected to of SAS (2013) to determine the effect of roughage or treatment quality and RF measurement time on RF. The model used was:

$\boldsymbol{Y_{ijkl} = \mu + S_i + P_j + (SP)_{ij} + BW_k + \varepsilon_{ijkl}}$; where Y_{ijkl} is the observation, μ is the overall mean common to all observation, S_i is the effect of diet, P_j is the effect of time, $(SP)_{ij}$ is the interaction between diet & time and ε_{ijkl} is the residual error. Time was declared as a repeated measurement. Pearson correlation analysis (SPSS) was used to determine the relationships between RF and other digesta contents, and among the digesta contents.

5.7 Artificial neural network (ANN) model prediction of reticulo-rumen fill of goats: The DM, CP, NDF, ADF, CHO, SPT, AGE, PHY, MGT, LBW, MBW and TD of the experimental goats were uploaded into ANN for prediction of reticulo-rumen fill (g/kgBW). Both the predicted and observed values were subjected to statistical test using SAS (2013).

5.8 RESULTS

5.8.1 Daily feeding pattern of goats

The feeding pattern of goats fed UTH, USH and NTH, as shown in Figure 5.1 was generally undulating throughout the day but a peak was attained within 0700 h and 0900 h just immediately after a transition period in 6th hr. The transition between the peak and the nadir (period between 0300 h and 0500 h) was 0600 h. Within this peak period, time spent feeding by goats fed UTH and USH were similar and higher than NTH ($P<0.01$ & $P<0.001$) at 0700 h. Likewise, USH was higher than NTH ($P<0.01$) at 0800 h and 0900 h though UTH and NTH were similar. At 2100 h, time spent eating by goats fed UTH was higher than USH ($P<0.05$) but similar to NTH. Nonetheless, in other hours of the day, time spent feeding by goats were similar among diets ($P>0.05$).

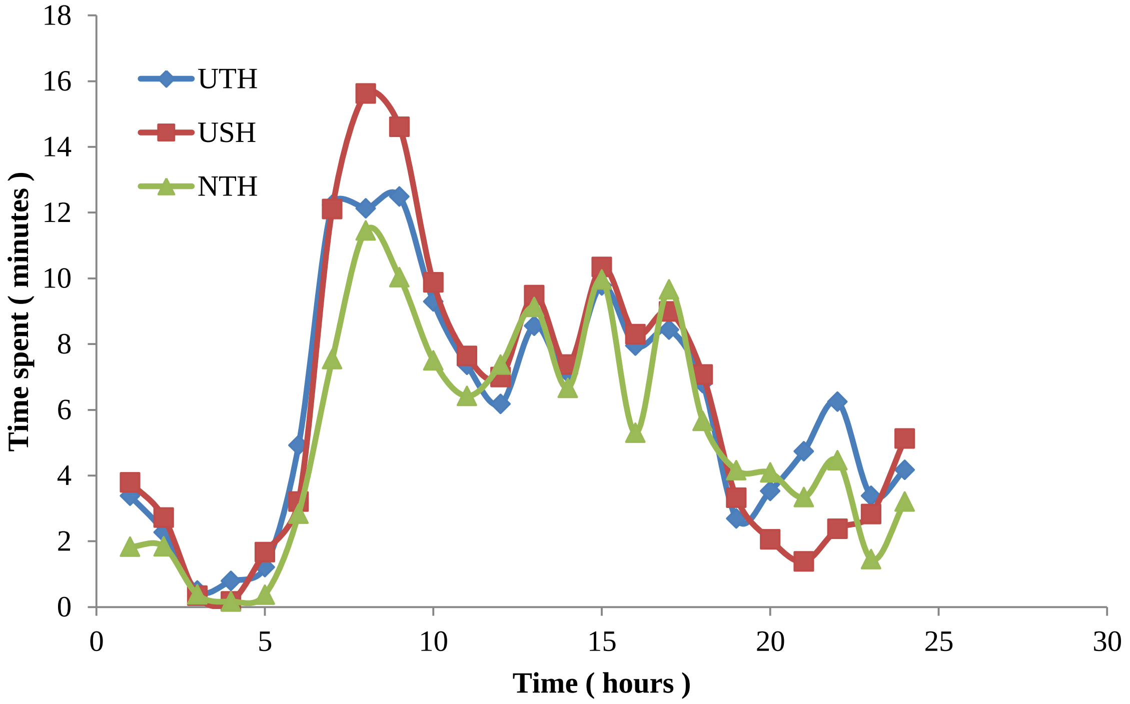


Figure 5.1 Feeding pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay

5.8.2 Daily rumination pattern of goats while lying down

Time spent on rumination by goats fed UTH, USH and NTH while lying down was fairly zigzagged and cup shaped as shown in Figure 5.2. Differences in the ruminating time of goats while lying down were in the early hours of the evening, late hours of the night, mid-day and sometimes late afternoon. At 1100 h, 1200 h and 1600 h, goats fed UTH spent more time ruminating than those fed NTH ($P<0.05$). Also, those on USH spent more time on rumination over NTH ($P< 0.01$) at 1700 h and 1900 h.

At 2000 h, time spent by goats fed USH on rumination was similar to UTH but higher ($P< 0.05$) than NTH. Also, goats fed UTH spent more ($P<0.05$) time than NTH at 2100 h and 2200 h while those on USH spent even more ($P<0.001$) compare to NTH as well. In the same vein, rumination time by goats fed UTH was higher than NTH ($P<0.05$) when NTH was similar to USH at 0300 h, 0400 h and 0500 h. Likewise, rumination time of goats fed UTH was higher than USH ($P<0.05$) at 0400 h and 0500 h.

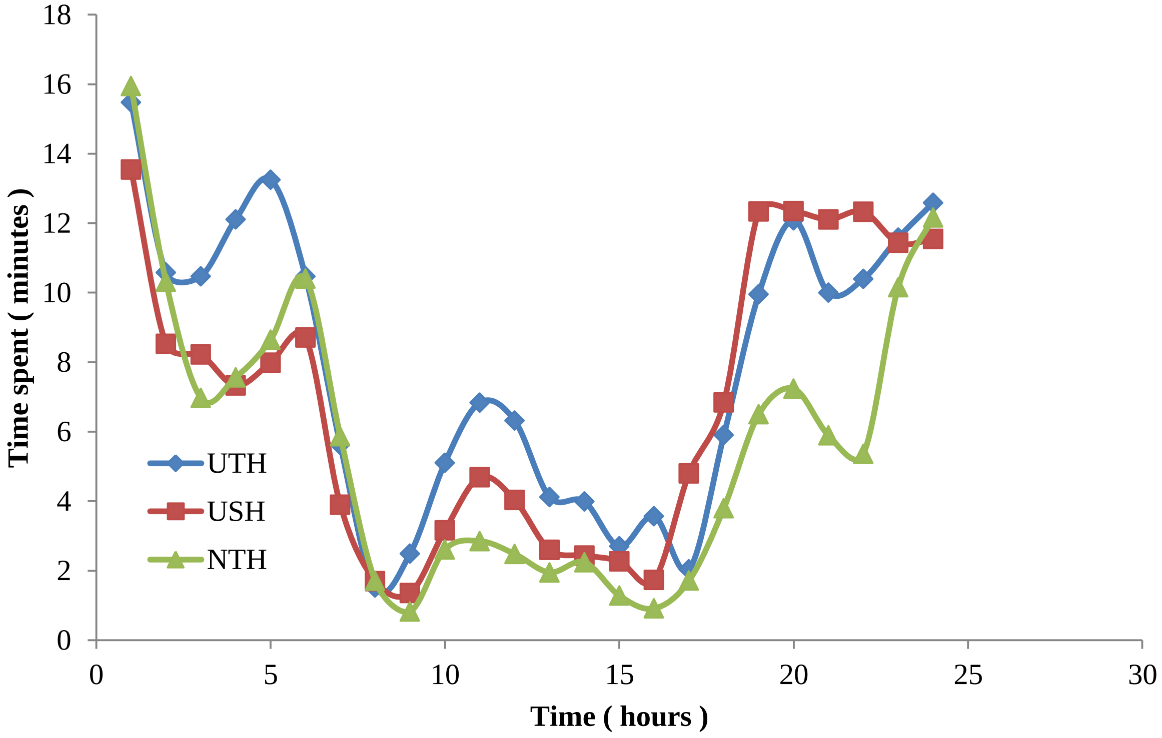


Figure 5.2 Rumination pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay while lying down

5.8.3 Daily rumination pattern of goats while standing

The rumination pattern of goats while standing as shown in the Figure 5.3 is on the overall zigzagged and goats at different times of the day attained the peak. However, times spent by goats on rumination while standing were similar ($P>0.05$) throughout the day.

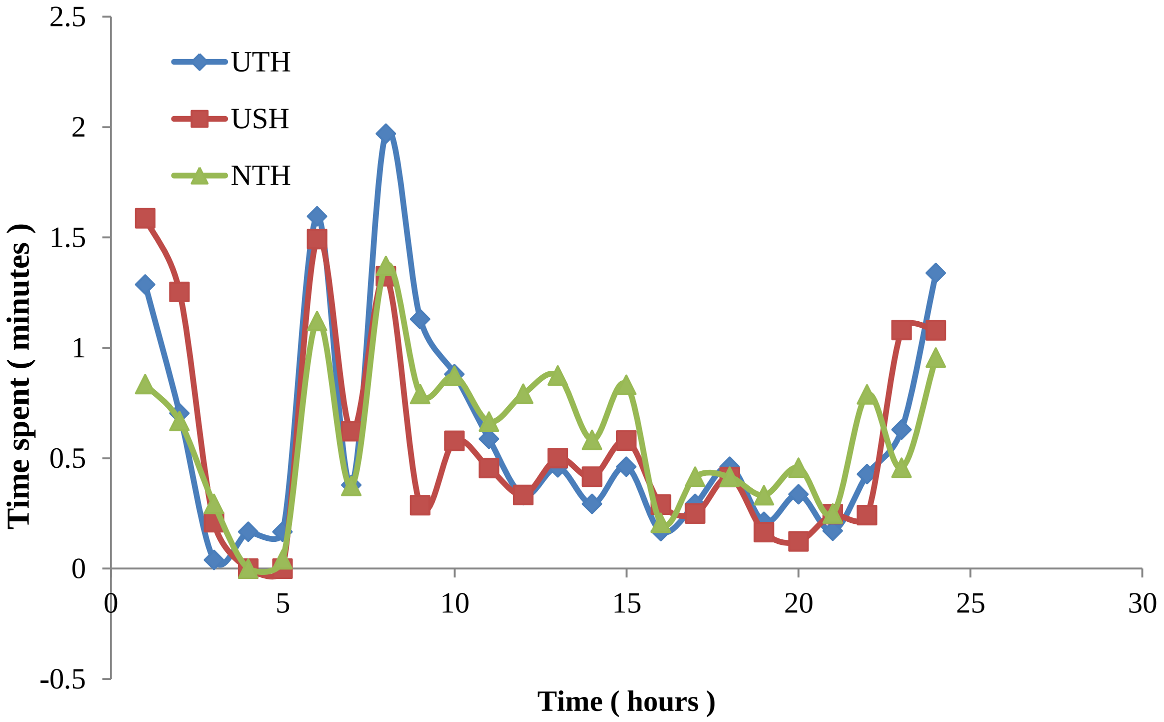


Figure 5.3 Rumination pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay while standing

5.8.4 Daily idling pattern of goats while lying down

Goats as shown in Figure 5.4 idled more while lying down around 0200 h, 0300 h and 0400 h but significant differences in the level ($P<0.05$) of idling while lying down by goats fed UTH, NTH and USH. At other times of the day, this behaviour did not differ between feeds.

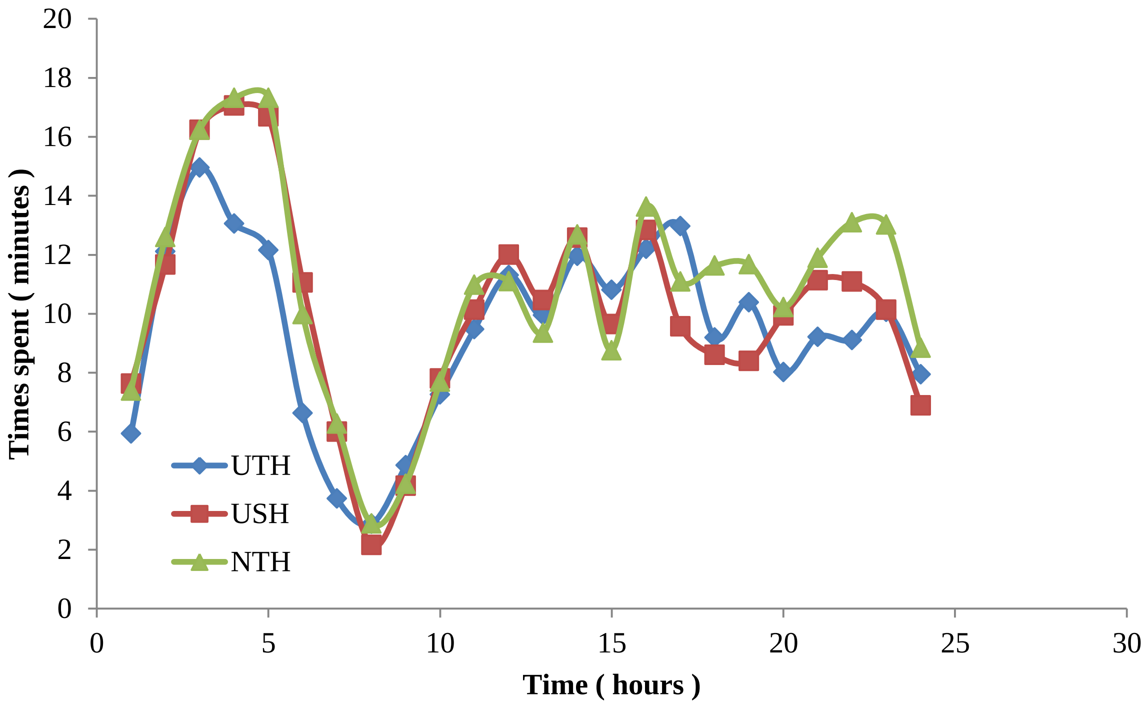


Figure 5.4 Idling pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay while lying down

5.8.5 Daily idling pattern of goats while standing

Time spent by goats idling while standing as shown in Figure 5.5 increased from 0500 h to peak at 0800 - 0900 h of the day, whence a steady fall till the 2400 h. Goats fed NTH attained the most standing time peak at 0900 h.

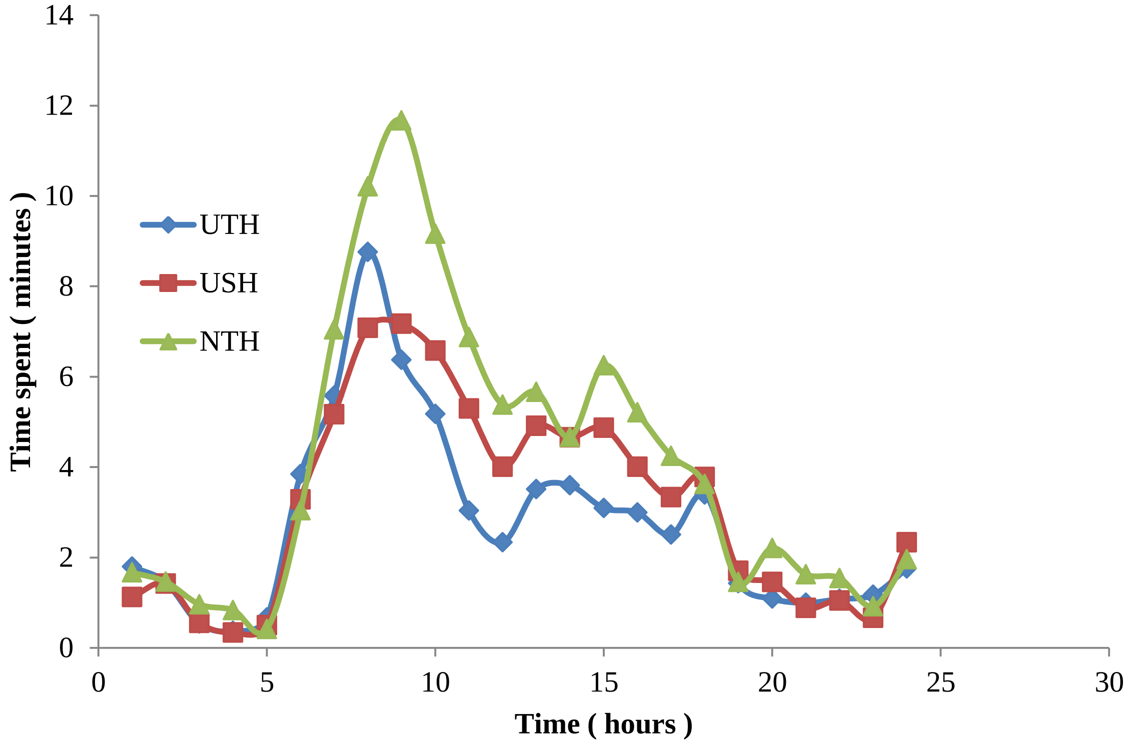


Figure 5.5 Idling pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay while standing

5.8.6 Daily sleeping pattern of goats

Time spent by goats sleeping appears like cup in pattern as shown in Figure 5.6 following some consistent rises and falls but it was amazing that time spent by goats to sleep were similar. This simply implied that with the behaviour of these ruminants, they rarely sleep.

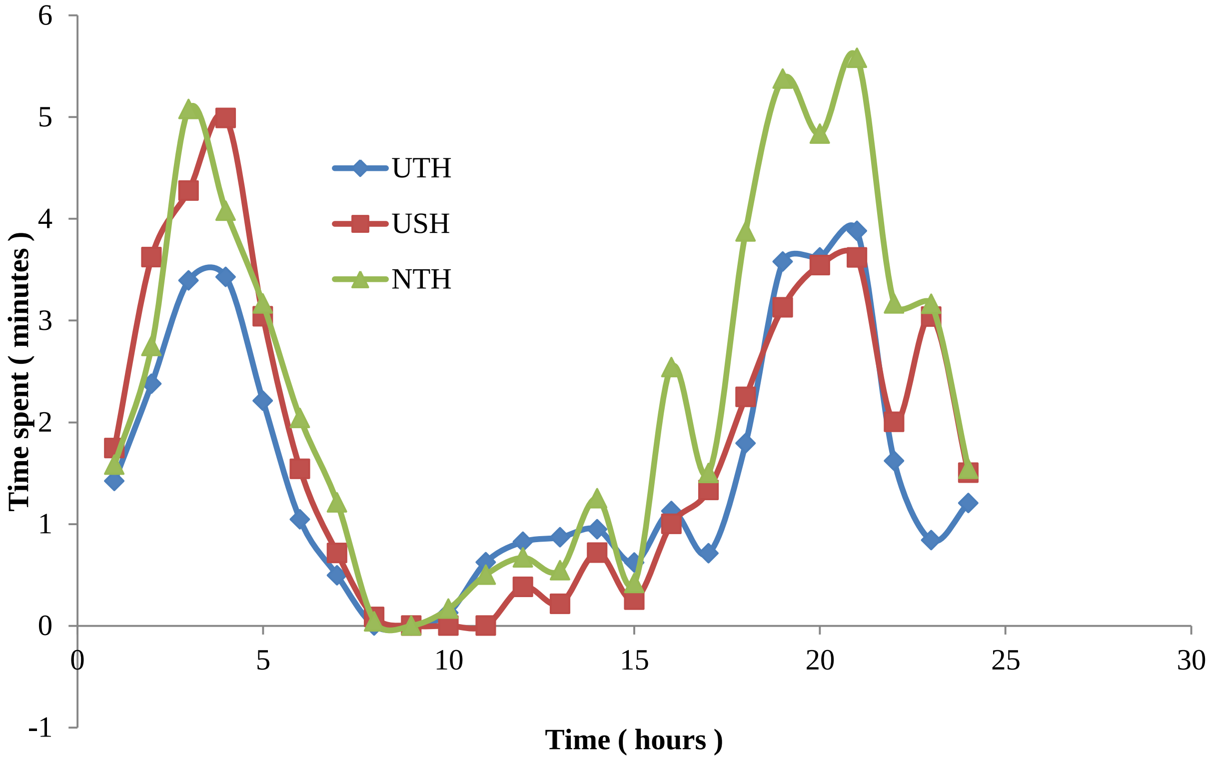


Figure 5.6 Sleeping pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay

5.8.7 Daily recreational activities pattern of goats

Goats fed UTH, USH and NTH as shown in Figure 5.7 attained peaks of recreational activities between 0500 h and 1000 h of the day. Goats fed UTH spent more time ($P<0.05$) to play at 0800 h than those fed USH. Besides, at 1800 h, 1900 h, 2000 h, 2100 h and 2200 h, goats fed UTH spent more time ($P<0.001$) to play compare to those fed USH and NTH. This is a signal to hyperactivity of goats fed urea-treated hay at night.

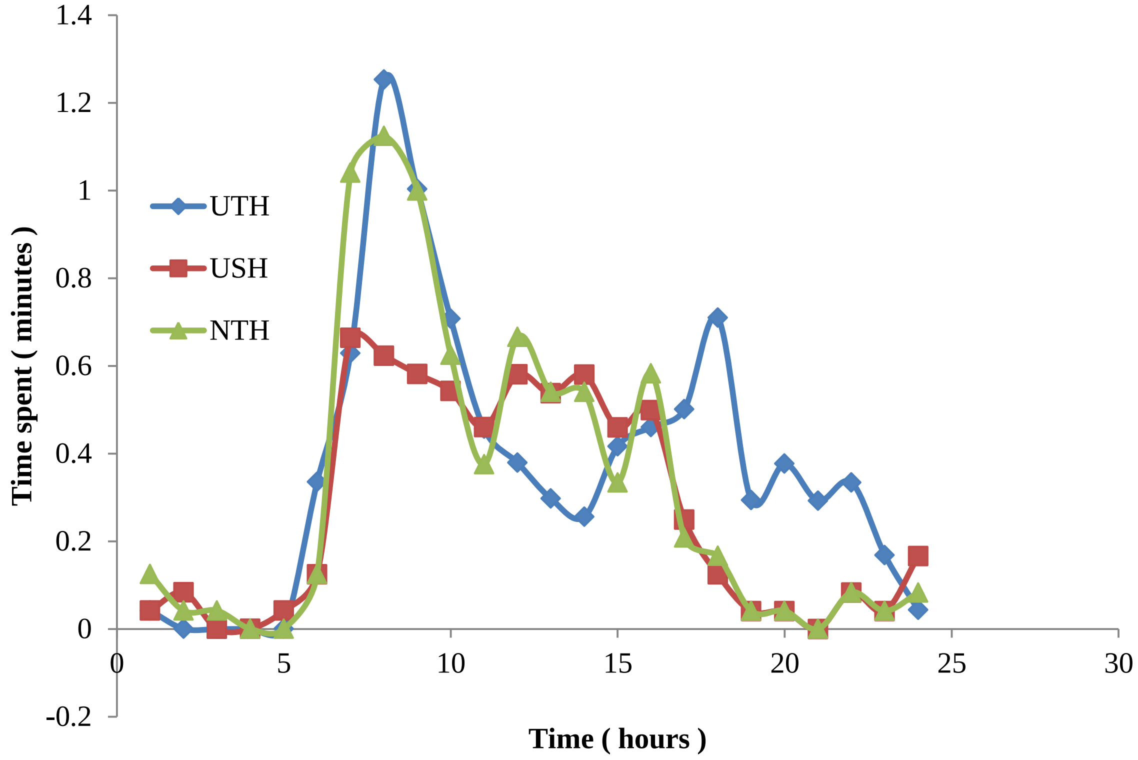


Figure 5.7 Recreational activities pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay

5.8.9 Daily offensive activities pattern of goats

The conflict pattern among goats as shown in Figure 5.8 indicates that goats fed UTH attained peak of offensive activities at 0600 h, 0700 h and 0800 h over NTH and USH (P<0.05). Besides, it equally signalled to hyperactivity of goats fed UTH even though at other times of the day, time spent fighting was not significant (P>0.05).

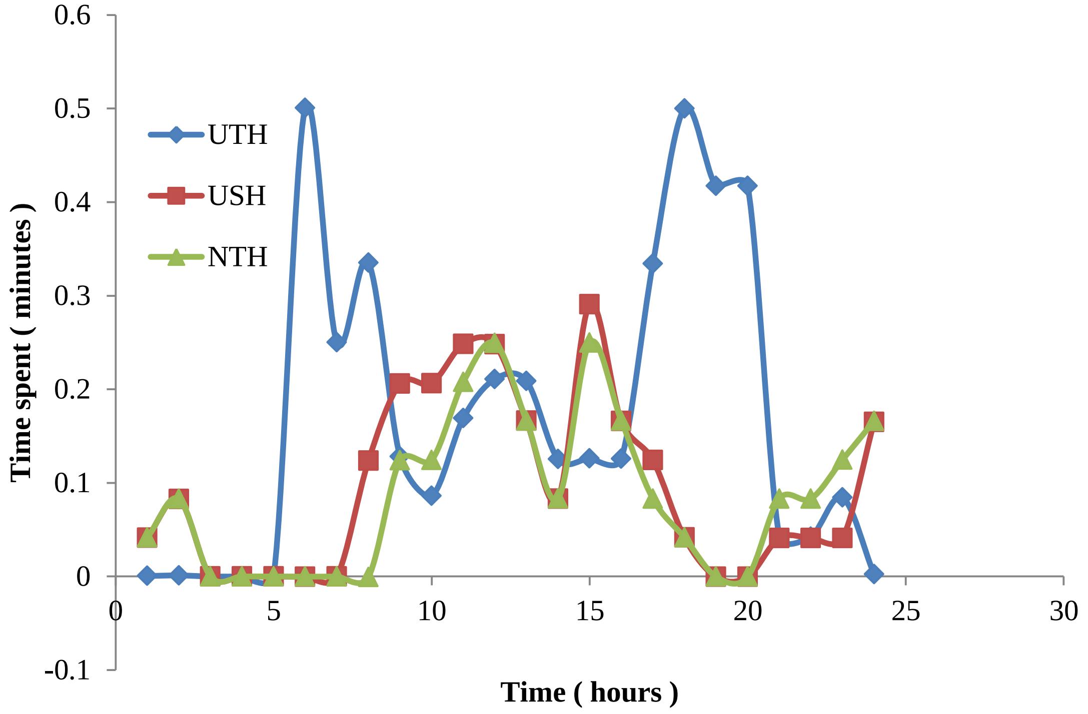


Figure 5.8 Offensive activities pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay

5.8.10 Daily hygienic activities pattern of goats

Time spent on hygiene by goats fed UTH, USH and NTH as shown in Figure 5.9 appeared undulating in general. However, at least either UTH or USH were significantly higher at certain periods of time in the morning, afternoon or evening ($P< 0.01$). It may signal the presence of external and or internal parasites.

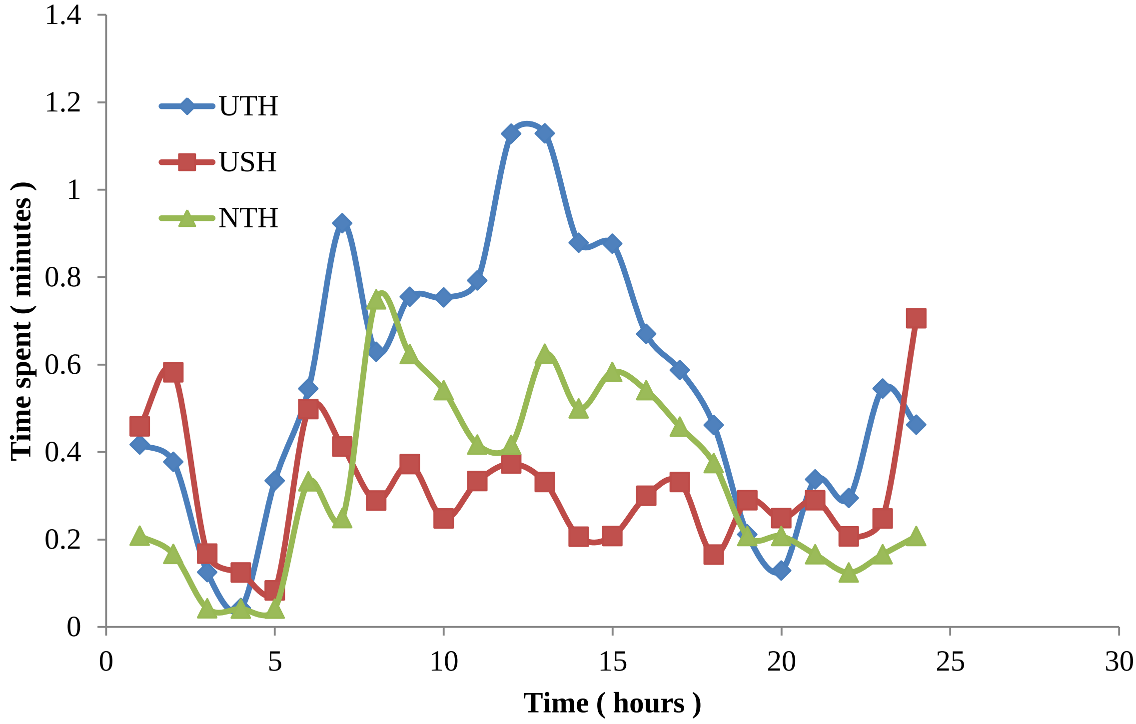


Figure 5.9 Body scratching activities pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay

5.8.11 Daily pattern of drinking of goats

The Figure 5.10 shows inconsistency in the overall drinking pattern of goats but it appears that goats fed NTH spent more time in drinking water than goats fed other feeds. Nonetheless, it is worth to note that drinking of water by goats was not significant (P >0.05).

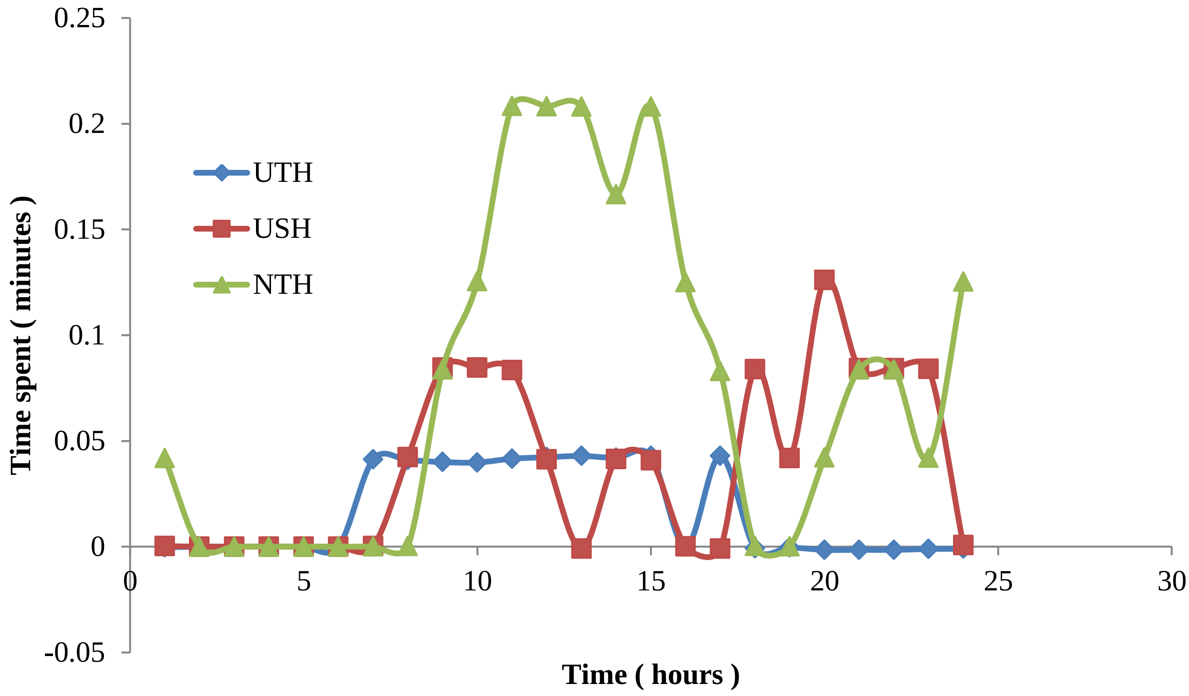


Figure 5.10 Drinking pattern of goats fed urea-treated hay, urea-sprayed hay and non-treated hay

5.8.12 Daily minerals or salt licking by goats

All goats were observed to lick more of minerals in the form of salt blocks. Although its rate of consumption appeared to be relatively high, times spent by goats for this activity were not significant (P >0.05) from 0100 h till 1600 h of the day and on 1800 h, 2300 h and 2400 h. However, goats fed UTH spent more time licking minerals than NTH (P < 0.01) at 17.00 hr and 1900 hr but less time than NTH (P < 0.05) at 2100 h and 2200 h. Goats fed USH also spent a less significant time than NTH (P < 0.01) at 2000 h and 2200 h.

Table 5.2 Diet effect on wet and dry reticulo-rumen fill, omasal digesta load and abomasum digesta load (g) of goats

Diets	UTH	USH	NTH	*RMSE*	P Value
Wet matter					
Reticulo-rumen	5004	5479	6410	496.9	0.0282
Omasum	314	468	322	76.5	0.0133
Abomasum	214	99	230	57.4	0.0110
Dry matter					
Reticulo-rumen	680	1016	972	216.2	0.0538
Omasum	78	110	78	23.4	0.0916
Abomasum	14	7	31	9.2	0.0492
Wet matter					
Small intestine	36	64	88	54.2	0.5079
Large intestine	311	377	322	82.2	0.3969
Caecum	375	415	605	94.7	0.0667
Colon	228	253	278	58.1	0.5961
Dry matter					
Small intestine	7	5	10	4.3	0.5156
Large intestine	54	134	95	153.6	0.6735
Caecum	58	62	124	23.0	0.0264
Colon	72	76	107	24.6	0.3233

5.8.13 Effects of roughage quality on wet and dry digesta in the reticulo-rumen, omasum, abomasum and other distal organs

5.8.13.1 Wet digesta in proximal organs

Inclusion of urea to feed either by treatment or spraying was accompanied by a progressive decline ($P < 0.05$) in the fill; consequently, the quality of diets negatively influenced reticulo-rumen fill of goats. Thus, reticulo-rumen fill decreases with improved roughage quality. Omasal digesta load of USH was larger than UTH ($P<0.01$) while abomasum digesta of USH was less than UTH ($P<0.01$) and NTH ($P<0.05$). Both digesta load in omasum and abomasum were influenced by the diet quality ($P<0.05$).

5.8.13.2 Dry digesta in proximal organs

Diets had similar ($P>0.05$) dry reticulo-rumen fill and digesta load of omasum but affected ($P< 0.05$) the digesta in the abomasum. Abomasum digesta of goats fed USH was less

(P<0.05) than NTH and NTH value was larger (P<0.05) than UTH. Diet had no effect on the digesta load of distal organs of the GIT either in dry or wet form.

5.8.13.3 Dry and wet digesta in distal organs

Diet quality affected (P<0.05) digesta load in caecum in the order: NTH>USN>UTH. All other distal organs had simiar digesta irrespective of diet consumed.

5.8.14 Effects of period of meal termination on dry reticulo-rumen fill, omasal digesta load and abomasum digesta in goats

5.8.14.1 Wet digesta in proximal organs

The period of meal termination affected (P<0.05) both wet reticulo-rumen fill and abomasum digesta load. Reticulo-rumen was higher (P<0.05) in the evening than afternoon while RF for both morning and afternoon were similar. Abomasum digesta load was lower (P<0.05) in the evening compared to morning but were similar for both afternoon and evening.

5.8.14.2 Dry digesta in proximal organs

Period did not influence rumen fill and digesta loads of the omasum and abomasum. Amazingly, all dry values of RF, ODL and abomasum digesta load were similar (P >0.05) for all feeds.

5.8.14.3 Dry and wet digesta in distal organs

Trends of wet digesta load in other distal compartments of the gastro intestinal tract comprising small intestine, large intestine and colon were (P>0.05) independent of period of meal termination but declined (P<0.05) with time from morning to afternoon and till evening except in the caecum. However, differences among feeds approached significance (P=0.0507) only in wet colon. Differences among dry caecal digesta were significant (P<0.01) in the order: Morning>afternoon = evening.

Table 5.3 Period effect on wet and dry reticulo-rumen fill (g), omasal digesta load (g) and abomasum digesta load (g) of goats

Diets	Morning	Afternoon	Evening	*RMSE*	Period Effects
Wet matter					
Reticulo-rumen	5481	5274	6139	496.9	0.0424
Omasum	369	361	375	76.5	0.9569
Abomasum	266	140	138	57.4	0.0367
Dry matter					
Reticulo-rumen	797	819	1052	216.2	0.2129
Omasum	75	94	97	23.4	0.5332
Abomasum	22	17	12	9.2	0.3890
Wet matter					
Small intestine	102	45	42	54.2	0.3854
Large intestine	376	335	300	82.2	0.5596
Caecum	573	426	395	94.7	0.1146
Colon	258	299	202	58.1	0.0507
Dry matter					
Small intestine	13	5	5	4.3	0.0894
Large intestine	96	63	124	153.6	0.7918
Caecum	125	61	58	23.0	0.0092
Colon	90	100	65	24.6	0.1037

5.8.15 Correlation between wet and dry digesta along the GIT

Rumen fill was positively correlated with omasum (P<0.01), large intestine (P<0.01), caecum (P<0.01) and colon (P<0.01). Likewise ODL was also positively correlated with small intestine (P<0.01), large intestine (P<0.01) and colon (P<0.05). Abomasum digesta load was only correlated positively with caecum (P<0.05). While the caecum load was positively correlated with colon (p<0.01), large intestine was also correlated positively with caecum (P<0.01) and colon (P<0.05).

Table 5.4 Correlation matrix of wet and dry reticulo-rumen fill and digesta loads in distal compartments of the GIT of goats

Compartments	Colon	Caecum	Large intestine	Small intestine	Abomasum	Omasum
Wet digesta loads						
Colon	1.00					
Caecum	0.60**	1.00				
Large intestine	0.71**	0.54*	1.00			
Small intestine	0.17	0.34	-0.04	1.00		
Abomasum	0.09	0.48*	0.10	0.08	1.00	
Omasum	0.51*	0.62**	0.69**	0.13	0.22	1.00
Reticulo-rumen	0.64**	0.73**	0.60**	0.04	0.29	0.62**
Dry digesta loads						
Colon	1.000					
Caecum	0.52*	1.00				
Large intestine	-0.10	0.29	1.00			
Small intestine	0.09	0.30	0.08	1.00		
Abomasum	0.33	0.55*	0.12	0.20	1.00	
Omasum	0.41	0.27	0.23	-0.08	0.20	1.00
Reticulo-rumen	0.50*	0.44	0.22	0.01	0.11	0.72**

In dry form, reticulo-rumen fill was positively correlated with omasum ($P<0.01$) and colon ($P<0.05$); the abomasum digesta load with caecum ($P<0.05$) and caecum content with colon ($P< 0.05$) but digesta in other compartments were not correlated.

Table 5.5 Effect of diet quality on NDF and ADF digesta (kg) and (kg/100kg BW) in the rumen and omasum

Nutrient concentration	Diets			*RMSE*	Diet effects
	UTH	USH	NTH		
NDF and ADF digesta (kg)					
Rumen NDF	0.529^b	0.757^a	0.519^b	0.134	0.0436
Rumen ADF	0.394^b	0.562^a	0.363^b	0.098	0.0322
Omasum NDF	0.051^b	0.074^a	0.056^{ab}	0.015	0.0698
Omasum ADF	0.035	0.049	0.036	0.010	0.0941
NDF and ADF digesta (kg/100kgBW)					
Rumen NDF	2.031^b	2.726^a	2.272^{ab}	0.439	0.0484
Rumen ADF	1.501	2.019	1.603	0.345	0.0506
Omasum NDF	0.193	0.285	0.252	0.061	0.0568
Omasum ADF	0.134	0.192	0.163	0.041	0.0753

NDF=neutral detergent fibre, ADF=acid detergent fibre, ^{ab} =significance difference

Diets affected ($P<0.05$) both concentrations (kg/kg) of NDF and ADF in the rumen fill but in kg/100kgBW, only RNDF was affected ($P<0.05$). The effects of diets on concentrations of (kg/kg and kg/100kgBW) of NDF and ADF in the omasal digesta load was not significant ($P>0.05$). Likewise, RADF (kg/100kgBW) was not significant ($P>0.05$). However, it is noteworthy that RNDF (kg/kg) and RADF (kg/kg) of USH were significantly larger ($P<0.05$) than both UTH and NTH. Also, ONDF (kg/kg) and RNDF (kg/100kgBW) of USH were significantly larger than UTH but similar to NTH.

Table 5.6 Effect of period on rumen and omasum digesta NDF and ADF

		Period of meal termination			
Nutrients	**Morning**	**Afternoon**	**Evening**	***RMSE***	**Period effects**
NDF and ADF digesta (kg/kg)					
Rumen NDF	0.443^{b}	0.585^{b}	0.776^{a}	0.134	0.0101
Rumen ADF	0.324^{b}	0.430^{b}	0.564^{a}	0.098	0.0119
Omasum NDF	0.053	0.065	0.063	0.015	0.5192
Omasum ADF	0.036	0.044	0.042	0.010	0.4752
NDF and ADF digesta (kg/100kgBW)					
Rumen NDF	1.789^{b}	2.302^{b}	2.338^{a}	0.439	0.0024
Rumen ADF	1.304^{b}	1.681^{b}	2.137^{a}	0.345	0.0043
Omasum NDF	0.227	0.265	0.239	0.061	0.5118
Omasum ADF	0.151	0.179	0.158	0.041	0.4296

NDF=neutral detergent fibre, ADF=acid detergent fibre

Period of meal termination affected ($P<0.05$) both RNDF (kg/kg) and RADF (kg/kg). In the same vein but on a different magnitude, it affected ($P<0.01$) both RNDF (kg/100kgBW) and RADF (kg/100kgBW). ONDF and OADF (kg/kg and kg/100kgBW) were not affected ($P>0.05$) by time. Interestingly, all of RNDF (kg/kg) RADF (kg/kg), RNDF (kg/100kgBW) and RADF (kg/100kgBW) were significantly larger ($P<0.05$) in the evening than morning and afternoon while they remain similar for both morning and afternoon.

Table 5.7 Artificial neural network (ANN) model predictions of reticulo-rumen fill of goats

SPT	AGE (yr)	PHY	MGT	LBW (kg)	MBW (kg)	TD (hr)	Observed RF (g/kgBW)	Predicted RF (g/kgBW)
2	1.5	0	1	13	60	0.5	34.19	19.713
2	1.5	0	1	16.5	60	0.5	30.73	19.72
2	1.5	0	1	14.5	60	0.5	54.79	20.018
2	1.5	0	1	16.5	60	0.5	46.09	19.829
2	1.5	0	1	16	60	0.5	38.03	20.023
2	2	0	1	20.5	60	0.5	36.85	20.231
2	2	0	1	18.5	60	0.5	30.35	20.213
2	2	0	1	17.5	60	0.5	22.05	20.733
2	2.5	0	1	22.5	60	0.5	25.02	20.556
2	3.5	0	1	31	60	0.5	26.95	21.947
2	3	0	1	27.5	60	0.5	24.04	22.044
2	3.5	0	1	31	60	0.5	27.53	22.008
2	3.5	0	1	29.5	60	0.5	22.31	22.129
2	3.5	0	1	34	60	0.5	44.68	22.009
2	3.5	0	1	38	60	0.5	28.86	21.953
2	3.5	0	1	36.5	60	0.5	33.22	21.952
2	3.5	0	1	41	60	0.5	58.18	22.011
2	3.5	0	1	38	60	0.5	37.05	22.13

SPT=specie/type, AGE=age, PHY=physiological state, LBW=body weight, MBW=mature body weight,TD=time delay, RF=rumen fill

Reticulo-rumen fill (g/kgBW) of predicted by the ANN model for all the treatments are less than the observed by range from 0.1 to 37 g/kgBW. The under prediction is clearly shown in Figure 5.11.

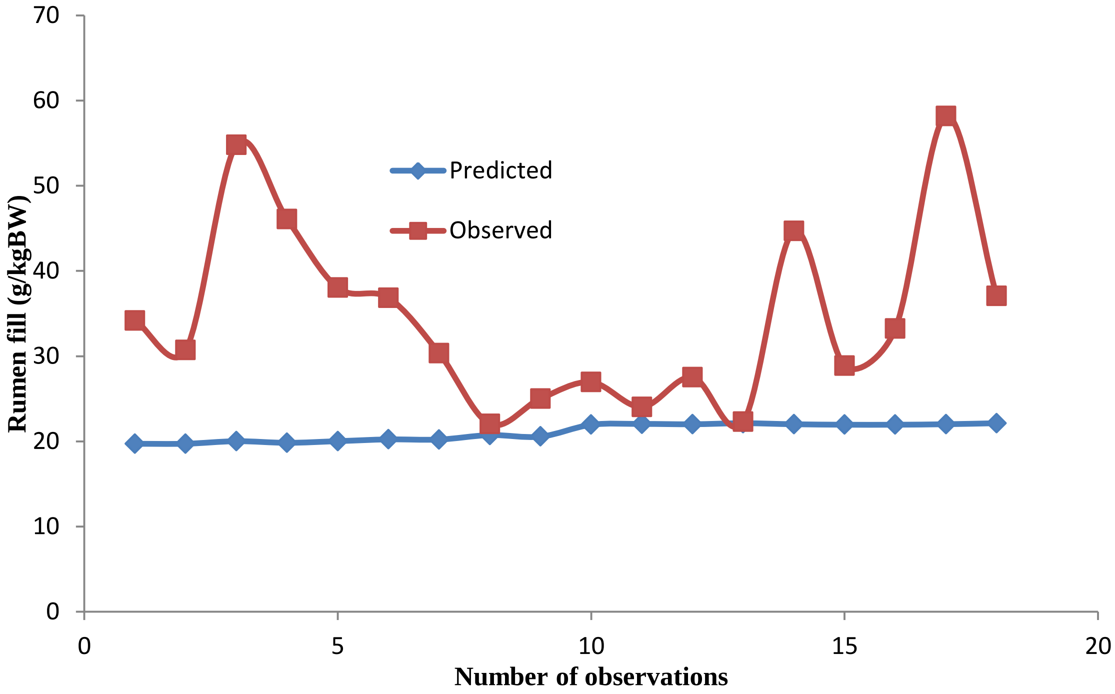


Figure 5.11 Pattern of ANN model predicted and observed reticulo-rumen fill of goats fed UTH, USH and NTH

5.9 DISCUSSION

5.9.1 Behavioural observation

The behaviour of goats observed were relatively diverse as if they were on free range system or semi-intensive one (Miranda-de la Lama and Mattiello, 2010) but they were in confinement and still exhibited the following; eating or feeding, rumination while standing and lying down, idling while standing, lying down and sleeping, recreation, conflict, mineral salt licking and drinking. These multiple behaviours may have been influenced by nutritive value and sensory properties (Baumont, 1996) of the different fed roughages. In general though, goats fed UTH appeared to be involved in all the mentioned behavioural activities than those of USH and NTH and it may be due to the treatment process carried out with urea which grossly improved the colour, aroma or odour, texture and possibly taste of the roughage (Forbes, 2007). All these are pre-ingestive characteristics of feed that hold strong influence on behavioural adjustments and patterns of eating activity of ruminants and it aligns with the recent reports of Baumont *et al*. (2000) and Favreau *et al*. (2010).

Besides, it is worth stating that unlike the non-significant effect of feed quality and eating cum rumination time observed by Baumont *et al*. (1997) on reticlo-rumen fill, we recalled the existence of differences between diets and time of measurement in the reticulo-rumen fill. Invariably, the behavioural patterns enlisted of these goats were also significant in the fill of the reticulo-rumen, some other wet digesta loads like that of omasum, abomasum and dry digesta loads of abomasum and caecum.

5.9.2 Behaviour over time

Time spent for most of these behaviours was relatively large but non-significant on the overall assessment. However, some activities were distinctively significant while some were also distinctively non-significant throughout the day. There were instances where time spent by goats fed UTH was at some periods of the day very significant on eating, ruminating while lying down, playing and fighting but time spent by goats fed not only UTH but also USH and NTH, on ruminating while lying down, sleeping and idling while lying down was not significant. It is logical to infer that goat spend majority of their time on eating, ruminating and recreation (Abdelsalam and Al-Seaf, 2012). This finding is in agreement with previous ones. On another note, goats rarely sleep except that they engage in any of the activities that preoccupy their time and they rarely do anything while lying down or even standing though they could be idle. Also, water drinking of goats as reflected in this behavioural study, still agrees with the result and findings in chapter 3 on water intake. The basic reasons could be the decreased environmental temperature or increased humidity resulting from the experienced winter as at the time of this study (Maynard *et al*., 1981).

Goats were observed using horns, legs or even mouth to scratch their body and the time taken per day to carry out this activity was found to be significantly higher for goats fed either UTH or USH than NTH. Nonetheless, scratching may not just be a spontaneous or habitual thing except there are factors evoking it. Hence, it is suspected that the cause may be biotic factors of either ecto-parasites like lice, ticks etc or internal ones like worms.

The importance of mineral licks cannot be under estimated in the nutritional needs of the animals as they naturally seek for it, making it available in confinement is very essential as goats consumed 8 mineral blocks of 25 kg per each throughout the experimental period. Although time spent for licking salt was small but for the less significant time spent too, mineral licking is important (FAO, 2007).

5.9.3 Digesta load in the reticulo-rumen and other organs of the GIT

Unlike Estrada *et al*. (2004) who reported little variation in reticulo-rumen fill at a longer time after meal termination, reticulo-rumen fill measurement in goats fed UTH, USH and NTH upon termination of meals differed. This variation was probably due to different nutritional quality of roughages (Campling *et al*., 1996; Nsahlai and Apaloo, 2007). This variation in the reticulo-rumen fill was affected by diet quality, dry matter intake and water intake which may be moisture content of feed, metabolic water or drinking water, and it is still in contrast with previous findings (McLaren and Doyle, 1988; West, 1998; Estrada *et al*., 2004).

Wet reticulo-rumen fill of goats fed UTH was less than that of goats fed NTH and could be the result of fast rate of degradation due to urea treatment of hay (Baumont *et al*., 1997). It is possible that improved quality of roughage increases microbial mass and activity eliciting greater degradation of roughage, as witnessed in high rate and effective DM disappearance, possibly reducing the retention of feed in the reticulo-rumen (Kreikemeier *et al*., 1990).

Invariably, reticulo-rumen fill was decreased with improved roughage quality. On the contrary, dry reticulo-rumen fill of goats fed UTH was only less than that of goats fed USH and not NTH. This signals to the possible fact that rumen fluid in the reticulo-rumen digesta load of goats fed NTH was rather higher than those of UTH and USH, more so, that the dry matter intake of the two feeds were higher than NTH. However, both wet and dry digesta in the reticulo-rumen, omasum and abomasum followed a decreasing trend reinstating the result in all treatment feeds UTH, USH and NTH in the same order.

Period of measurement of reticulo-rumen fill of goats and digesta in other compartments was also significant. Wet reticulo-rumen fill of goats measured in the evening was larger than in the afternoon which was similar to that of the morning. But on the contrary, wet abomasum load in the morning was larger than evening which was similar to afternoon. Wet reticulo-rumen fill was strongly related to omasum positively. It also implied that as the fill of the reticulo-rumen increases, omasal digesta load also increases (r= 0.623). Besides, wet reticulo-rumen fill of goats has strong positive relationship with digesta loads of all distal compartments except the abomasum and small intestine. It simply means that for every increase in the weight of the fill of reticulo-rumen, there is a corresponding and resultant increase in the weights of digesta load in omasum, large intestine, caecum and colon. Invariably, there are predictable relationships between wet reticulo-rumen fill and digesta loads in these distal compartments.

The wet omasal digesta load was positively correlated with colon, caecum and large intestine, so its value could be invariably used to predict the expected values in these distal compartments having unraveled that the more it increases, the more the contents of these compartments would increase. Amazingly, abomasum load both in wet and dry form was positively correlated with the caecum digesta load and could apparently be used for its prediction as increase in its value leads to a corresponding increase in caecum digesta load

(Schlecht et al., 2003). There seems to be an inverse relationship between the wet digesta load of the large intestine of goats in relation to the colon and the dry digesta load of the large intestine of goats in relation to the colon as well since the former was significant and positively correlated (r= 0.706) with colon while the later was not significant and negatively correlated (r= -0.097) with colon. Hence, increase in wet digesta load of the large intestine leads to an increase in digesta load of the colon and decrease in dry digesta load of the large intestine leads to increase in dry digesta load of the colon as well.

5.9.4 Neutral detergent fibre (NDF) and acid detergent fibre (ADF) loads

The NDF loads in the rumen of goat was affected by dietary nutritional composition and higher in goats fed urea-sprayed hay just as the dry matter content of the reticulo-rumen fill was higher and led to a corresponding decrease in the dry matter intake of goats fed the same diet though at certain times of data collection period. This outcome is in agreement with the findings of Tjardes *et al*. (2002). On the contrary to a believed standard (1.7 kg of NDF/100 kg of body weight) in the rumen and in conformity to the minimum NDF intake of 320 g/kgBW controlled by the fill according to Hoover (1986), the load of NDF for diets in this study, during varioud periods, were greater than this standard but less than 2.8 kg/100kg and likewise greater than the minimum but not more than 776 g/kg. With this remarkable outcome and without underestimating the effect of time, it should still be clearly emphasized that the load of NDF in the evening was larger than that of morning and afternoon just like it was ordinarily for the reticulo-rumen fill. Hence, it could invariably be inferred that the load NDF in the rumen is not only an indicator for fill (Van Soest, 1994; Hoover, 1986) but determinant for the large size of the reticulo-rumen fill in the evening after a long day eating by the animals (Tedeschi *et al*., 2012).

5.9.5 Artificial neural network (ANN) model prediction

Values of reticulo-rumen fill (g/kgBW) predicted by ANN model were lower than the observed values for goats fed UTH, USH and NTH but were significant ($P<0.001$) relative to the observed. This may be due to limitations and constraints observed in the training and validation datasets adapted from publications**.** Among these were that ANN model (I) had R^2 of 0.92 and 0.83 for validation and training respectively but has negative predictions while ANN model (II) has positive predictions all through but R^2 of 0.37 and 0.22 for training and validation. The variability of 37% and 22% explained by ANN model (II) is a signal to the non-linearity and complexity of the relationship between parameters in the datasets, thereby causing noise (Shahinfar *et al*., 2012; Salawu *et al*., 2014).

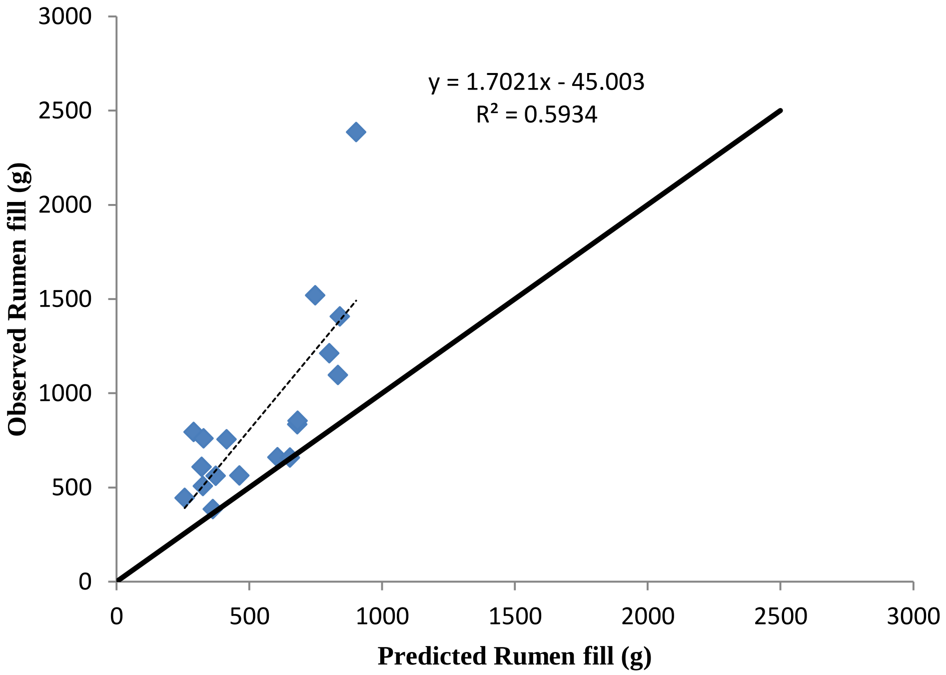


Figure 5.12 Relationship between the artificial neural network (ANN) predicted and observed values of reticulo-rumen fill of goats

Besides, reticulo-rumen fill (RF) of goats may be negatives when the input is zero but for every increase in the input, RF will also increase by 1.7021. Nonetheless, there is a high tendency for a fairly accurate prediction of reticulo-rumen fill of goats fed UTH, USH and NTH as shown in Figure 5.12.

5.10 CONCLUSIONS

Improved nutritional quality of roughages initiated with urea treatment or spray, and most especially the treatment significantly improved colour, aroma and taste of the roughage. These three pre-ingestive attributes of the roughage greatly influenced the behaviour of goats. Consequently, post- ingestive consequences such as effects of diets on performance of goats and the reticulo-rumen fill differed. Thus, more time was spent on eating and rumination and these are the major activities of goats throughout the day in confinement. It is, therefore, postulated that goats rarely sleep, neither do they remain idle at any time of the day while lying down or standing and that quality feed seems to incite joy or excitement in goats. Furthermore, there is:

(1) reduced rumen NDF and ADF most especially in goats fed urea-treated hay;

(2) reduced reticulo-rumen fill of goats possibly by increasing soluble fraction. Likewise the digesta loads in omasum, abomasum and other distal compartments of the GIT were affected.

The period (morning, afternoon or evening upon meal termination) also affected the reticulo-rumen fill of goats. It is therefore postulated that reticulo-rumen fill reduced with improved diet quality, becomes larger in the evening and can be predicted via digesta load in other distal compartments. Also, ANN with further modification in datasets could be effective tool for prediction of reticulo-rumen fill of goats.

Chapter 6

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATION

Goats fed urea-treated hay (UTH) readily consumed their feed and it was adduced to the effect of quality improved with urea. Likewise, goats fed urea-sprayed hay (USH) ate better than those fed non-treated hay (NTH) and urea inclusion could also be the reason for such observation. By treatment and spraying hay with urea, dry matter intake of goats was significantly large unlike in non-treated hay.

On the contrary, goats fed NTH drank more water than those fed UTH and USH and this may be that water in the hay was not enough to complement for the requirement in the goats and perhaps the environmental temperature and humidity in winter period. Live weight changes were inconsistent and not significant except for few times in the collection period and for goats fed UTH and USH. This only corroborated the benefit of urea as protein supplement for low-quality roughage optimization.

Reticulo-rumen fill and digesta loads in other distal compartments of the digestive tract, as measured upon termination of meal in the morning, afternoon or evening significantly varied with treatment and period. However, reticulo-rumen fill of goats followed a decreasing trend in this order UTH<USH<NTH. Besides, measure of the fill in the evening seemed significantly larger than morning and evening (morning=afternoon).

Time spent by goats on feeding, rumination and recreation were significantly different and these activities were observed to be statistically significant in their daily activities. Nonetheless, goats fed UTH surpassed others in their spent time for feeding, ruminating, playing and fighting. These activities portend that the goats were hyperactive, probably as a result of the effect of the diet quality. Hence, quality roughage also influenced behaviour of goats.

Artificial neural network on training and validation for datasets adapted from publications explained 83% and 92%, respectively of the variation between rumen fill predicted and observed but with negative predictions. When data were modified with time delay before measurement included and rumen fill scaled to g/kg body weight, only 37% and 22% of the variation could be explained during training and validation respectively with amazing predictions of all positive values. In conclusion, the feeding behaviour evoked by diet quality has implication on dry matter intake of the goats and consequential effect on the reticulo-rumen fill cum digesta loads in other compartments of the digestive tract. Also, degradation of dry matter and digestibility of nutrients were invariably affected. Hence, all phenomena studied were intertwined and purposefully interconnected. It is therefore, recommended that further studies could be carried out with goats, sheep and cattle to populate data from actual field work datasets in order to create a generic model for predicting the reticulo-rumen fill of ruminants.

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APPENDICES

Appendix 1 Goat in individual pen

Appendix 2 Urea spraying, drying and bagging of hay at Ukulinga farm livestock section

Appendix 3 Oven drying of faecal sample at Ukulinga farm

Appendix 4 Goats with faecal bags and emptying of bag

Appendix 5 CCTV cameras positioned strategically in the goats pen and linked with monitor and digital video recorder

Appendix 6 PerkinElmer series 11 CHNS/O analyzer in Chemistry laboratory of UNIZULU, Kwadenglazwa

Appendix 7 Electric stunning of goats and their slaughtering

Appendix 8 Processing of slaughtered goats and evacuation of reticulo-rumen fill and digesta loads in the distal compartments of the GIT

Appendix 9 Data of dry matter intake, water intake and weights of goats

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                          The SAS System                    1000

                               10:23 Sunday, September 1, 2013

Obs anid treat   dm    iwt day  wt   int cumin water  cumw   dmi    cumi

  1   1   UT   0.9044 13.0   0 12.0 2.44  2.44  2.88  2.88 2.20674  2.2067

  2   2   UT   0.9044 15.5   0 15.0 3.22  3.22  2.88  2.88 2.91217  2.9122

  3   3   NT   0.9229 15.5   0 15.0 3.02  3.02  4.80  4.80 2.78716  2.7872

  4   4   ST   0.9204 16.0   0 14.0 4.98  4.98  4.80  4.80 4.58359  4.5836

  5   5   NT   0.9229 18.0   0 16.5 6.02  6.02  6.03  6.03 5.55586  5.5559

  6   6   ST   0.9204 19.0   0 18.5 4.04  4.04  6.03  6.03 3.71842  3.7184

  7   7   ST   0.9204 19.5   0 17.0 2.68  2.68  6.26  6.26 2.46667  2.4667

  8   8   NT   0.9229 23.0   0 19.0 6.60  6.60  6.26  6.26 6.09114  6.0911

  9   9   UT   0.9044 25.5   0 24.5 4.34  4.34  4.90  4.90 3.92510  3.9251

 10  10   UT   0.9044 32.5   0 28.5 5.98  5.98  4.90  4.90 5.40831  5.4083

 11  11   NT   0.9229 32.5   0 28.5 6.20  6.20  5.92  5.92 5.72198  5.7220

 12  12   ST   0.9204 34.0   0 32.5 5.48  5.48  5.92  5.92 5.04379  5.0438

 13  13   NT   0.9229 35.5   0 34.0 4.92  4.92  6.52  6.52 4.54067  4.5407

 14  14   ST   0.9204 35.5   0 31.5 8.24  8.24  6.52  6.52 7.58410  7.5841

 15  15   UT   0.9044 36.5   0 33.5 8.10  8.10  7.44  7.44 7.32564  7.3256

 16  16   UT   0.9044 36.5   0 36.0 6.50  6.50  7.44  7.44 5.87860  5.8786

 17  17   ST   0.9204 39.5   0 38.0 6.70  6.70  7.19  7.19 6.16668  6.1667

 18  18   NT   0.9229 40.5   0 38.0 8.32  8.32  7.19  7.19 7.67853  7.6785

 19   1   UT   0.9044 13.0   7 12.5 3.40  5.84  4.20  7.08 3.07496  5.2817

 20   2   UT   0.9044 15.5   7 13.0 4.76  7.98  4.44  7.32 4.30494  7.2171

 21   3   NT   0.9229 15.5   7 12.0 3.42  6.44  4.82  9.62 3.15632  5.9435

 22   4   ST   0.9204 16.0   7 11.0 5.44 10.42  4.80  9.60 5.00698  9.5906

 23   5   NT   0.9229 18.0   7 14.0 2.92  8.94  5.84 11.87 2.69487  8.2507
```

24	**6**	**ST**	**0.9204**	**19.0**	**7**	**15.0**	**6.50**	**10.54**	**5.40**	**11.43**	**5.98260**	**9.7010**
25	**7**	**ST**	**0.9204**	**19.5**	**7**	**14.0**	**4.56**	**7.24**	**5.42**	**11.68**	**4.19702**	**6.6637**
26	**8**	**NT**	**0.9229**	**23.0**	**7**	**17.5**	**4.08**	**10.68**	**5.56**	**11.82**	**3.76543**	**9.8566**
27	**9**	**UT**	**0.9044**	**25.5**	**7**	**21.0**	**6.88**	**11.22**	**4.92**	**9.82**	**6.22227**	**10.1474**
28	**10**	**UT**	**0.9044**	**32.5**	**7**	**26.0**	**6.42**	**12.40**	**5.00**	**9.90**	**5.80625**	**11.2146**
29	**11**	**NT**	**0.9229**	**32.5**	**7**	**27.0**	**5.48**	**11.68**	**5.44**	**11.36**	**5.05749**	**10.7795**
30	**12**	**ST**	**0.9204**	**34.0**	**7**	**31.5**	**6.72**	**12.20**	**5.68**	**11.60**	**6.18509**	**11.2289**
31	**13**	**NT**	**0.9229**	**35.5**	**7**	**33.5**	**4.68**	**9.60**	**5.56**	**12.08**	**4.31917**	**8.8598**
32	**14**	**ST**	**0.9204**	**35.5**	**7**	**32.5**	**8.98**	**17.22**	**6.46**	**12.98**	**8.26519**	**15.8493**
33	**15**	**UT**	**0.9044**	**36.5**	**7**	**35.0**	**6.58**	**14.68**	**6.44**	**13.88**	**5.95095**	**13.2766**
34	**16**	**UT**	**0.9044**	**36.5**	**7**	**36.0**	**6.74**	**13.24**	**6.68**	**14.12**	**6.09566**	**11.9743**
35	**17**	**ST**	**0.9204**	**39.5**	**7**	**39.5**	**7.44**	**14.14**	**7.00**	**14.19**	**6.84778**	**13.0145**
36	**18**	**NT**	**0.9229**	**40.5**	**7**	**39.0**	**5.96**	**14.28**	**6.82**	**14.01**	**5.50048**	**13.1790**
37	**1**	**UT**	**0.9044**	**13.0**	**14**	**13.0**	**4.92**	**10.76**	**4.50**	**11.58**	**4.44965**	**9.7313**
38	**2**	**UT**	**0.9044**	**15.5**	**14**	**16.0**	**5.64**	**13.62**	**4.52**	**11.84**	**5.10082**	**12.3179**
39	**3**	**NT**	**0.9229**	**15.5**	**14**	**16.0**	**3.14**	**9.58**	**4.84**	**14.46**	**2.89791**	**8.8414**
40	**4**	**ST**	**0.9204**	**16.0**	**14**	**16.5**	**4.98**	**15.40**	**4.86**	**14.46**	**4.58359**	**14.1742**
41	**5**	**NT**	**0.9229**	**18.0**	**14**	**18.0**	**3.94**	**12.88**	**4.20**	**16.07**	**3.63623**	**11.8870**
42	**6**	**ST**	**0.9204**	**19.0**	**14**	**20.0**	**6.40**	**16.94**	**4.20**	**15.63**	**5.89056**	**15.5916**
43	**7**	**ST**	**0.9204**	**19.5**	**14**	**16.0**	**3.76**	**11.00**	**5.36**	**17.04**	**3.46070**	**10.1244**
44	**8**	**NT**	**0.9229**	**23.0**	**14**	**19.0**	**4.70**	**15.38**	**5.34**	**17.16**	**4.33763**	**14.1942**
45	**9**	**UT**	**0.9044**	**25.5**	**14**	**24.0**	**6.76**	**17.98**	**4.96**	**14.78**	**6.11374**	**16.2611**
46	**10**	**UT**	**0.9044**	**32.5**	**14**	**31.0**	**9.26**	**21.66**	**5.02**	**14.92**	**8.37474**	**19.5893**
47	**11**	**NT**	**0.9229**	**32.5**	**14**	**33.5**	**5.08**	**16.76**	**4.74**	**16.10**	**4.68833**	**15.4678**
48	**12**	**ST**	**0.9204**	**34.0**	**14**	**32.0**	**6.48**	**18.68**	**4.76**	**16.36**	**5.96419**	**17.1931**
49	**13**	**NT**	**0.9229**	**35.5**	**14**	**33.5**	**5.40**	**15.00**	**5.02**	**17.10**	**4.98366**	**13.8435**
50	**14**	**ST**	**0.9204**	**35.5**	**14**	**35.5**	**8.34**	**25.56**	**5.32**	**18.30**	**7.67614**	**23.5254**

```
51  15   UT   0.9044 36.5  14 37.0 9.46 24.14  5.02 18.90 8.55562 21.8322
52  16   UT   0.9044 36.5  14 33.5 9.52 22.76  5.36 19.48 8.60989 20.5841
53  17   ST   0.9204 39.5  14 39.0 9.18 23.32  5.70 19.89 8.44927 21.4637
54  18   NT   0.9229 40.5  14 42.0 6.84 21.12  5.74 19.75 6.31264 19.4916
55   1   UT   0.9044 13.0  21 13.0 3.82 14.58  6.72 18.30 3.45481 13.1862
56   2   UT   0.9044 15.5  21 16.0 5.46 19.08  6.72 18.56 4.93802 17.2560
57   3   NT   0.9229 15.5  21 15.5 3.48 13.06  5.56 20.02 3.21169 12.0531
58   4   ST   0.9204 16.0  21 16.5 3.82 19.22  5.56 20.02 3.51593 17.6901
59   5   NT   0.9229 18.0  21 18.0 4.12 17.00  6.44 22.51 3.80235 15.6893
60   6   ST   0.9204 19.0  21 19.0 4.82 21.76  8.46 24.09 4.43633 20.0279
61   7   ST   0.9204 19.5  21 19.0 4.18 15.18  6.00 23.04 3.84727 13.9717
62   8   NT   0.9229 23.0  21 22.0 4.40 19.78  8.90 26.06 4.06076 18.2550
63   9   UT   0.9044 25.5  21 24.0 6.92 24.90  6.98 21.76 6.25845 22.5196
64  10   UT   0.9044 32.5  21 30.5 8.52 30.18  7.74 22.66 7.70549 27.2948
65  11   NT   0.9229 32.5  21 32.5 4.92 21.68  8.88 24.98 4.54067 20.0085

                       The SAS System                    1001

                            10:23 Sunday, September 1, 2013

Obs anid treat   dm    iwt day  wt   int cumin water  cumw  dmi    cumi
66  12   ST   0.9204 34.0  21 32.0 6.04 24.72  7.98 24.34 5.55922 22.7523
67  13   NT   0.9229 35.5  21 33.0 4.80 19.80  7.46 24.56 4.42992 18.2734
68  14   ST   0.9204 35.5  21 34.0 6.94 32.50  8.12 26.42 6.38758 29.9130
69  15   UT   0.9044 36.5  21 37.0 8.22 32.36  8.36 27.26 7.43417 29.2664
70  16   UT   0.9044 36.5  21 34.0 8.54 31.30  8.38 27.86 7.72358 28.3077
71  17   ST   0.9204 39.5  21 39.0 8.32 31.64  8.10 27.99 7.65773 29.1215
72  18   NT   0.9229 40.5  21 41.0 7.66 28.78  8.16 27.91 7.06941 26.5611
73   1   UT   0.9044 13.0  28 12.5 3.74 18.32  6.82 25.12 3.38246 16.5686
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74	**2**	**UT**	**0.9044**	**15.5**	**28**	**16.0**	**5.36**	**24.44**	**7.54**	**26.10**	**4.84758**	**22.1035**
75	**3**	**NT**	**0.9229**	**15.5**	**28**	**15.0**	**3.20**	**16.26**	**6.68**	**26.70**	**2.95328**	**15.0064**
76	**4**	**ST**	**0.9204**	**16.0**	**28**	**15.0**	**5.08**	**24.30**	**8.12**	**28.14**	**4.67563**	**22.3657**
77	**5**	**NT**	**0.9229**	**18.0**	**28**	**16.5**	**4.04**	**21.04**	**7.88**	**30.39**	**3.72852**	**19.4178**
78	**6**	**ST**	**0.9204**	**19.0**	**28**	**19.0**	**7.14**	**28.90**	**8.58**	**32.67**	**6.57166**	**26.5996**
79	**7**	**ST**	**0.9204**	**19.5**	**28**	**18.0**	**4.78**	**19.96**	**6.62**	**29.66**	**4.39951**	**18.3712**
80	**8**	**NT**	**0.9229**	**23.0**	**28**	**16.0**	**4.90**	**24.68**	**8.02**	**34.08**	**4.52221**	**22.7772**
81	**9**	**UT**	**0.9044**	**25.5**	**28**	**23.5**	**6.88**	**31.78**	**6.12**	**27.88**	**6.22227**	**28.7418**
82	**10**	**UT**	**0.9044**	**32.5**	**28**	**30.5**	**9.02**	**39.20**	**9.80**	**32.46**	**8.15769**	**35.4525**
83	**11**	**NT**	**0.9229**	**32.5**	**28**	**31.0**	**5.16**	**26.84**	**9.02**	**34.00**	**4.76216**	**24.7706**
84	**12**	**ST**	**0.9204**	**34.0**	**28**	**31.5**	**6.46**	**31.18**	**6.60**	**30.94**	**5.94578**	**28.6981**
85	**13**	**NT**	**0.9229**	**35.5**	**28**	**32.0**	**5.68**	**25.48**	**7.46**	**32.02**	**5.24207**	**23.5155**
86	**14**	**ST**	**0.9204**	**35.5**	**28**	**34.0**	**8.06**	**40.56**	**7.46**	**33.88**	**7.41842**	**37.3314**
87	**15**	**UT**	**0.9044**	**36.5**	**28**	**37.0**	**9.32**	**41.68**	**7.44**	**34.70**	**8.42901**	**37.6954**
88	**16**	**UT**	**0.9044**	**36.5**	**28**	**35.0**	**8.90**	**40.20**	**7.44**	**35.30**	**8.04916**	**36.3569**
89	**17**	**ST**	**0.9204**	**39.5**	**28**	**39.5**	**9.02**	**40.66**	**8.12**	**36.11**	**8.30201**	**37.4235**
90	**18**	**NT**	**0.9229**	**40.5**	**28**	**40.5**	**6.44**	**35.22**	**8.12**	**36.03**	**5.94348**	**32.5045**
91	**1**	**UT**	**0.9044**	**13.0**	**35**	**12.5**	**4.10**	**22.42**	**6.80**	**31.92**	**3.70804**	**20.2766**
92	**2**	**UT**	**0.9044**	**15.5**	**35**	**16.5**	**4.72**	**29.16**	**6.00**	**32.10**	**4.26877**	**26.3723**
93	**3**	**NT**	**0.9229**	**15.5**	**35**	**15.0**	**3.02**	**19.28**	**6.02**	**32.72**	**2.78716**	**17.7935**
94	**4**	**ST**	**0.9204**	**16.0**	**35**	**16.5**	**4.24**	**28.54**	**5.70**	**33.84**	**3.90250**	**26.2682**
95	**5**	**NT**	**0.9229**	**18.0**	**35**	**17.0**	**3.32**	**24.36**	**6.44**	**36.83**	**3.06403**	**22.4818**
96	**6**	**ST**	**0.9204**	**19.0**	**35**	**19.0**	**5.64**	**34.54**	**7.44**	**40.11**	**5.19106**	**31.7906**
97	**7**	**ST**	**0.9204**	**19.5**	**35**	**18.5**	**4.36**	**24.32**	**7.22**	**36.88**	**4.01294**	**22.3841**
98	**8**	**NT**	**0.9229**	**23.0**	**35**	**21.0**	**3.94**	**28.62**	**8.24**	**42.32**	**3.63623**	**26.4134**
99	**9**	**UT**	**0.9044**	**25.5**	**35**	**24.0**	**5.74**	**37.52**	**6.02**	**33.90**	**5.19126**	**33.9331**
100	**10**	**UT**	**0.9044**	**32.5**	**35**	**30.5**	**7.06**	**46.26**	**9.14**	**41.60**	**6.38506**	**41.8375**

101	11	NT	0.9229	32.5	35	31.5	4.32	31.16	6.18	40.18	3.98693	28.7576
102	12	ST	0.9204	34.0	35	31.5	5.84	37.02	6.28	37.22	5.37514	34.0732
103	13	NT	0.9229	35.5	35	32.0	5.82	31.30	6.60	38.62	5.37128	28.8868
104	14	ST	0.9204	35.5	35	34.5	7.84	48.40	6.20	40.08	7.21594	44.5474
105	15	UT	0.9044	36.5	35	37.0	9.70	51.38	7.20	41.90	8.77268	46.4681
106	16	UT	0.9044	36.5	35	34.5	8.96	49.16	7.40	42.70	8.10342	44.4603
107	17	ST	0.9204	39.5	35	40.5	8.76	49.42	6.92	43.03	8.06270	45.4862
108	18	NT	0.9229	40.5	35	40.0	7.70	42.92	7.00	43.03	7.10633	39.6109
109	1	UT	0.9044	13.0	42	12.5	3.42	25.84	6.74	38.66	3.09305	23.3697
110	2	UT	0.9044	15.5	42	17.0	4.58	33.74	5.18	37.28	4.14215	30.5145
111	3	NT	0.9229	15.5	42	14.5	2.78	22.06	11.66	44.38	2.56566	20.3592
112	4	ST	0.9204	16.0	42	17.0	3.98	32.52	10.40	44.24	3.66319	29.9314
113	5	NT	0.9229	18.0	42	16.5	3.48	27.84	11.88	48.71	3.21169	25.6935
114	6	ST	0.9204	19.0	42	19.5	5.48	40.02	12.90	53.01	5.04379	36.8344
115	7	ST	0.9204	19.5	42	18.5	4.74	29.06	11.00	47.88	4.36270	26.7468
116	8	NT	0.9229	23.0	42	20.0	3.74	32.36	11.70	54.02	3.45165	29.8650
117	9	UT	0.9044	25.5	42	24.0	6.22	43.74	9.52	43.42	5.62537	39.5585
118	10	UT	0.9044	32.5	42	31.0	7.78	54.04	12.10	53.70	7.03623	48.8738
119	11	NT	0.9229	32.5	42	30.0	4.38	35.54	23.70	63.88	4.04230	32.7999
120	12	ST	0.9204	34.0	42	31.5	5.18	42.20	12.01	49.23	4.76767	38.8409
121	13	NT	0.9229	35.5	42	31.5	4.92	36.22	12.64	51.26	4.54067	33.4274
122	14	ST	0.9204	35.5	42	34.5	8.62	57.02	13.74	53.82	7.93385	52.4812
123	15	UT	0.9044	36.5	42	37.5	9.44	60.82	15.58	57.48	8.53754	55.0056
124	16	UT	0.9044	36.5	42	36.0	8.55	57.71	16.26	58.96	7.73262	52.1929
125	17	ST	0.9204	39.5	42	40.5	8.58	58.00	17.92	60.95	7.89703	53.3832
126	18	NT	0.9229	40.5	42	39.5	6.94	49.86	17.94	60.97	6.40493	46.0158
127	1	UT	0.9044	13.0	49	12.5	3.12	28.96	4.90	43.56	2.82173	26.1914

```
 128   2   UT   0.9044 15.5  49 16.5 4.12 37.86  5.56 42.84 3.72613 34.2406

 129   3   NT   0.9229 15.5  49 14.5 3.06 25.12  6.36 50.74 2.82407 23.1832

 130   4   ST   0.9204 16.0  49 16.5 4.12 36.64 10.40 54.64 3.79205 33.7235


                              The SAS System                    1002

                                   10:23 Sunday, September 1, 2013

Obs anid treat  dm    iwt day  wt   int cumin water  cumw    dmi     cumi

 131   5   NT   0.9229 18.0  49 16.5 2.88 30.72  7.36  56.07 2.65795 28.3515

 132   6   ST   0.9204 19.0  49 19.5 5.68 45.70  9.12  62.13 5.22787 42.0623

 133   7   ST   0.9204 19.5  49 18.5 4.90 33.96  4.70  52.58 4.50996 31.2568

 134   8   NT   0.9229 23.0  49 19.5 3.24 35.60  8.40  62.42 2.99020 32.8552

 135   9   UT   0.9044 25.5  49 24.0 5.46 49.20  5.46  48.88 4.93802 44.4965

 136  10   UT   0.9044 32.5  49 31.0 7.52 61.56  8.36  62.06 6.80109 55.6749

 137  11   NT   0.9229 32.5  49 30.5 4.16 39.70 15.12  79.00 3.83926 36.6391

 138  12   ST   0.9204 34.0  49 31.0 5.72 47.92  8.66  57.89 5.26469 44.1056

 139  13   NT   0.9229 35.5  49 31.5 4.32 40.54 10.76  62.02 3.98693 37.4144

 140  14   ST   0.9204 35.5  49 34.5 8.82 65.84  9.26  63.08 8.11793 60.5991

 141  15   UT   0.9044 36.5  49 36.5 8.40 69.22  9.96  67.44 7.59696 62.6026

 142  16   UT   0.9044 36.5  49 36.5 7.32 65.03  9.38  68.34 6.62021 58.8131

 143  17   ST   0.9204 39.5  49 40.5 8.24 66.24  9.92  70.87 7.58410 60.9673

 144  18   NT   0.9229 40.5  49 39.5 6.76 56.62 16.82  77.79 6.23880 52.2546

 145   1   UT   0.9044 13.0  56 12.5 2.32 31.28  4.28  47.84 2.09821 28.2896

 146   2   UT   0.9044 15.5  56 16.0 1.06 38.92  6.62  49.46 0.95866 35.1992

 147   3   NT   0.9229 15.5  56 14.0 2.84 27.96  8.92  59.66 2.62104 25.8043

 148   4   ST   0.9204 16.0  56 17.0 4.76 41.40  6.88  61.52 4.38110 38.1046

 149   5   NT   0.9229 18.0  56 16.0 2.50 33.22 10.94  67.01 2.30725 30.6587

 150   6   ST   0.9204 19.0  56 19.5 6.98 52.68 10.66  72.79 6.42439 48.4867
```

151	7	ST	0.9204	19.5	56	18.0	6.00	39.96	9.00	61.58	5.52240	36.7792
152	8	NT	0.9229	23.0	56	18.0	2.22	37.82	8.62	71.04	2.04884	34.9041
153	9	UT	0.9044	25.5	56	23.0	5.30	54.50	6.76	55.64	4.79332	49.2898
154	10	UT	0.9044	32.5	56	30.0	7.84	69.40	10.24	72.30	7.09050	62.7654
155	11	NT	0.9229	32.5	56	29.5	3.98	43.68	18.70	97.70	3.67314	40.3123
156	12	ST	0.9204	34.0	56	30.5	1.68	49.60	12.28	70.17	1.54627	45.6518
157	13	NT	0.9229	35.5	56	30.0	3.36	43.90	10.64	72.66	3.10094	40.5153
158	14	ST	0.9204	35.5	56	34.0	9.52	75.36	9.82	72.90	8.76221	69.3613
159	15	UT	0.9044	36.5	56	38.0	7.54	76.76	9.66	77.10	6.81918	69.4217
160	16	UT	0.9044	36.5	56	36.0	7.76	72.79	16.18	84.52	7.01814	65.8313
161	17	ST	0.9204	39.5	56	39.5	8.86	75.10	10.12	80.99	8.15474	69.1220
162	18	NT	0.9229	40.5	56	39.0	5.48	62.10	25.32	103.11	5.05749	57.3121
163	1	UT	0.9044	13.0	63	13.0	.	.	.	.	.	.
164	2	UT	0.9044	15.5	63	16.5	.	.	.	.	.	.
165	3	NT	0.9229	15.5	63	13.5	.	.	.	.	.	.
166	4	ST	0.9204	16.0	63	16.5	.	.	.	.	.	.
167	5	NT	0.9229	18.0	63	16.0	.	.	.	.	.	.
168	6	ST	0.9204	19.0	63	19.5	.	.	.	.	.	.
169	7	ST	0.9204	19.5	63	18.5	.	.	.	.	.	.
170	8	NT	0.9229	23.0	63	18.5	.	.	.	.	.	.
171	9	UT	0.9044	25.5	63	23.0	.	.	.	.	.	.
172	10	UT	0.9044	32.5	63	31.0	.	.	.	.	.	.
173	11	NT	0.9229	32.5	63	28.5	.	.	.	.	.	.
174	12	ST	0.9204	34.0	63	30.0	.	.	.	.	.	.
175	13	NT	0.9229	35.5	63	29.5	.	.	.	.	.	.
176	14	ST	0.9204	35.5	63	33.5	.	.	.	.	.	.
177	15	UT	0.9044	36.5	63	37.0	.	.	.	.	.	.

```
178  16   UT   0.9044 36.5  63 36.0 .    .    .    .    .      .
179  17   ST   0.9204 39.5  63 39.5 .    .    .    .    .      .
180  18   NT   0.9229 40.5  63 37.0 .    .    .    .    .      .
```

Appendix 10 Data of dry and wet values of reticulo-rumen fill and digesta loads in the distal compartments of goats

```
                    The SAS system 10:23 Sunday, September 1, 2013

Obs  anid   iwt  treat  stime   swt    WRF     DRF    WOMA   DOMA  WABOM

  1    1   13.0   UT    even   13.0   3091.0   444.5  161.0   44.5   91.0
  2    2   15.5   UT    after  16.5   3939.5   507.0  174.5   41.5   99.5
  3    3   15.5   NT    even   14.5   4473.5   794.5  194.5   55.5   59.0
  4    4   16.0   ST    even   16.5   4850.0   760.5  270.0   64.0   48.0
  5    5   18.0   NT    after  16.0   3759.0   608.5  327.5   84.5  150.0
  6    6   19.0   ST    after  20.5   4567.5   755.5  384.5  104.0  147.5
  7    7   19.5   ST    morn   18.5   4380.0   561.5  406.0   90.0  135.0
  8    8   23.0   NT    morn   17.5   3037.0   385.8  358.5   85.5  274.5
  9    9   25.5   UT    morn   22.5   3956.5   563.0  284.0   57.5  318.0
 10   10   32.5   UT    morn   31.0   5506.0   835.5  310.0   72.0  290.0
 11   11   32.5   NT    morn   27.5   4583.0   661.0  349.0   59.0  249.5
 12   12   34.0   ST    morn   31.0   5676.0   853.5  594.5  111.5  155.0
 13   13   35.5   NT    after  29.5   4570.0   658.0  376.5  109.5  165.5
 14   14   35.5   ST    after  34.0   7369.0  1519.0  536.0  128.5   32.0
 15   15   36.5   UT    after  38.0   8902.5  1096.5  330.0   85.0  290.0
 16   16   36.5   UT    even   36.5   8252.5  1212.5  567.5  154.0  306.5
 17   17   39.5   ST    even   41.0  10546.5  2385.5  599.0  154.0  214.0
 18   18   40.5   NT    even   38.0   9901.0  1408.0  408.5   97.0  240.0

Obs  DABOM    WSI    DSI    WLI     DLI   WCAEC   DCAEC   WCOLON
                          DCOLON

  1    9.0    46.0   6.0   212.5   31.5   175.5    37.0   123.0    42.5
  2    1.5    17.5   2.5   370.0   51.5   276.0    58.5   275.0    98.0
```

3	**22.0**	**45.0**	**4.5**	**233.5**	**35.5**	**328.5**	**60.0**	**165.5**	**51.5**
4	**6.5**	**30.5**	**3.5**	**254.5**	**34.0**	**385.5**	**64.5**	**159.0**	**52.0**
5	**20.5**	**13.0**	**2.5**	**202.5**	**31.0**	**408.0**	**77.0**	**240.5**	**87.0**
6	**24.0**	**66.0**	**9.5**	**342.0**	**43.0**	**422.0**	**74.5**	**221.5**	**68.0**
7	**4.5**	**164.5**	**14.1**	**401.5**	**27.0**	**494.0**	**87.5**	**326.0**	**91.5**
8	**23.5**	**33.5**	**4.0**	**364.0**	**47.0**	**336.0**	**69.5**	**186.5**	**61.5**
9	**4.5**	**57.0**	**8.5**	**141.5**	**17.0**	**259.0**	**51.0**	**100.5**	**29.5**
10	**22.0**	**35.0**	**19.0**	**416.5**	**39.0**	**489.0**	**80.5**	**294.0**	**79.5**
11	**22.0**	**212.5**	**11.5**	**228.0**	**34.0**	**653.0**	**138.5**	**232.0**	**135.0**
12	**16.0**	**40.5**	**4.5**	**494.0**	**525.0**	**618.0**	**108.0**	**211.0**	**57.0**
13	**14.5**	**41.5**	**5.5**	**264.0**	**84.5**	**447.0**	**0.0**	**303.0**	**102.0**
14	**10.0**	**94.0**	**4.0**	**455.0**	**62.5**	**389.5**	**71.0**	**398.5**	**124.0**
15	**44.5**	**59.0**	**8.0**	**428.5**	**61.0**	**772.5**	**147.5**	**407.0**	**141.5**
16	**28.0**	**45.5**	**6.0**	**430.5**	**50.5**	**649.0**	**109.0**	**297.5**	**95.5**
17	**9.5**	**35.0**	**5.5**	**475.0**	**65.0**	**616.0**	**111.0**	**353.0**	**126.0**
18	**24.5**	**96.0**	**13.5**	**345.0**	**460.0**	**646.0**	**115.0**	**263.0**	**85.0**

Appendix 11 Data sample for behavioural observation of goats

```
The SAS System       07:36 Sunday, September 1, 2013 121

Obs  anid  trt  iwt  day  time  feed  dde  isi  ist  rsi  rst  fl  isl  sp  sf  ss  ff

 1    1    UT   12   1     9     5    0    21   0    0    0    3   0   1   0   0   1
 2    1    UT   12   1    10     1    0    20   5    1    0    3   0   0   0   0   0
 3    1    UT   12   1    11     1    0    25   2    0    0    2   0   0   0   0   0
 4    1    UT   12   1    12     0    0    29   0    1    0    0   0   0   0   0   0
 5    1    UT   12   1    13    16    0     4   6    0    0    4   0   0   0   0   0
 6    1    UT   12   1    14     9    0    14   6    0    0    0   0   1   0   0   0
 7    1    UT   12   1    15     8    0    15   3    0    0    3   0   1   0   0   0
 8    1    UT   12   1    16     6    0    20   2    0    0    1   0   1   0   0   0
 9    1    UT   12   1    17     8    0    15   3    0    0    1   0   2   0   1   0
```

10	1	UT	12	1	18	0	0	20	0	9	1	0	0	0	0	0	0
11	1	UT	12	1	19	0	0	14	1	9	0	1	5	0	0	0	0
12	1	UT	12	1	20	2	0	24	1	0	0	0	3	0	0	0	0
13	1	UT	12	1	21	14	0	12	1	0	0	1	0	1	0	1	0
14	1	UT	12	1	22	4	0	23	2	0	0	0	1	0	0	0	0
15	1	UT	12	1	23	0	0	28	0	0	0	2	0	0	0	0	0
16	1	UT	12	1	0	2	0	2	2	23	1	0	0	0	0	0	0
17	1	UT	12	1	1	2	0	6	3	16	3	0	0	0	0	0	0
18	1	UT	12	1	2	0	0	29	0	1	0	0	0	0	0	0	0
19	1	UT	12	1	3	0	0	30	0	0	0	0	0	0	0	0	0
20	1	UT	12	1	4	0	0	28	2	0	0	0	0	0	0	0	0
21	1	UT	12	1	5	0	0	30	0	0	0	0	0	0	0	0	0
22	1	UT	12	1	6	0	0	13	1	16	0	0	0	0	0	0	0
23	1	UT	12	1	7	7	0	3	13	6	0	0	0	1	0	0	0
24	1	UT	12	1	8	3	0	23	3	0	0	0	0	1	0	0	0
25	1	UT	12	2	9	3	1	23	2	0	0	0	0	1	0	0	0
26	1	UT	12	2	10	5	0	21	0	0	0	3	0	1	0	0	1
27	1	UT	12	2	11	2	0	19	5	1	0	3	0	0	0	0	0
28	1	UT	12	2	12	1	0	25	2	0	0	2	0	0	0	0	0
29	1	UT	12	2	13	1	0	26	2	1	0	0	0	0	0	0	0
30	1	UT	12	2	14	0	0	28	0	0	0	2	0	0	0	0	0
31	1	UT	12	2	15	1	0	25	2	0	0	2	0	0	0	0	0
32	1	UT	12	2	16	7	0	18	0	1	0	4	0	0	0	0	0
33	1	UT	12	2	17	13	0	9	7	0	0	0	0	1	0	0	0
34	1	UT	12	2	18	4	0	19	1	6	0	0	0	0	0	0	0
35	1	UT	12	2	19	0	0	15	1	12	1	1	0	0	0	0	0
36	1	UT	12	2	20	0	0	22	0	0	0	0	8	0	0	0	0
37	1	UT	12	2	21	9	0	16	2	0	0	1	0	1	0	1	0
38	1	UT	12	2	22	7	0	23	0	0	0	0	0	0	0	0	0

39	**1**	**UT**	**12**	**2**	**23**	**4**	**0**	**21**	**2**	**0**	**0**	**2**	**1**	**0**	**0**	**0**	**0**
40	**1**	**UT**	**12**	**2**	**0**	**3**	**0**	**17**	**1**	**7**	**0**	**2**	**0**	**0**	**0**	**0**	**0**
41	**1**	**UT**	**12**	**2**	**1**	**1**	**0**	**17**	**1**	**9**	**1**	**0**	**1**	**0**	**0**	**0**	**0**
42	**1**	**UT**	**12**	**2**	**2**	**0**	**0**	**20**	**0**	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
43	**1**	**UT**	**12**	**2**	**3**	**0**	**0**	**29**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
44	**1**	**UT**	**12**	**2**	**4**	**0**	**0**	**28**	**2**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
45	**1**	**UT**	**12**	**2**	**5**	**0**	**0**	**27**	**0**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
46	**1**	**UT**	**12**	**2**	**6**	**1**	**0**	**9**	**1**	**18**	**0**	**1**	**0**	**0**	**0**	**0**	**0**
47	**1**	**UT**	**12**	**2**	**7**	**13**	**0**	**0**	**12**	**2**	**0**	**1**	**0**	**2**	**0**	**0**	**0**
48	**1**	**UT**	**12**	**2**	**8**	**5**	**1**	**13**	**10**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
49	**1**	**UT**	**12**	**3**	**9**	**1**	**0**	**24**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
50	**1**	**UT**	**12**	**3**	**10**	**0**	**0**	**27**	**0**	**1**	**0**	**2**	**0**	**0**	**0**	**0**	**0**
51	**1**	**UT**	**12**	**3**	**11**	**8**	**0**	**18**	**0**	**0**	**0**	**4**	**0**	**0**	**0**	**0**	**0**

Appendix 12 SAS outcome for degradation parameters of UTH, USH and NTH fed to goats

```
                    The SAS System                  39

                      18:32 Sunday, September 1, 2013

               The SAS System                  42

                      18:32 Sunday, September 1, 2013

                  Obs    feed    _TYPE_     dmd0

                    1     NTH       0      22.8604

                    2     USH       0      28.1149

                    3     UTH       0      36.8970

                    The SAS System                  43

                      18:32 Sunday, September 1, 2013

                 _      a                        d

                 T      n                        m

               f Y   d  i t                       l

          O e P   m   m i  b    s    f    d    o

          b e E   d  a m  w     w    w    m    s
```

```
s d _   0  l e  t    t    t    l    s
1 NTH 0 22.8604 A 96 1.1456 2.0051 1.6463 1.5044 75.0287
2 NTH 0 22.8604 A 72 1.2373 2.0014 1.7877 1.4510 72.4993
3 NTH 0 22.8604 A 48 1.1640 2.0028 1.8068 1.3600 67.9049
4 NTH 0 22.8604 A 24 1.2129 2.0033 2.1070 1.1092 55.3686
5 NTH 0 22.8604 A  9 1.8442 2.0049 3.1516 0.6975 34.7898
6 NTH 0 22.8604 A  6 1.7893 2.0016 3.1620 0.6289 31.4199
7 NTH 0 22.8604 A  3 1.2663 2.0006 2.7299 0.5370 26.8419
8 NTH 0 22.8604 B 96 1.1127 2.0014 1.7262 1.3879 69.3465
9 NTH 0 22.8604 B 72 1.8219 2.0003 2.4690 1.3532 67.6499
10 NTH 0 22.8604 B 48 1.1932 2.0023 1.9537 1.2418 62.0187
11 NTH 0 22.8604 B 24 1.8201 2.0011 2.8584 0.9628 48.1135
12 NTH 0 22.8604 B  9 1.1992 2.0008 2.6145 0.5855 29.2633
13 NTH 0 22.8604 B  6 1.1888 2.0014 2.6292 0.5610 28.0304
14 NTH 0 22.8604 B  3 1.1790 2.0004 2.6568 0.5226 26.1248
15 USH 0 28.1149 A 96 1.9237 2.0003 2.3538 1.5702 78.4982
16 USH 0 28.1149 A 72 1.1261 2.0029 1.6394 1.4896 74.3722
17 USH 0 28.1149 A 48 1.1816 2.0002 1.7628 1.4190 70.9429
18 USH 0 28.1149 A 24 1.9221 2.0044 2.6551 1.2714 63.4305
19 USH 0 28.1149 A  9 1.1328 2.0021 2.3740 0.7609 38.0051
20 USH 0 28.1149 A  6 1.5966 2.0024 2.9686 0.6304 31.4822
21 USH 0 28.1149 A  3 1.8012 2.0008 3.2411 0.5609 28.0338
22 USH 0 28.1149 B 96 1.1639 2.0004 1.7328 1.4315 71.5607
                 The SAS System                    44
                   18:32 Sunday, September 1, 2013
          _       a                          d
          T       n                          m
        f Y   d   i  t                       l
      O  e P   m    m  i   b    s    f    d    o
    b  e  E   d   a  m   w    w    w    m    s
      s d _   0  l  e  t    t    t    l    s
23 USH 0 28.1149 B 72 1.1657 2.0022 1.7643 1.4036 70.1029
```

```
24 USH 0 28.1149 B 48 1.1705 2.0042 1.9094 1.2653 63.1324
25 USH 0 28.1149 B 24 1.1537 2.0042 2.2130 0.9449 47.1460
26 USH 0 28.1149 B  9 1.1121 2.0012 2.5002 0.6131 30.6366
27 USH 0 28.1149 B  6 1.6508 2.0018 2.9346 0.7180 35.8677
28 USH 0 28.1149 B  3 1.7997 2.0006 3.2733 0.5270 26.3421
29 UTH 0 36.8970 A 96 1.1884 2.0004 1.5361 1.6527 82.6185
30 UTH 0 36.8970 A 72 1.8479 2.0030 2.2292 1.6217 80.9636
31 UTH 0 36.8970 A 48 1.7253 2.0010 2.1349 1.5914 79.5302
32 UTH 0 36.8970 A 24 1.6796 2.0017 2.3631 1.3182 65.8540
33 UTH 0 36.8970 A  9 1.9816 2.0009 2.9996 0.9829 49.1229
34 UTH 0 36.8970 A  6 1.1153 2.0003 2.4552 0.6604 33.0150
35 UTH 0 36.8970 A  3 1.7756 2.0023 3.1449 0.6330 31.6136
36 UTH 0 36.8970 B 96 1.1432 2.0004 1.6063 1.5373 76.8496
37 UTH 0 36.8970 B 72 1.1531 2.0016 1.6545 1.5002 74.9500
38 UTH 0 36.8970 B 48 1.1832 2.0007 1.7578 1.4261 71.2801
39 UTH 0 36.8970 B 24 1.7500 2.0008 2.6441 1.1067 55.3129
40 UTH 0 36.8970 B  9 2.2244 2.0003 3.4136 0.8111 40.5489
41 UTH 0 36.8970 B  6 1.7170 2.0015 2.5240 1.1945 59.6802
42 UTH 0 36.8970 B  3 1.0992 2.0009 2.5583 0.5418 27.0778
                    The SAS System                45
                         18:32 Sunday, September 1, 2013
---------------------------------- feed=NTH ----------------------------------
                        The NLIN Procedure
                     Dependent Variable dmloss
                           Grid Search
                                             Sum of
             Bdm        Cdm        lt1      Squares


           390.0     0.0300    10.0000      499669
           390.0     0.0300    11.0000      500661
           390.0     0.0300     9.0000      501091
           391.0     0.0300    10.0000      502648
```

```
                    391.0     0.0300     11.0000      503636

                    391.0     0.0300      9.0000      504085

                    390.0     0.0300     12.0000      504291

                    390.0     0.0300      8.0000      504717

                    392.0     0.0300     10.0000      505635

               The SAS System                         46

                         18:32 Sunday, September 1, 2013

---------------------------------- feed=NTH ----------------------------------

                          The NLIN Procedure

                       Dependent Variable dmloss

                        Method: Gauss-Newton

                           Iterative Phase

                                                  Sum of

              Iter      Bdm        Cdm       lt1     Squares

                0      390.0     0.0300    10.0000     499669

                1    50.9893     0.0306     8.8960     1218.1

                2    51.1031     0.0348     1.6022      114.2

                3    51.5286     0.0355     1.8730      111.5

                4    51.5546     0.0355     1.8585      111.5

                5    51.5529     0.0355     1.8590      111.5

                6    51.5530     0.0355     1.8589      111.5

                           Approx     Approximate 95% Confidence

         Parameter     Estimate    Std Error            Limits

         Bdm           43.0526      4.7475     32.6034     53.5019

         Cdm            0.0478      0.0190     0.00603      0.0895

         lt1            4.4677      1.7091      0.7060      8.2295
```

Appendix 13 ANN training output

Model predictions and Statiscal Analysis

Run	Observed	Model 1 (12,11,1)	Model 2 (12,15,1)	Model 3 (12,20,1)	Model 4 (12,22,1)	Model 5 (12,26,1)	Average predicted
0	1.3	1.0091	-2.2875	-1.3163	-0.26051	-1.3091	-0.83286
1	1.5	0.79164	2.5203	-0.1327	-0.6885	-0.059259	0.4863
2	1.3	1.0903	-1.2973	3.2033	-1.4885	-0.54955	0.19167
3	1.3	0.87702	-2.2875	-1.4548	-0.28381	-1.3986	-0.90954
4	1.4	0.8097	2.773	0.023663	-0.72617	-0.032844	0.56948
5	1.2	1.0915	-1.1086	3.3107	-1.4798	-0.5527	0.25222
6	1.3	0.87702	-2.2875	-1.4548	-0.28381	-1.3986	-0.90954
7	1.5	0.71135	1.3192	-0.74014	-0.55993	-0.21353	0.10338
8	1	1.0848	-1.6248	3.03	-1.5092	-0.54457	0.08722
9	0.9	0.78483	-2.2875	-1.5291	-0.31437	-1.4556	-0.96034
10	1.5	0.77274	2.2471	-0.28923	-0.65296	-0.090471	0.39743
11	0.9	1.0848	-1.6248	3.03	-1.5092	-0.54457	0.08722
12	0.9	0.74895	-2.2275	-1.8572	-0.32288	-1.4076	-1.0133
13	0.8	0.019453	-2.2875	-1.8589	1.8154	-1.9749	-0.85728
14	0.7	0.58561	-2.2875	-0.67111	-0.86541	-1.0317	-0.85401
15	8.7	12.659	8.1884	6.7221	23.11	5.056	11.147
16	13.9	12.697	8.1884	6.3789	23.112	5.0609	11.087
17	11.3	12.679	8.1884	6.2396	23.109	5.0604	11.055
18	9.2	12.673	8.1884	8.2361	23.112	5.0608	11.454
19	10.8	12.714	8.1884	6.908	23.112	5.0612	11.197
20	10.8	12.682	8.1884	6.2403	23.112	5.0606	11.057
21	16.5	13.377	8.1884	16.927	23.112	4.7059	13.262
22	11.1	11.769	8.1884	7.2762	23.112	4.3359	10.936
23	11.8	13.377	8.1884	16.927	23.112	4.7059	13.262
24	9.6	11.769	8.1884	7.2762	23.112	4.3359	10.936
25	11	11.014	8.1884	6.7137	23.112	4.9435	10.794
26	9.3	10.304	8.1884	6.261	23.112	4.5266	10.478
27	8.9	11.014	8.1884	6.7137	23.112	4.9435	10.794
28	6.5	10.304	8.1884	6.261	23.112	4.5266	10.478
29	17.3	13.377	8.1884	16.927	23.112	4.7059	13.262
30	17.1	11.769	8.1884	7.2762	23.112	4.3359	10.936
31	15.7	13.377	8.1884	16.927	23.112	4.7059	13.262
32	14.4	11.769	8.1884	7.2762	23.112	4.3359	10.936
33	13.5	11.014	8.1884	6.7137	23.112	4.9435	10.794
34	12.7	10.304	8.1884	6.261	23.112	4.5266	10.478
35	10.7	11.014	8.1884	6.7137	23.112	4.9435	10.794
36	11.8	10.304	8.1884	6.261	23.112	4.5266	10.478
37	13.7	12.687	8.1884	6.2477	23.091	4.9896	11.041

38	15.9	12.687	8.1884	6.2477	23.091	4.9896	11.041
39	16.5	12.687	8.1884	6.2477	23.091	4.9896	11.041
40	15.7	12.687	8.1884	6.2477	23.091	4.9896	11.041
41	9.6	12.689	8.1884	6.2465	23.094	4.9897	11.042
42	17.4	12.689	8.1884	6.2465	23.094	4.9897	11.042
43	15.3	12.689	8.1884	6.2465	23.094	4.9897	11.042
44	14.3	12.689	8.1884	6.2465	23.094	4.9897	11.042
45	0.9	0.34599	-1.5012	-1.8564	1.0677	-1.7435	-0.73748
46	1	0.057454	-1.7532	-1.8564	1.0735	-1.7372	-0.84316
47	1.1	-0.48583	-1.2295	-1.8563	1.1743	-1.7357	-0.82661
48	1.4	0.34599	-1.5012	-1.8564	1.0677	-1.7435	-0.73748
49	1.4	0.057454	-1.7532	-1.8564	1.0735	-1.7372	-0.84316
50	1.6	-0.48583	-1.2295	-1.8563	1.1743	-1.7357	-0.82661
51	1.3	0.34599	-1.5012	-1.8564	1.0677	-1.7435	-0.73748
52	1.4	0.057454	-1.7532	-1.8564	1.0735	-1.7372	-0.84316
53	1.9	-0.48583	-1.2295	-1.8563	1.1743	-1.7357	-0.82661
54	1.8	0.34599	-1.5012	-1.8564	1.0677	-1.7435	-0.73748
55	1.9	0.057454	-1.7532	-1.8564	1.0735	-1.7372	-0.84316
56	2.3	-0.48583	-1.2295	-1.8563	1.1743	-1.7357	-0.82661
57	1.2	0.5249	-1.5766	-1.769	0.56847	-1.8954	-0.82954
58	1.1	0.36914	-1.166	-1.7191	1.9741	-1.8801	-0.48439
59	1	-0.32658	-1.1989	-1.7466	1.9636	-1.8804	-0.63779
60	1	-0.51969	-1.1911	-1.7695	0.57934	-1.8933	-0.95885
61	1.8	0.5249	-1.5766	-1.769	0.56847	-1.8954	-0.82954
62	1.8	0.36914	-1.166	-1.7191	1.9741	-1.8801	-0.48439
63	1.8	-0.32658	-1.1989	-1.7466	1.9636	-1.8804	-0.63779
64	1.8	-0.51969	-1.1911	-1.7695	0.57934	-1.8933	-0.95885
65	11.2	10.006	8.1884	6.8148	23.112	4.7369	10.572
66	12.1	10.162	8.1884	6.7785	23.112	4.7252	10.593
67	11.1	9.9523	8.1884	6.6093	23.112	4.7258	10.518
68	11.6	10.874	8.1884	6.5219	23.112	4.7234	10.684
69	20.7	19.299	8.1884	21.249	23.112	16.97	17.764
70	21.1	16.799	8.1884	20.647	23.112	7.1763	15.184
71	21.1	21.048	8.1884	21.377	23.112	22.205	19.186
72	21.9	19.386	8.1884	21.189	23.112	12.664	16.908
73	2	2.0053	4.3975	-0.4596	-0.92143	-0.40462	0.92343
74	2.1	1.5129	3.2527	0.26783	-1.2238	-0.50249	0.66144
75	2.3	1.5234	3.2132	0.23467	-1.2062	-0.5011	0.6528
76	2.1	1.1417	2.8436	1.861	-1.7197	-0.51749	0.72182
77	10.3	12.297	8.1884	8.8535	23.112	4.9216	11.475
78	11.8	12.758	8.1884	6.8654	23.112	4.7839	11.142
79	11.5	12.664	8.1884	10.214	23.112	4.9349	11.823
80	12.6	12.93	8.1884	7.1118	23.112	4.5935	11.187
81	7.7	5.6406	-1.0262	-1.6942	10.69	-0.52068	2.6179
82	6.7	4.7341	3.6251	1.0229	10.671	-0.12313	3.9859

83	**0.4**	**-0.0014439**	**3.5053**	**2.1467**	**-1.9494**	**-0.11646**	**0.71694**
84	**0.4**	**1.0636**	**3.2833**	**2.2874**	**-1.9243**	**0.078247**	**0.95766**
85	**0.5**	**0.4913**	**3.4392**	**2.1589**	**-1.9399**	**-0.75479**	**0.67894**
86	**9.9**	**9.2496**	**8.1883**	**6.2385**	**21.351**	**4.1104**	**9.8275**
87	**8.7**	**8.556**	**8.1883**	**6.2356**	**21.351**	**4.1107**	**9.6883**
88	**10.6**	**9.3569**	**8.1884**	**6.2377**	**21.351**	**4.1287**	**9.8526**
89	**9.9**	**8.5895**	**8.1884**	**6.2347**	**21.351**	**4.1207**	**9.6968**
90	**10.3**	**8.3144**	**8.1884**	**6.2438**	**21.394**	**4.0271**	**9.6336**
91	**10.5**	**9.6531**	**8.1884**	**6.2496**	**21.405**	**4.0965**	**9.9185**
92	**11.5**	**10.639**	**8.1884**	**6.2605**	**21.412**	**4.0655**	**10.113**
93	**11.3**	**11.065**	**8.1884**	**6.2588**	**21.375**	**4.0894**	**10.195**
94	**0.9**	**0.90596**	**3.7679**	**1.5665**	**-1.8672**	**-0.39209**	**0.79621**
95	**0.9**	**0.72835**	**3.9539**	**1.7745**	**-1.9129**	**-0.1267**	**0.88343**
96	**1**	**0.69932**	**3.5371**	**2.1159**	**-1.9244**	**0.24338**	**0.93427**
97	**1**	**0.6557**	**3.7856**	**2.0071**	**-1.9244**	**0.15717**	**0.93624**
Model analysis:		**r=:0.96265** **r2=:0.9267** **t-test:34.839**	**r=:0.84375** **r2=:0.71191** **t-test:15.402**	**r=:0.87301** **r2=:0.76215** **t-test:17.539**	**r=:0.91555** **r2=:0.83823** **t-test:22.303**	**r=:0.88103** **r2=:0.77621** **t-test:18.248**	**r=:0.95404** **r2=:0.83102** **t-test:31.193**

APPENDIX 14 ANN Validation output

BIOPRO_ LAB PREDICTION USING A COMMITTEE OF FIVE ARTIFICIAL NEURAL NETWORKS						
	Individual Model Performance on Training Data					
	MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	
Topology	12,11,1	12,15,1	12,20,1	12,22,1	12,26,1	
R-square	0.9217	0.71191	0.97215	0.83823	0.87621	
	Individual Model Prediction on Submitted Input data					
MODEL 1	MODEL 2	MODEL 3	MODEL 4	MODEL 5	AVERAGE	observed
14.552	1.3153	1.073	1.2515	-0.21276	3.5958	0.9
17.988	1.5067	1.3759	1.4145	-0.04294	4.4484	0.9
19.43	1.5053	1.4158	1.3795	-0.08948	4.7282	1
20.457	1.6225	0.034076	1.5212	-0.0274	4.7214	1
13.324	15.243	12.16	15.421	10.146	13.259	9.6
13.32	15.24	12.156	15.415	10.1	13.246	11
13.285	15.212	12.131	15.373	9.7922	13.159	11.9
15.173	14.867	18.945	15.161	7.4365	14.317	8.2
15.183	14.882	19.055	15.187	7.4772	14.357	8.1
13.382	14.427	11.727	14.795	6.7696	12.22	9.4
13.378	12.895	11.715	14.632	6.7547	11.875	11.3
13.325	12.96	11.715	13.318	6.755	11.615	8.9

13.325	12.96	11.715	13.318	6.755	11.615	9.4
13.366	12.45	11.715	12.956	6.7552	11.448	8.3
13.366	12.45	11.715	12.956	6.7552	11.448	7.3
13.366	12.45	11.715	12.956	6.7552	11.448	7
13.366	12.45	11.715	12.956	6.7552	11.448	6.3
13.366	12.45	11.715	12.956	6.7552	11.448	6.1
2.3834	0.68846	-0.07348	0.69728	-1.5294	0.43325	0.7
0.58386	0.16824	-0.07341	0.23802	-1.535	-0.12366	0.8
0.65446	0.085502	-0.07269	0.20146	-1.5355	-0.13335	0.8
0.58075	-0.14884	-0.06306	-0.01251	-1.5361	-0.23595	0.6
-1.8551	5.734	4.7275	4.3042	24.392	7.4606	1
4.9647	4.2181	4.5665	3.0764	19.93	7.351	0.8
-1.8151	0.76611	10.977	2.1363	0.074443	2.4277	1
10.157	1.0922	6.7542	1.633	-1.6055	3.6061	0.8
-1.7845	0.18341	3.0546	1.2613	-1.5692	0.22912	0.9
0.22756	-0.00129	0.4907	-0.02216	-1.535	-0.16804	0.4
0.2355	0.020483	0.49094	-0.01534	-1.5372	-0.16112	0.4
0.24353	0.052214	0.49094	-0.00071	-1.5445	-0.1517	0.4
8.4117	8.0098	11.706	6.8666	0.82504	7.1638	13
8.4452	8.0573	11.706	6.9171	0.823	7.1897	12.1
8.4173	8.0178	11.706	6.875	0.82462	7.1681	13.1
8.4564	8.0731	11.706	6.934	0.82255	7.1983	12
8.4117	8.0098	11.706	6.8666	0.82504	7.1638	12.9
8.4285	8.0336	11.706	6.8919	0.82389	7.1767	10.4
8.4341	8.0415	11.706	6.9003	0.82356	7.181	13.6
8.4229	8.0257	11.706	6.8835	0.82424	7.1724	10.9
8.4397	8.0494	11.706	6.9087	0.82326	7.1853	13.5
8.4117	8.0098	11.706	6.8666	0.82504	7.1638	11
8.4229	8.0257	11.706	6.8835	0.82424	7.1724	12.6
8.4117	8.0098	11.706	6.8666	0.82504	7.1638	11