UNIVERSITY OF KWAZULU-NATAL

DEGRADATION PARAMETERS AND MODELLING OF DEGRADATION RATE IN THE RUMEN OF CATTLE FED NON-SUPPLEMENTED ROUGHAGES

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Degradation parameters and modelling of degradation rate in the rumen of cattle fed non-supplemented roughages

By

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PREFACE

DECLARATION

I, **Masande Katamzi**, vow that this dissertation has not been presented in any previous institution for a degree other than the University of KwaZulu-Natal and that it is my original work conducted under the supervision of Prof. I. V. Nsahlai. All assistance towards the production of this work and all the references contained herein have been duly acknowledged.

Signed……………… Date………………….

I, Prof Ignatius V. Nsahlai the supervisor, approved the release of this thesis for examination

Signed………………….. Date………………..

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Finally, I wish to register my respect to God without Him nothing would be possible in my life.

DEDICATION

To: God who has brought me this far, my family who have been great sources of motivation and inspiration, my mentors for developing me to my fullest potential and all those who believe in the richness of learning.

GENERAL ABSTRACT

Feeding of animal has become increasingly a big challenge in livestock production systems as it is the most costly input. Ruminants are very important to mankind because they can convert fibre-rich vegetation into high quality protein sources for human consumption. The objective of this study was to determine roughage intake in ruminants using data. The study was conducted using two fistulated jersey cows and data from several literature records with feed properties, diet properties and *in sacco* degradation parameters. An *in sacco* degradation study was conducted at Ukulinga Research farm. Ten different roughages were used, namely; (MS) maize stover (*Zea Mays*), maize leaves (ML), (WS) wheat straw (*Tritium sativa*), (KK) kikuyu (*Pennisetum clandenstinum*), (EC) weeping love grass (*Erograstis curvula*), (ECC) weeping love grass at bloom stage (*Erograstis curvula*), veld grass hays (VGHA, VGHD, VGHC & VGHP) from Airport at Pietermaritzburg, Dundee, Camperdown and Ukulinga Research Farm, respectively. All collected data for both experimental and from the literature were used to determine correlations and build regression models based on degradation parameters, diet and incubated feed properties. Also, intake and total digestibility were predicted based on degradation rate and particle passage rate.

In the study to determine degradation properties of roughages and their interaction with three different rumen environments, roughages in rumen environments supplemented with lucerne had increased ($P<0.0001$) insoluble but potential degradable fraction (*b*), potential degradability (PD) and effective degradability (ED) of dry matter. Rate of degradation (*c*), the potential and effective degradability differed ($P<0.0001$) amongst roughages in three different rumen environments but the DM solubility (*a*) did not. The outcome of the study to establish a regression model for degradation rate of roughages in non-supplemented diets produced six regression models & there were strong correlations ($P<0.0001$) between degradation parameters, diet properties and feed properties. In the study to use a model to simulate intake and digestibility, results showed small chances of predicting intake pertaining relationships in all observations with values of coefficient of determination (R^2) ranging from 10% to 24%, suggesting that some factor may not have been fully appreciated. The best coefficient of determination (R^2) for the digestibility relationship were 82% and 44% for two studies out of four meaning that there are possible chances that digestibility can be predicted.

Significant variations of *in sacco* degradability parameters were reported among roughages incubated in different rumen environments. Therefore, these results may be linked with other studies and be used to find a relationship between degradation rates of low quality roughages. In conclusion, the inclusion of variables like retention time and other factors that significantly affects intake in addition to diet and incubated feed properties, may improve simulation of intake and total digestibility of non- supplemented low quality roughages.

Key words: Intake, digestibility, regression, *in sacco* degradability, ruminant

CONFERENCE ABSTRACT

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CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Ruminants depend on grazing and/or browsing or being served harvested forages for their body requirements and production (FAO, 1996). Roughages are predominant sources of feeds for herbivores, especially ruminants that are very important to mankind because they can convert these fibre-rich vegetations into high quality protein sources for human consumption (Scholtz *et al.*, 2012). The quality of roughages can be determined by their nutritive value which can be measured by feed intake together with the availability of digestible nutrients to the animal (Hsu *et al.*, 1987; Scholtz *et al.*, 2009). However, roughages with adequate quantities of required nutrients (chemical components) can be poor because of anti-nutritional compounds prohibiting nutrient availability and decrease the degradation rate of the degradable matter in the rumen (Aganga & Tshwenyane, 2003; Soetan & Oyewole, 2009). Depending on processing or stage at which they are consumed some forages such as lucerne, red clover, white clover and multipurpose trees have superior nutritional value than tropical roughages which exposed them to be recognized as supplements to low quality feedstuffs of ruminants (Aganga & Tshwenyane, 2003). The availability of body requirements for ruminants from forages depend on the condition of rumen environment, degradation activity of microbes in the rumen, and the quality of forage (Kariuki *et al.*, 2001).

Roughages also have a role of normalizing the digestive functions in the gastro-intestinal tract (GIT) and influence the chemical composition of products produced by ruminants (Bilik *et al.*, 2012). Furthermore, in commercial production systems small proportions of roughages are mixed with high concentrate diets for feedlot cattle to supply a balanced diet for improved feed intake, degradation rate and average daily gain (ADG) (Defoor *et al*., 2002). Potential intake of roughage diet consumed by ruminants differs because of the effect of roughage qualities (Fasae *et al.,* 2010). Rumen degradation characteristics of roughages are suitable tools to predict intake of digestible dry matter (DDM) (Fonseca *et al*., 1998). Intake together with selective behavior has been found to be aspects important to differentiate digestive efficiencies of forages amongst ruminant species such as sheep and goats (Hadjigeorgiou *et al*., 2001; 2003). The age, type and parts of forages that are fed to the ruminant animal have an effect on intake through their influence on physical properties and digestibility (Van *et al*., 2002). In addition, chemical composition of forages cannot be used to accurately predict forage nutritive value but should be used to determine if requirements for protein, fibre and minerals are met in the diet (Dugmore & Nsahlai, 2010).

Straws and native pasture hay are deficient in nutrients (nitrogen, sulphur, phosphorus, etc.) essential for microbial activity, the reason being soil type, plant type and seasons influencing their availability (Ngwa *et al*., 2000; Haenlein and Ramirez, 2007). Although these roughages remain part of ruminant rations and provide energy, most of them are unable to supply adequate crude protein (CP) for milk or meat production (Anil *et al*., 2000). Consequently, these deficiencies are alleviated by supplementing roughage diets with feeds containing deficient nutrients. Legumes and other protein-rich forages have been recognized as good sources of CP (Wilkins & Jones, 2000; Kariuki *et al*., 2001). The strategy of growing `energy' and `protein' forages simultaneously in the same land has been shown to be one of the solutions of CP deficiency in ruminant rations (Anil *et al*., 2000). The CP content of a forage plant decreases with maturity while neutral detergent fibre (NDF) and DM contents increase (Van *et al*., 2002). However, intake, digestibility and potential of forage to meet the nutrient requirements of a ruminant also depend at a stage at which the forage is grazed or harvested (Bruinenberg *et al.*, 2002).

Crop residues and other agro-industrial by-product have a potential to supply nutritional needs of ruminants, but commonly have a poor nutritive value with high fiber content (Pires *et al.*, 2010). Nutrient deficiencies in ruminants fed low quality roughage diets (e.g. tropical pastures in the dry season or cereal crop residues) constrain their performance (Goodchild & Mcmeniman, 1994). Nutritive value has been improved by chemical treatments and supplementing by mixing in total mixed rations because low quality roughages have secondary cell wall, with cellulose, hemicelluloses and lignin contents in which lignin bonds with cellulose and hemicelluloses matrix (Yalchi & Hajieghrari, 2011). Ultimately, in many countries of the world crop residues and other agro-industrial by-product are used as ruminant feed complementing pastures, silages and hay (Owen & Jayasuriya, 1989).

Nutritive value of roughages has been determined using their chemical composition (Dewhurst *et al.*, 2009). Chemical composition has been a tool to predict intake and digestibility using simple and multiple regression equations (Steel & Torrie, 1980; Fonseca *et al.*, 1998; Dugmore & Nsahlai, 2010). In addition, other feed evaluation methods such as the nylon bag, *in vitro* and *in vivo* methods have been established to predict intake and digestibility of feeds (Ørskov and McDonald, 1979; Tilley and Terry, 1963; Cone *et al.*, 1996). These methods involve the incubation of feeds in the rumen or using the rumen fluid to determine the kinetics of rumen digestion (Fonseca *et al.*, 1998). Feed evaluation methods provides ways of ranking feeds according to the rate and extent of degradation of dry matter, organic matter, nitrogen or other nutritional parameters. Therefore, feed evaluation is necessary for farmers trying to optimize feed rations for livestock and for feed manufacturers trying to produce the best and cheapest diets (Madsena *et al*., 1997).

Interaction between farmers, markets and consumers had influenced scientific researchers to simulate models that would improve ruminant feeding strategies and benefit future livestock producers. Eventually, a model would require actual values from several feed evaluation studies to be validated (Nsahlai & Apaloo., 2007). Many models have been simulated to describe intake as a function of animal requirements or intake as a function of animal requirements and forage quality or predict intake on the basis of animal requirements, forage quality and forage quantity (Barr & Brown, 1995; Pittroff & Kothmann, 2001; Cannas *et al*., 2004; Nsahlai & Apaloo, 2007; Scholtz *et al*., 2009). Furthermore, a model may be required to predict intake and digestibility over a wide range of animal species and forage qualities if some existing limitations are covered by the model (Hackmann & Spain, 2010). Gas production data have been mostly used to fit in created models to make comparison and validation (France *et al*., 2005; Lopez *et al*., 2007). More work should be done with models using data obtained from various feed evaluation studies. This suggests that degradation properties and intake of roughages by ruminant may be predicted with accuracy under supplemented or non-supplemented condition, which means that both poor and good quality roughages would be utilized efficiently.

1.2 Problem statement

There is a positive link between degradation and intake whereas the effect of degradation rate on simulation of intake has only been seen in multiple regressions (Shem *et al*., 1995; Khazaal *et al*., 1995; Kibont & Ørskov, 1993). For a given rumen load and feed quality, the rate of feed intake is expected to increase in direct proportion with the fractional outflow rate of fine particles (kp) and fractional degradation rate but intake has been poorly predicted for roughages that had high intake such as crop residues comprised of a mixture of legume and cereal straws (Nsahlai & Apaloo, 2007). All these statements may be pointing to two possible sources of errors, use of different rumen environment during degradation and intake studies together with poor rumen fill estimates.

1.3 Justification

Roughages are poor quality forages, which are rich in fibre and would require supplementation or any other way of improving nutrient availability to encourage consumption. Intake and degradation of roughages in different rumen environments vary. Hence, the interrelation of intake and degradation would result to accurately predict measurements to meet the animals' requirements for future recommendations. To achieve a more comprehensive understanding on degradation characteristics of roughages, there is need to evaluate degradation in different rumen environments. Understanding degradation properties of roughages in various environments would assists farmers to determine how much supplement animals should be given when consuming different basal roughages. The need to model intake and digestibility of roughages assist feed compounders to design appropriate feed programmes which ensure that optimum nutrient intake and performance could be achieved. Knowledge of how much roughage of a particular quality would be consumed and degraded can help to improve feed utilization efficiency interms of intake and digestility.

1.4 Objectives

Aims of this research are to: (a) determine degradation properties of roughages in three different rumen environments (First rumen environment: Veld grass hay only; Second rumen environment: Veld grass hay and 1.5kg/d Lucerne & Third rumen environment: Veld grass hay and 3kg/d Lucerne); (b) inter-relate the degradation properties from three different rumen environments, and (c) determine the effect of re-calculated roughage properties on intake and digestion in ruminants.

1.5 Hypothesis

1.5.1 Corresponding degradation parameter produced in different environment will relate to each other.

1.5.2 Predicted intake = observed intake of different roughages**.**

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In feedlots, cattle are fed high-concentrate; low roughage diets henceforth energy concentrates are included to further increase the energy density of roughage mixed diets (Bartle *et al*., 1994). The digestibility of concentrates has a tendency to disturb the normal function of the gastro-intestinal tract (GIT) of ruminants causing acidosis, bloat, liver abscesses, and laminitis (Cozzi & Gottardo, 2005; Turgeon *et al*., 2010). The use of feeding strategy which divides feeding system into starter, grower and finisher diets; with gradual incremental feeding of the mixture of low roughage to high concentrate diet may overcome the dysfunction of the rumen (Brown *et al*., 2006;Meissner *et al*., 2010). Mixing concentrate with roughage will force cattle to ingest concentrate and roughage equally thus, preventing rapid consumption of concentrate (Orskov, 1999). Moreover, a good knowledge about degradation parameters in the rumen, adaptation time, selection of cereal grain (e.g., corn, barley, and wheat) and various feed additives (e.g., ionophores) may help to reduce the likelihood of rumen dysfunction (Cheng *et al*., 1998). The inclusion of roughages in diets eliminates digestive disorders and the percentage of neutral detergent fiber (NDF) in different roughage sources incorporated in high-concentrate feed mixture accounts for most of the variation in (DMI) dry matter intake (Galyean & Defoor, 2003). Crop residues and industrial by-products such as cotton seed hulls, sugarcane bagasse, molasses, maize stover, soyabean straw, barley straw, wheat straw, sorghum straw and oat straw are used to sustain livestock production (beef, dairy, sheep and goat) in South Africa (Brand, 2000; Bhasker *et al*., 2013). Hence, they compensate the continuous depletion of pastures in winter season. Research on DMI and the effect of including various levels of roughages in ruminant feeds has been recommended to support existing information and add more useful facts on their degradation parameters and predicted intake (Galyean & Defoor, 2003). A variety of feed evaluation methods have been used to evaluate feeds for ruminants to ensure efficiency of feed utilization, ruminant output and financial returns to the producer (Dijkstra *et al*., 2005). It has been noticed that scarcity of good quality feedstuffs and abundance of poor quality feedstuffs has been a major limitation to ruminant production in many tropical regions of Africa, Asia and Latin America (Promkot *et al*., 2007). This paper will review previous research findings about the effect of roughage qualities on intake and degradability in ruminants.

2.2 Rumen environments

Ruminants with their unique character of the forestomach are well equipped with a wide range of symbiotic relationship with micro-organisms that digest fibrous feedstuffs and hence, they have competitive advantage over monogastrics/hindgut fermenters (Pearson *et al*., 2006). The rumen ecosystem has a mutual relationship between microbial population and the ruminant animal that privileges the ruminants to utilize roughages for their requirements. “Rumen microbial populations consist of three main groups: bacteria, protozoa and fungi” (Kamra, 2005). The pH above 6.0 and adequate amount of ammonia (NH_3) obtained from the ingested diet provides a suitable environment to microbes hence, promoting efficient utilization of roughages (Ørskov, 1999). Rumen microbes require a receptive environment for desirable fermentation patterns. Therefore, “a continual supply of substrate, and salivary buffering salts and the removal of end products and residues will result in a relatively stable rumen environment”. Microbial population together with fermentation patterns vary with changing rumen environment, however, promoting high microbial populations require ammonia (NH_3) and branched - chain fatty acids as growth factors (Ørskov and Ryle, 1990). Low quality feeds results in lower ruminal ammonia nitrogen in the rumen and might affect feed degradation (Promkot *et al*., 2007). The availability of nitrogen

(N) to rumen microbes, NH_3-N derived from proteolysis which is used in microbial protein synthesis to improve rumen ecology together with the utilization of roughages and amino acids in the small intestine to the host animal are determined by the rate and extent of protein degradation (Promkot *et al*., 2007).

2.3 Properties of roughages

2.3.1Chemical properties of roughages

Percentage chemical components of dry matter of roughage determine its nutritive value (Getachew *et al*., 2004). Chemical properties of roughages may be used to estimate digestibility, intake and determine their quality. A meaningful relationship between chemical properties, digestibility and intake of roughages can be made through degradation characteristics; particularly rate of degradation that provides an estimate of feed digestibility in the rumen which to a large extent influences intake (Ibrahim *et al*., 1995). Tropical forages generally have a large proportion of lignified cell walls with low fermentation rates and digestibility, leading to low rates of dry matter disappearance through digestion or passage rate and decreased intake (Ibrahim *et al*., 1995). Roughages may be deficient in protein, vitamin and minerals due to the stage of maturity and seasonal changes (Ngwa *et al*., 2000; Ouda *et al*., 2006; Patra, 2009a). Consequently, prediction of quality of roughages would be important for prediction of animal performance (Iantcheva *et al*., 1999). Major chemical components that determine roughage characteristic are neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) contents. There would be no sufficient information to support results of work done evaluating feeds using feed evaluation techniques without the knowledge of chemical components. In most studies, supplementation of crop residues have shown that their utilization may be increased though they have more indigestible components than digestible components to be efficiently utilized by ruminants (Abule *et al*., 1995; Bonsi *et al*., 1995; Nsahlai *et al*., 1999;

Ngwa *et al*., 2000; Abdou, 2010)**.** In addition, other agro-industrial by products that have a better CP content (e.g. groundnut haulms, cottonseed cake and sunflower husks) are used as supplements.

2.4 Use of agro-industrial by-products, crop residues and hay in livestock production

2.4.1 Agro-industrial by products

Agro-industrial by-products include bran, mills, oil cakes, malt, molasses and brewery by-products, which are all derived from primary processing of crops. Agro-industrial by-products such as oilseed cakes and meals, wheat bran and molasses are important sources of relatively high quality feeds mostly as part of concentrate rations. They serve as energy and protein supplements in concentrate mixtures. Moreover, cottonseed cake is rich in total nitrogen and energy. Hence, production performance in terms of fattening, milk production and maintenance has been improved in ruminants when supplemented with Agro-industrial by-products (Abdou, 2010).

2.4.2 Crop residues

Crop residue is the term used for describing fibrous by-products of cereals, sugarcane, roots/tubers, pulses, oilseeds, oil plants, vegetables and fruits (Owen & Jayasuriya, 1989). Furthermore, about two thirds of crop residues are produced from cereals, particularly in Asia, Africa and other developing regions. Farmers usually harvest whole plant except roots. After removing the edible parts for human consumption, the residues are reserved as by-products to be used during periods of feed shortage for ruminants. However, maize is more available than other feed resources in African countries (Abera *et al*., 2014). After maize harvesting approximately 70.5% of the total crop residue produced is not utilized as animal feed and the remaining part for other purposes whereas from teff straw approximately 86.8% is used as animal feed and the remaining part for other purposes (Abera *et al*., 2014). Ultimately, the major crops can be ranked in the descending order of their potential (wheat, maize, teff, sorghum & barley) to produce residues as ruminant feed. Hence, it is presented in Table 1 which crop produces more yields of residue per hector than other crops.

Table 2.1 Area of predominant crops grown, their estimated grain produce and potential of crop residues as feed in ruminants in a selected African country (e.g. Ethiopia)

		Major crops				
	parameter	Maize	Teff	Sorghum	Wheat	Barley
Abera *et al.*, 2014	Cultivated area (ha)	26.5	21.8	4.5	9.4	1.3
	Total Grain yield (ton/year)	68.9	26.2	9.04	26.3	2.02
	Residue yield DM (ton/year)	137.8	39.3	13.6	39.5	3.02

DM=dry matter

2.5 Classification of roughage quality

2.5.1Characteristics of straws

Table 2.2 demonstrates the variation in chemical components (NDF, ADF, ADL, CP, and Hemicellulose & Cellulose) of straw as presented in variety of reports. The NDF and CP are within the ranges 712-879 g/kgDM and 29-57 g/kgDM, respectively. Subsequently, they are invariably fibrous, low in digestibility and nitrogen content (Fon, 2012). This variation could be influence by age, season, soil type and the type of plant that produced the straw. It is therefore, important that in order to meet requirements for a given level of productivity supplement should be included to alleviate nutrient deficiencies. Hence, it has been found that total dry matter intake (DMI) increased with increasing level of supplementation (Abule *et al.*, 1995). This should be practiced during periods of feed scarcity during April to June to avoid production losses (Abdou, 2010).

Table 2.2 Chemical composition (g/kgDM) of various types of straws

Feed	NDF	ADF	ADL	CP	HC	CELL	Source
MIS	859	532	197	-	327	336	Abdou, 2010
WS	777.5	518.3	83.7	42.8	259.2	436.7	Yalchi & Hajieghrari., 2011
RSS	772.8	582.5	97.3	53.1	190.3	485.2	Yalchi & Hajieghrari., 2011
TS	781	482	52.0	-	(299)	(430)	Abule *et al*., 1995
RS	721	533	49	30	(188)	(484)	Chumpawadee *et al*., 2006
OS	659	490	76.1	30.5	(169)	(413.9)	Kafilzadeh *et al*., 2012
BS	713	411	59.3	-	301	351	Caneque *et al*., 1998
SBS	808	632	130	51.0	(176)	(502)	Maheri-sis *et al*., 2011
MS	878	543	73	56	335	470	Fon, 2012
Mean	774.7	524.9	90.8	43.9	249.4	434.3	
SD	69.7	62.6	47.0	11.4	68.6	59.1	

Millet stover (MIS); Wheat straw(WS);Rapeseed straw(RSS); Teff straw (TS); Rice straw (RS); Oat Straw (OS); Barley straw (BS); Soyabean straw (SBS); Maize stover (MS)

Standard deviation (SD)

Note: (#) calculated value

2.5.2 Characteristics of hays

Hay is made from different forage species with desirable characteristics such as tall, leafy and thin stems together with erect growth form. Grasses such as Rhodes grass, Guinea grass and oats are among grass species suitable for hay making while forage legumes such as alfalfa (lucerne), vetch, lablab and cowpea make good quality hay (Sruamsiri, 2007). The nutritive value of legume hays predominate over grass hays (Sruamsiri, 2007). Furthermore, fiber content is lower, whereas the protein, energy and mineral contents are higher in legume hays than in grass hays. The stage of maturity and the time of harvesting are the most important factors affecting forage quality (Van *et al*., 2002). Forage quality is highest when forage crops (grasses & legumes) are in the vegetative (immature) stage. In general, to make good quality hay forage crops should be harvested for hay making immediately before or at the beginning of flowering.

It is clearly seen in (Table 2.3) that hays have better nutritive value than straw in (Table 2.2) when considering NDF and CP. Unlike straw, hays have NDF and CP that are within the range

508-730 g/kgDM and 40-169 g/kgDM respectively. However, feed evaluation procedures must be used to measure nutrient digestibility in order to determine the amount of nutrients that can be available and used by the animal (Nsahlai & Umunna, 1996). Furthermore, it is important to study feed characteristics because they have a dominant effect when low quality roughages offered (Fonseca *et al*., 1998). Use of feed evaluation methods makes it possible to gather information about low quality roughages on intake and digestibility.

Table 2.3 Chemical composition (g/kgDM) of various types of hays

Feed	NDF	ADF	ADL	CP	HC	CELL	Source
CVH	599	416	115	109	(183)	(301)	Chumpawadee *et al*., 2006
IRGH	664	376	52	105	(288)	(324)	Fonseca *et al*., 1998
GH	673	407	-	204	(266)	-	Keyserlingk *et al.,* 1996
CYH	700	405	-	62.5	(295)	-	Nsahlai & Umunna, 1996a
DZnH	729	448	-	50	(281)	-	Nsahlai & Umunna, 1996a
SnH	713	425	-	50	(288)	-	Nsahlai & Umunna, 1996a
VH	700	772	-	41	228	-	Ngwa *et al*., 2000
PH	669	437	-	79	(232)	-	Stalker *et al*., 2013
Mean	661.8	466.7	97.7	95.4	257.6	337.7	
SD	68.5	120.7	39.9	55.3	39.6	45.1	

Cassava hay (CH); Cavalcade hay (CVH); Italian ryegrass hay (IRGH); Grass hay (GH); Cynodon hay (CYH); Debre Zeit native hay (DZnH); Sululta hay (SnH); Veld hay (VH); Prairie hay (PH)

Standard deviation (SD)

Note: (#) calculated values

2.5.3 Characteristics of agro-industrial by products

It is demonstrated in Table 2.4 that agro-industrial by-products have even more nutritive value than straw and hays. Agro-industrial by products, if used in right proportions in feed formulations; animal performance in production will increase definitely (Fon, 2012). The NDF and CP are within the range on 38-483 g/kgDM and 137-238 g/kgDM respectively. High effective digestibility and the rate of degradation of agro-industrial by-products indicate that these feeds could constitute good supplements for roughage basal diet in feeding ruminants

(Abdou, 2010). Depending on the availability of industries the by-products vary from one country to another.

Table 2.4 Chemical composition (g/kgDM) of various types of agro-industrial by products

Feed	NDF	ADF	ADL	CP	HC	CELL	Source
RB	455	303	97	107	(152)	(206)	Ibrahim *et al*., 1995
CM	475	247	41	238	(228)	(206)	Ibrahim *et al*., 1995
WB	482	140	43	164	342	96	Abdou, 2010
MB	383	71	37	138	312	35	Abdou, 2010
Mean	448.8	190.3	54.5	161.8	258.5	135.8	
SD	45.3	104.4	28.4	55.9	85.8	84.9	

Rice bran (RB); Coconut meal (CM); Wheat bran (WB); Millet bran (MB)
Standard deviation (SD)
Note: (#) calculated values

The feeding value of crop residues, especially straw is limited compared to other ruminant feed classes because they are high in NDF and low in N (Tables 2.2, 2.3 & 2.4), subsequently supplementation is required (Ørskov, 1999). “During the dry season ruminants in tropical and sub-tropical regions mostly survive on low quality roughage such as standing hay or crop residues” (Ouda *et al*., 2006). Crop residues fulfill a strategic role in the fodder flow program of ruminants in the summer rainfall areas (Snyman & Joubert, 2002). Furthermore, during winter when roughage is scarce and the nutritive value of natural veld has declined to a very low level, ruminants rely on crop residues. Eventually, the quantity of cereal straws have been increased in respect to time, particularly in developing countries because of the demand to produce more and more cereal grains for human consumption (Antongiovanni & Sargentini., 1991). Therefore, utilization of straws as feed for ruminants in the future would hypothetically increase. The quality of straws varies greatly because of maturity at harvest, soil and climate changes which are influenced by either tropical or temperate regions (Antongiovanni & Sargentini., 1991; Abdou, 2010). The chemical composition of straw has helped to mix appropriate quantities with other ingredients to balance the nutrients in the diet because straws have low digestibility (Antongiovanni & Sargentini., 1991). Therefore, most straws can be termed as poor quality roughages/crop residues. Table 2.4 shows that agro-industrial by products have high NDF and the digestibility decreases as NDF increases. The nutritive value of ruminant feed classes as presented in Tables 2.2, 2.3 & 2.4 allows the raking of feed classes according to their ability to meet ruminant nutrient requirements, namely; agro-industrial by-products, hay and crop residues.

2.5.4 Degradation properties of roughages

Table 2.5 *In sacco* ruminal dry matter (DM) degradability properties of roughages

Source	Feed	Supplement	Quality	Parameters			
				a (g/kgDM)	b (g/kgDM)	c (g/kgDMh)	Lag (h)
Ibrahim *et al*., 1995	Rice bran	No	good	309	467	0.086	1.0
Abdou, 2010	Wheat bran	L	good	456	353	0.077	-
Keyserlingk *et al.*, 1996	Alfalfa hay	CMPC	good	459	359	0.0747	1.66
Ibrahim *et al*., 1995	Jack leaves	No	good	569	171	0.071	10.7
Ørskov, 1998	Barley leaf	No	good	156	702	0.067	5.0
Abdou, 2010	Millet stover stem	L	good	217	152	0.063	-
Abdou, 2010	Millet stover	L	good	152	260	0.058	-
Ørskov, 1998	Spring barley straw	No	good	128	371	0.0580	6.7
Ørskov, 1998	Rice stems	No	good	300	335	0.048	4.7
Keyserlingk *et al.*, 1996	Grass silage	CMPC	good	411	432	0.0484	6.17
Keyserlingk *et al.*, 1996	Maize silage	CMPC	good	482	382	0.0470	2.42
Keyserlingk *et al.*, 1996	Grass hay	CMPC	good	462	408	0.0462	4.74
Fonseca *et al*., 1998	Italian-ryegrass hay	SBM	good	24.8	48.2	0.046	4.0
Ørskov, 1998	Maize leaf	No	poor	197	380	0.041	14.2
Ørskov, 1998	Barley stems	No	poor	135	364	0.041	7.3
Ibrahim *et al*., 1995	Ruzi grass	No	poor	524	229	0.041	2.2
Ibrahim *et al*., 1995	NB21 grass	No	poor	614	228	0.039	1.9

Fonseca *et al*., 1998	Rice straw	SBM	poor	161	528	0.037	4.4
Ørskov, 1998	Oat leaf	No	poor	113	494	0.035	3.9
Ørskov, 1998	Maize stem	No	poor	141	369	0.032	11.2
Ibrahim *et al*., 1995	Signal grass	No	poor	530	319	0.031	1.7
Ibrahim *et al*., 1995	Guinea grass	No	poor	609	253	0.031	3.1
Chumpawadee *et al*., 2006	kraphanghom	CM	poor	276	615	0.025	-
Ørskov, 1998	Winter barley straw	No	poor	66	391	0.0247	3.3
Ørskov, 1998	Maize cob	No	poor	125	415	0.024	16.1
Fonseca *et al*., 1998	Oat hay	SBM	poor	243	497	0.024	2.0
Chumpawadee *et al*., 2006	Maize stover	CM	poor	309	530	0.022	-
Fonseca *et al*., 1998	Wheat straw	SBM	poor	107	568	0.022	1.4
Chumpawadee *et al*., 2006	Chinese spinach	CM	poor	309	530	0.022	-
Abdou, 2010	Millet bran	L	poor	439	408	0.215	-
Fonseca *et al*., 1998	Rye straw	SBM	poor	124	507	0.020	3.2
Chumpawadee *et al*., 2006	Cassava hay	CM	poor	207	676	0.020	-
Chumpawadee *et al*., 2006	Cavalcade hay	CM	poor	207	676	0.020	-
Chumpawadee *et al*., 2006	Sugarcane top	CM	poor	180	535	0.018	-
Ørskov, 1998	Oat stems	No	poor	124	298	0.015	1.5

a = Solubility; b = Insoluble; c = Degradation rate; SBM= Soyabean meal; CMPC= Commercially mixed protein concentrate; CM= Concentrate mixture; L: Lucerne

The purpose of this Table 2.5 is to demonstrate the expected pattern of degradation of roughages in the rumen and determine roughages that may be firstly preferred as feed for ruminants. Roughages in Table 2.5 show a great variation in degradability. Chumpawadee *et al*. (2006) revealed that the degradability of roughages can be ranked from highest to lowest. It is clearly seen in Table 2.5 that the degradation rate of supplemented poor quality roughages does not exceed the degradation rate of non-supplemented good quality roughages. Therefore, adequate retention time, passage of particles, degradable nitrogen and minerals are factors that may promote high microbial activity so that roughages may be degraded according to their potential

(Fonseca *et al*., 1998). But the effect of supplementation may also manifest via retention time and particle passage rate. Most crop residues are poorly degradable hence they are poor quality feeds to ruminants. Excluding commercially mixed protein concentrate and lucerne hay that are expensive, millet bran, wheat bran and groundnut haulms showed a potential to be good supplements for roughage basal diet in ruminants (Abdou, 2010).

2.5.5 In vivo and in vitro digestibility of roughages

Table 2.6 Apparent *in vivo*, *in vitro* (g/kgDM) digestibility of roughages and intake (g DM/kg) in cattle/sheep

Source	Feed	*In vivo* DMD (g/kgDM)	*In vitro* DMD (g/kgDM)	Intake (gDM/kg)	Average Animal Weight (kg)	Number of animals per treatment
Stalker *et al*., 2013	Prairie hay	(464)	(514)	-	323	8
Khazaal *et al*., 1995	Rye grass pre-bloom	508	521	57.9	60	4
	Rye grass early bloom	693	680	75.6	60	4
	Rye grass mid bloom	589	509	53.6	60	4
	Rye grass in seed	568	528	49.6	60	4
Nsahlai & Umunna, 1996	Barley straw	481	519	20.7	25.6	4
	Maize stover	493	656	20.0	25.6	4
	Sorghum stover	469	582	22.7	25.6	4
	Teff straw	435	561	17.4	25.6	4
	Wheat straw	385	536	17.5	25.6	4
	Oat early bloom	590	644	57.3	60	4
	Oat mid bloom	585	594	55.8	60	4
	Oat in seed	449	607	42.7	60	4
	Oat hay	550	614	26.0	25.6	4
	Oat straw	394	467	20.3	25.6	4
	Cynodon Hay	493	470	19.1	25.6	4
	Debre Zeit native hay	474	491	26.1	25.6	4

DM (Dry matter); DMD (Dry matter digestibility); (#) calculated values

In vivo method is the method that has been designed to measure digestibility of feeds by considering the quantity of the nutrient flowing through the gastro-intestinal tract (Mohamed & Chaudhry, 2008). It involves markers that are classified as internal and external markers which enable dietary protein entering the small intestine to be differentiated from microbial protein. *In vivo* method requires large quantities of feed, intensive labour and considerable investment that makes it too expensive to be used in feed evaluation (Hamid *et al*, 2007).

In vitro method involves use of buffers, chemical solvents, rumen fluid and enzymes that are either commercially available or extracted from rumen contents to estimate nutrient degradation (Mohamed & Chaudhry, 2008). Generally, gas production is a unique *in vitro* approach to measure digestion. *In vitro* method has been considered less expensive, offer the possibility of analysing both the residue and the metabolites of microbial degradation and best method to evaluate the nutritive value of the feed because the volume of a gas produced is directly related to the prediction of digestibility, short chain fatty acids (SCFA) production and microbial protein synthesis (Getachew *et al*, 2004; Mohamed & Chaudhry, 2008).

Table 2.6 demonstrates that there is no correlation between *in vitro* DMD and *in vivo* DMD because the digestibility values of the same feed are largely different. *In vitro* method is an accurate method in predicting digestibility and intake according to the results obtained by Stalker *et al*. (2013). Nsahlai & Umunna, (1996) found that the rate at which microbes degrade the feed in the rumen environment using reconstituted faeces may equalize with the rumen environment using rumen fluid after 48 hour. Eventually, microbial activity determines the change in degradation rate, which means that microbial masses would be approximately the same in both inoculums (rumen fluid and reconstituted faeces) after 48 hour. Since protein is not fermented in the rumen, *in vitro* gas production method would results in poor predictions of intake and apparent digestibility from protein based diets (Khazaal *et al*., 1995). Degradation parameters from nylon bag technique have been observed to be accurate predictors of intake and DMD of ruminant feeds than any other feed evaluation method (Khazaal *et al*., 1995; Nsahlai & Umunna, 1996). The live weight of the animal could not make a difference between in vitro DMD and in vivo DMD as presented in Table 2.6 where animals with average weight of 323 kg showed DMD values that were approximately equal to values of animal weighing 25-60 kg. This means that the quality of the feed, particle size and other nutrition related factors exert an effect on intake except the weight of the animal. Subsequently, prediction of intake can be done in one of the animal species sheep/cattle and a feasible solution that applies in both animals can be made because they possess same ruminant characteristics excepting goats.

Table 2.7 effects of rumen pH and concentration of ammonia on roughage digestibility

Source	animal	Treatment feed	pH	Ammonia (NH_3-N, mg %)	DMD (%)
Paengkoum *et al*., 2010	cattle	UTS50	6.6	20.0	(56)
	cattle	UTS100	6.6	26.6	(59)
	Cattle	CH50	6.6	23.5	64.8
	Cattle	CH100	6.6	27.8	67.4
Cantalapiedra-Hijar *et al*., 2009	Goats	GF	6.43	12.9	46.4
	Goats	GC	6.21	30.1	45.8
	Goats	AF	6.43	22.9	49.3
	Goats	AC	6.26	31.0	51.3
Wanapat *et al*., 2009	cattle	URS	6.48	13.7	49.5
	cattle	UTRS	6.78	17.3	60.5
	cattle	TRS	6.81	16.7	61.6

UTS: urea-treated rice straw; CH: cassava hay; LC: Low concentrate; HC: High concentrate 50/100: inclusion level of urea; 1GF = 70% grass hay and 30% concentrate, DM basis; GC: 30% grass hay and 70% concentrate, DM basis; AF: 70% alfalfa hay and 30% concentrate, DM basis; AC: 30% alfalfa hay and 70% concentrate, DM basis; URS: Untreated rice straw; UTRS: 5.5% urea-treated rice straw; TRS: 2.2% urea+2.2% Ca(OH) 2 treated rice straw; (#): calculated value

Changes in pH level and the amount of ammonia produced may depend on the given feed (Table 2.7). Ngwa *et al*. (2003) revealed that sometimes the ingested feed may not influence fluctuations of pH level in the rumen. Given different feeds, ruminants would compensate to stabilize the rumen pH level at approximately 6.2 but the type of feed offered may impose an effect resulting in the pH pattern presented in (Table 2.7). Furthermore, roughage treatment have a tendency to increase pH and DMD but ruminal NH_3-N decreases. Hence, micro-organisms may efficiently utilize ruminal NH_3-N under high pH conditions. It is demonstrated in (Table 2.7) that high NH_3-N content increase the DMD of the feed ingested. Ruminal ammonia N is mostly used for microbial protein synthesis hence the significant increase in DMD of the feed (Cantalapiedra-Hijar *et al*., 2009; Agle *et al*., 2010**)**. Roughages stimulate more salivary secretions through prolonged mastication thus possessing a potential to maintain acceptable pH level, rumen NH_3-N and bacteria population (Paengkoum *et al*., 2010). In other words, roughages are good feeds for homeostasis of the rumen though some would require supplementation because they are poorly degradable.

2.6 Effect of supplementing roughages on intake

2.6.1 Roughages supplemented with non-protein or protein sources

Table 2.8 Intake of supplemented roughages and the effect of level supplemented

Source	animal	Feed	Type of supplement	Level of Supplement (gDM/d)	Intake (gDM/d)
Bonsi *et al*., 1995	sheep	Teff straw	CSC	182	733
	sheep	Teff straw	CSC	260	579
	sheep	Teff straw	CSC	257	506
	sheep	Teff straw	CSC	267	522
Abdou, 2010	sheep	Millet stover	GH	200	777
	sheep	Millet stover	GH	400	890
	sheep	Millet stover	GH	600	1039
	sheep	Millet stover	GH/MB	600/100	1122
	sheep	Millet stover	GH/WB	600/75	1183

Ngwa *et al.*, 2000	sheep	Veld hay	SPAS	330	1206
	sheep	Veld hay	SPAS/WB	165/135	1129
	sheep	Veld hay	SPAS/WB	82.5/202.5	956

CSC: cottonseed cake; GH: groundnut haulms; MB: Millet bran; WB: wheat bran; SPAS: silage from pods of acacia sieberian

Feed intake is extremely variable, and predicting it is a worthy goal for most feeding systems in the production enterprise (Nsahlai & Apaloo, 2007). Supplementation is one of the options to take for success in livestock production but levels of each supplement being offered should be known for economic reasons. Improved digestibility and particle passage rate are key supplementation factors that clarify the effect of increased feed intake by the supplement (McCollum & Galyean, 1985; Woyengo *et al*., 2004). According to (Table 2.8) a supplement on its own or in combination with others may have negative or positive effects on feed intake. This implies that NDF digestibility of low quality roughages may be suppressed or increased depending on the protein source supplemented (Bonsi *et al*., 1995). Supplements such as leguminous fodder trees or leaves and twigs of multipurpose trees (MPTs) do not only improve intake, but also contain minerals and vitamins essential for the growth of rumen microorganisms that degrade feedstuff prior to gastric and intestinal digestion (Osuji & Odenyo, 1997). In addition, fodder trees have additional advantages, providing fuel, timber, fruits and shade for livestock and humans when they are integrated into agro-forestry farming systems (Patra, 2009b). Some forage could provide a good source of protein, vitamins and minerals to animals at critical periods of the year when pastures are deficient both in quantity and quality, so in this case supplementing forages is not necessary (Masama *et al*., 1997; Ngwa *et al*., 2000; Patra, 2009b). A practical example in goats is lespedeza (*Lespedeza cuneata*) as a low cost pasture, which provides good quality early spring and autumn grazing, makes good quality and ‘cheap’ hay, hay cures quickly and does not require the use of pesticides but unable to be used as foggage because of slow establishment and frost sensitivity (Ouda *et al*., 2006). In general, supplementing a ruminant fed on low quality basal roughage with an energy source under N limiting conditions intensifies the imbalance between protein and energy leading to reduced feed intake. Non-protein nitrogen compounds (NPN) such as urea and forage legumes may have low input cost to feed in production than true protein hence they are capable of supplying both rumen degradable and non-degradable protein (Patra *et al*., 2003, 2006). Urea treatment at 5.5% has a high potential of making efficient utilization of roughages by improving rumen ecology and enhancing cellulolytic bacterial counts (Wanapat *et al*., 2009). Irrespective of good rumen ecology compounds such as tannins, hydrocyanic acid (HCN), oxalate and phytate may confound digestibility of ingested feed in ruminants.

2.7 Digestibility of roughages in ruminants

The inclusion of foliage from tree leaves or supplementation with seed meals or even urea can improve the utilization of low quality roughages, mainly through the supply of nitrogen to the rumen microbes (Chumpawadee *et al*., 2006**)**. Attention has been based on supplementing poor quality feeds to nourish rumen microorganisms to enhance their activity and increase utilization of low quality feeds (Ibrahim *et al*., 1995). Roughages have different ruminal disappearance characteristics due to their variation in chemical composition (Chumpawadee *et al*., 2006). However, digestibility of feed in the rumen is influenced by the activity of microbes which is influenced by the feed intake level and rumen fluid pH level (Dijkstra *et al*., 2005). The rate and extent of fermentation of DM in the rumen are very important determinants of utilized digestible nutrients by ruminants (Ozkan & Sahin, 2006). The fibre content of the diet may contain more indigestible material (ADF) especially lignin that bond with hemicelluloses forming complexes of indigestible materials hence limiting the fermentation process (Fon, 2006). Diets that contain more than 5% condensed tannins would decrease the digestibility of roughages by the ruminant because of their effect on increasing non-fibrolytic micro-organisms, thus, depressing fibrolysis (Ngwa *et al*., 2003; Nsahlai *et al*., 2011). High concentrate diets decreased rumen fluid pH but the addition of adequate amounts prevents pH fluctuations that impair the digestion of roughages (Tripathi *et al*., 2004). Furthermore, buffering the rumen to high pH level prevents tannin-protein complex formation in ruminants fed on tannin-rich diets (Fon, 2006).

Table 2.9 Influence of ruminant species and retention time on digestibility of roughages

Source	Animal	Feed	Total mean Retention time (h)	Dry matter digestibility (g/kg)
Silanikove *et al*., 1993	Goat	Rhodes grass & alfalfa hay	50.8	650
Hadjigeorgiou *et al*., 2003	Goat	Perenial rye grass hay	119	483
Schlecht *et al*., 2007	Goat	Green feed	58.4	591
	Goat	Bush hay	75.0	468
	Goat	Millet leaves	94.4	449
	Sheep	Millet leaves	75.3	445
	Sheep	Green feed	58.9	594
	Sheep	Bush hay	79.9	458
Hadjigeorgiou *et al*., 2003	Sheep	Perenial rye grass hay	153	513
Bartocci *et al*., 1997	Sheep	Alfalfa hay, Maize silage & Concentrate	61.6	-
Ezequiel *et al*., 2005	Cattle	in nature sugar cane	46.0	294
	Cattle	hydrolyzed sugar cane	42.6	654
	Cattle	hydrolyzed sugar cane hay	49.8	553
	Cattle	hydrolyzed sugar cane silage	84.8	505
Oshita *et al*., 2008	Cattle	Perennial ryegrass & Orchard grass	23.4	-
Bartocci *et al*., 1997	Cattle	Alfalfa hay, Maize silage & Concentrate	58.9	-
Abule *et al*., 1995	Cattle	Teff straw	109	836
	Cattle	Teff straw & cowpea	73.2	708
	Cattle	Teff straw & lablab	72.4	720
Nsahlai *et al*., 1999	Cattle	Barley straw& concentrate	56.7	695

The utilization of ingested feed in the rumen depends upon both rate of digestion and the animal's ability to reduce the volume of ruminal contents via particle size reduction and passage from the rumen (Schlecht *et al*., 2007). The digestibility of the roughage is directly proportional to its retention time in the gastro-intestinal tract of the ruminant (Table 2.9). It is demonstrated in Table 2.9 that sheep would needs more retention time to digest the same feed that would be given to goats to obtain same digestibility values. According to the retention time pattern in (Table 2.9); it seems that ruminants have a physiological mechanism that they use to determine how much time they need to give a particular feed to digest it efficiently. Supplements or concentrates may be responsible for this behavior since they influence the particle passage rate (Bartocci *et al*., 1997).

In addition, ruminants from temperate regions would differ from tropical ones in the ability to prevent reduction in rumen pH to levels which depress fermentation, maintain higher microbial activity and longer retention time to allow recycling of nutrients in the gastro-intestinal tract (Silanikove *et al*., 1993). Schlecht *et al*. (2007) found that the digestibility of roughages between cattle and sheep is the same, except the retention time of digesta that differs with cattle having a significantly longer retention of feed than small ruminants. Furthermore, sheep were reported to have a longer rumen mean retention time than goats (Hadjigeorgiou *et al*., 2003; Alcaide *et al*., 2000). The effect of retention on digestibility between ruminant species (cattle, sheep and goats) is mostly revealed as the quality of available vegetation decreases (Alcaide *et al*., 1997). In addition Schlecht *et al*. (2007) concluded that retention time is inversely related to passage rate and variation of digesta passage is generally attributed to the fibre content of feeds than ruminant species difference. This shows that ruminant species would utilize (intake and digestibility) the same type of roughage fed to them distinctively. Therefore, one type of roughage may be efficiently or poorly utilized by different ruminant species.

2.8 Estimation of intake and digestibility of roughages

Feed evaluation has been done using *in vitro* and nylon bag methods (Nsahlai & Umunna, 1996; Dijkstra *et al*., 2005; Kebreab *et al*., 2008). Feed intake, digestibility and how the feed contribute to various purposes of production (i.e., maintenance, growth, lactation and reproduction) have been determined using these feed evaluation techniques. It is very difficult to estimate forage intake in grazing animals, so prediction of intake by integrating evaluation techniques with simulation models may improve the predictive capabilities on intake (Fonseca *et al*., 1998; Faverdin *et al*., 2011). Integration of published literature has been the goal for many decades in animal production to maximize returns, minimize production risks and provides food security (Gradiz *et al*., 2007). However, a variety of data would allow development of models to determine the relationship between feed properties and the degradation characteristics so that intake and digestibility of roughages in ruminants could be predicted. Mathematical models are very important in evaluating the interaction between the components of animal production efficiency (Kebreab *et al*., 2008). Ultimately, models are used to describe predicted data, compare it with observed data and also show existing gaps in knowledge (Dijkstra *et al*., 2005; Tedeschi *et al*., 2005).

2.9 Conclusions

In order to predict intake and digestibility of low quality roughages, their response in both supplemented and non-supplemented conditions should be studied. Roughages have different qualities, thus they have different inputs in ruminant nutrition. However, improved utilization of low quality roughages requires supplementation with urea and/or with readily fermentable N sources. This would perhaps be helpful for high producing animals such as growing, pregnant and lactating animals. Suitable levels of forage legumes that are rapidly fermented and/or less bulky could be offered to enhance use of low quality roughages. Roughages exhibit different degradation rates, mean retention times, passage rates and dry matter intakes. It is therefore, important to relate their degradation parameters from supplemented and non-supplemented rumen environments with feed and diet properties. Finally it would be appropriate to predict roughage intake and degradability.

CHAPTER 3

IN SACCO DEGRADATION PROPERTIES AND INTER-RELATION OF TEN ROUGHAGES IN THREE DIFFERENT RUMEN ENVIRONMENTS

ABSTRACT

The aim of this study was to determine degradation properties of roughages and their interaction with three different rumen environments (lucerne hay supplemented in three levels; 0, 1.5 and 3kg per day in three trials respectively). Two rumen fistulated jersey cows were fed on veld grass hay *adlibitum*. The veld grass hay was supplemented with lucerne hay that was added in each trial; 0, 1.5 and 3kg per day. The experiment consisted of three trials that were given 10 days of adaptation period before data collection. Roughage samples were incubated in the rumen for 3, 6, 9, 24, 48, 72 and 96 hours. The roughages used as test feed were maize stover/*Zea May* (MS), maize leaves (ML), wheat straw/*Tritium sativa* (WS), kikuyu/*Pennisetum clandenstinum* (KK), weeping love grass/*Erograstis curvula* (EC), weeping love grass harvested at bloom stage/*Erograstis curvula* (ECC), veld grass hays (VGHA, VGHD, VGHC & VGHP) collected from Airport at Pietermaritzburg, Dundee, Camperdown and Ukulinga Research Farm, respectively. Roughages in rumen environments supplemented with lucerne had increased ($P<0.0001$) insoluble but potential degradable fraction (*b*), potential degradability (PD) and effective degradability (ED) of dry matter. Rate of degradation (*c*), the potential and effective degradability differed ($P<0.0001$) amongst roughages in three different rumen environments but the DM solubility (*a*) did not. Some crop residues (MS & ML) had highest degradability properties while wheat straw (WS) had lowest degradability properties among roughages. The pH of the rumen fluid ranged between 5.5 and 7.6 for all rumen environments. Rumen ammonia concentration drastically increases with every increment of lucerne in the diet. It was concluded that roughages will be degraded according to their quality at an increasing rate across rumen environments (1.5E to 3.0E) suggesting that nitrogen supply in the basal feed is a factor driving these changes.

Keywords: Degradability, Ammonia concentration, pH level

3.1 Introduction

Predicting digestibility and intake of forages using feed evaluation methods is not a modern procedure since feed characteristics predominates when low quality roughages are offered to ruminants (Fonseca *et al*., 1998; Stalker *et al*., 2013). Feed digestibility has been commonly assessed using chemical assays, *in vivo, in situ* (nylon bag method) and *in vitro* methods. Eventually, *in situ* and *in vitro* gas production methods have fewer disadvantages and they are often used in ruminant feed evaluations but they are unique in terms of accuracy, rapidness, costs and labor intensities to obtain expected results (Mohamed & Chaudhry, 2008). Nylon bag method has been found to be more accurate and validated in predicting organic matter digestibility (OMD) including crude protein (CP) than other evaluation methods (Gosselink *et al*., 2004; Promkot *et al*., 2007). Hence, it allows the possibility to study rumen digestion at different periods of time or the kinetics of rumen digestion (Fonseca *et al*., 1998).

Protein is partly degradable in the rumen, into peptides, amino acids and ammonia derived from proteolysis and used in microbial protein synthesis to improve rumen ecology (Promkot *et al*., 2007). Hence, protein consumed is very crucial to the rate and extent at which roughages are degraded in the rumen. Soybean meal (SBM), groundnut hay (GN), cowpea hay (CW), cotton seed meal (CSM) and *Leucaena* leaf meal (LLM) are protein sources that have been used in studying forage intake together with degradability in ruminants and may be recommended to improve rumen ecology for efficient utilization of low quality roughages (Chakerendza *et al*., 2002; Promkot et *al*., 2007). All selected ruminant feedstuffs have a great variation in chemical composition and degradability. However, the quality of crop residues approximates to that of low quality forages because quality of forages drops during dry seasons particularly energy and nitrogen content leading to low digestion rates and limited intake (Chumpawadee *et al*., 2006).

Therefore, relevant strategies for supplementing ruminant diets require an understanding of the interaction of different types of supplements with rumen ecology especially alteration in pH and ammonia concentrations (Lehmann *et al*., 2007).

The aim of this study was to determine degradation properties of roughages and their interaction with three different rumen environments (First rumen environment: Veld grass hay only; Second rumen environment: Veld grass hay and 1.5kg/d Lucerne & Third rumen environment: Veld grass hay and 3kg/d Lucerne).

3.2Materials and methods

3.2.1 Study site

The study was conducted at Ukulinga Research Farm, University of Kwa-Zulu Natal, and Pietermaritzburg. Ukulinga Research Farm is situated in a subtropical hinterland, located at 30° 24`S, 29° 24` E and is approximately 700 m above sea level. The climate is characterized by an annual rainfall of 735 mm, which falls mostly in summer between October and April. Maximum and minimum mean annual temperatures are 25.7°C and 8.9°C, respectively. Light to moderate frost occurs in winter.

3.2.2 Feeds and preparation for rumen degradation

Ten different roughages were collected from different places, namely; farmers/agricultural colleges participating in agriculture royal show, University of Kwa-Zulu Natal agriculture campus and Ukulinga Research Farm. These roughages are; (MS) maize stover (*Zea Mays*), maize leaves (ML), (WS) wheat straw (*Tritium sativa*), (KK) kikuyu (*Pennisetum clandenstinum*), (EC) weeping love grass (*Erograstis curvula*), (ECC) weeping love grass at bloom stage (*Erograstis curvula*), veld grass hays (VGHA, VGHD, VGHC & VGHP) collected from Airport at Pietermaritzburg, Dundee, Camperdown and Ukulinga Research Farm, respectively. They were chopped fine by hand and ground in the laboratory mill through 2-mm screen.

3.2.3 Animal and Housing

Two fistulated jersey cows with live weight of 324 kg and 280 kg, respectively, were used. They were kept in individual feedlot pens under roofed shed that are 48 m^2 in size.

3.2.4 Feeding management

These animals were given veld grass hay from Ukulinga Research Farm (VGHU) and incremental levels (0kg, 1.5 kg & 3 kg) of lucerne hay. Lucerne was given at 8H00 in the morning. Water was given *adlibitum*.

3.2.5 Experimental design

Three experimental diets were fed VGHU only, VGHU + 1.5 kg (33%) lucerne or VGHU + 3 kg (50%) lucerne during each of the trial periods. Each feed was catered for one trial thus the study consisted of three trials. An interval of ten days was allowed for adaptation period before measuring degradability, pH level and ammonia concentrations. In each trial 160 bags each containing 2 g of feed mentioned above were used.

3.2.6 Degradability

The degradability of dry matter (DM) of feeds was measured using the nylon bag method (Ørskov *et al.*, 1980). This method measures the disappearance of feed components such as DM and protein from synthetic nylon bags after rumen incubation at varying periods of time (0, 3, 6, 9, 24, 48, 72 & 96 hours). Each feed was grounded through a 2-mm screen size and 2 g of each feed sample was weighed into a nylon bag (one bag for each of the two cows). Bags containing the feed were suspended in the rumen through a rumen fistula. A sequential addition procedure was used to incubate samples. After withdrawal, bags containing the residue were immediately rinsed to remove excess ruminal contents and micro-organisms to stop any biological activity.

Bags for zero time were not incubated. All collected bags were washed in a domestic washing machine together with the zero time bags until the water was completely clear in 30 minutes. The water was changed six times, with each cycle lasting five minutes.

After washing, bags were dried in an oven at 60 ^{0}C for 48h, cooled in a desiccator and weighed. Hence, DM loss was calculated and expressed as percentage degradability of the original dry matter incubated. These data were used to estimate degradation parameters using the equation from Ørskov & McDonald (1979).

$$p = a + b\ (1-e^{-ct}) \qquad \textbf{(3.1)}$$

Where p = disappearance rate at time t, a = portion of soluble DM at initiation of incubation (time 0), b = the fraction of DM that is potentially degradable in the rumen, c = a rate constant of disappearance of fraction b, and t = time of incubation. The effective degradability of DM (EDDM) was calculated using the following equation.

$$EDDM = a + (bc/(c+k)) \qquad \textbf{(3.2)}$$

Where k is the estimated rate ($0.03h^{-1}$) of out flow from the rumen (Nsahlai *et al.*, 1998).

3.2.7 Measurement of pH and ammonia

After each incubation trial, animals were maintained on the same diet for one day and 250 ml rumen fluid was collected from the rumen of each animal for ammonia concentration and rumen pH during the following times after morning feeding: 9, 11, 13, 15 and 17 hours of the day. Immediately after collection, the rumen fluid was strained through a double layer of cheesecloth. The pH was measured immediately using a Crison portable pH metre. Thereafter 1.5 ml of sulphuric acid (98.0 % H_2SO_4) was poured into the rumen fluid to lower the pH and prevent the activity of micro-organisms. All collected samples were stored below 4 ^{o}C, and later taken to Talbot laboratory for ammonia analysis.

3.2.8 Chemical analysis

The dry matter (DM) was determined by using an oven at 60 ^{0}C during 48h. Methods described by Van Soest *et al*. (1991) were used to determine the neutral detergent fibre (NDF) and acid detergent fibre (ADF). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin were determined by using ANKOM fibre Analyzer. Hemicellulose and cellulose were obtained by calculating the difference between NDF and ADF or ADF and ADL, respectively. Crude protein and ash contents were determined using LECO TruSpec Nitrogen Analyzer and a muffle furnace at 550 ^{0}C overnight, respectively. The CP value as obtained by multiplying the nitrogen values with the factor of 6.25. All the analyses were done in laboratories of Animal and Poultry Science and Soil Science at University of KwaZulu-Natal, Pietermaritzburg.

3.2.9 Statistical analysis

Analysis of variance was carried out according to the Statistical Analysis System (SAS, 2013), using the GLM procedure for the constant *a*, *b*, *c,* potential and effective degradabilities. Data for pH and ammonia were analyzed using repeated measures (SAS, 2013) to isolate the effect of time, diet and their interaction.

3.3 Results and discussion

3.3.1 Chemical composition of diet and roughages

The chemical composition of the diet is shown in Table 3.1. Veld grass hay at Ukulinga research farm had low CP relative to its NDF. In contrast, lucerne had high CP relative to its NDF. Naturally, leguminous plants are fixers of nitrate into accessible nitrogen hence lucerne would make a good quality type of hay to improve rumen functioning (Sruamsiri, 2007; Ruiz *et al*., 2009). In other words, lucerne increased the nitrogen content of the diet. Some of roughages in Table 3.2 had a very low CP and high NDF. Weeping love grasses followed by maize leaves, maize stover and kikuyu had better CP compared to other roughages though they also had high NDF contents. Therefore, these chemical characteristics confirm that these roughages are poor in quality.

Table 3. 1 Chemical composition of the diet fed to the cows (g/kg DM)

Composition	DM	OM	CP	NDF	ADF	ADL	Hem	Cel
VGHU	933	867	69	795	603	190	192	413
Lucerne	895	564	165	487	356	77	131	279

DM: Dry matter; OM: Organic matter; OM: Organic matter; N: Nitrogen; NDF: Neutral detergent fibre; ADF: Acid detergent; ADL: Acid detergent lignin; Hem: Hemicellulose; Cel: Cellulose; VGHU: Veld grass hay from Ukulinga research farm

The deficiency of nitrogen (N) in ruminant feedstuffs restricts their degradability in the rumen because N stimulates a good quality environment (rumen ecology) for the degradability of different forages (Ruiz *et al*., 2009). Lucerne would lead to improved microbial activity such as promoting higher rate and extent of forage degradation especially low quality roughages. Furthermore, N is very important because true protein has a negligible effect if N is not limiting in the rumen (Chakerendza *et al*., 2002). Therefore, supplementing a rumen environment creates more favorable conditions for microbial activity, promote potential degradability of forages and provide nutrients to the animal (Muetzel *et al*., 2003).

Table 3. 2 Chemical composition of feeds used (g/kg DM)

Composition	DM	OM	CP	NDF	ADF	ADL	Hem	Cel
MS	930	828	96	718	614	118	104	496
ML	925	660	102	645	559	100	86	459
WS	878	800	42	764	691	175	73	516
EC	931	836	107	815	503	130	312	373
ECC	925	890	128	874	615	171	259	444
KK	919	833	99	778	666	189	112	477
VGHD	932	887	41	885	629	159	256	470
VGHC	929	866	41	834	564	110	270	454
VGHP	932	877	51	849	619	189	230	430
VGHA	936	882	37	876	609	142	267	467

DM: Dry matter; OM: Organic matter; OM: Organic matter; N: Nitrogen; NDF: Neutral detergent fibre; ADF: Acid detergent; ADL: Acid detergent lignin; Hem: Hemicellulose; Cel: Cellulose

MS: Maize stover; ML: Maize leaves; MT: Maize stalks; WS: Wheat straw; EC: Erograstis curvula; ECC: Erograstis curvula at bloom stage; KK: Kikuyu; VGHD: Veld grass hay from Dundee; VGHC: Veld grass hay Camperdown; VGHP: Veld grass hay below sheep pens; VGHA: Veld grass hay from the Airport; VGHU: Veld grass hay from Ukulinga research farm

3.3.2 Dry matter degradability

Table 3. 3 The rate of degradation (/h) and dry matter disappearance parameters (g/kg) of ten different roughages in different rumen environments at various incubation times in Jersey cow's *adlibitum* fed on veld grass hay

Feeds	a (g/kgDM)	b (g/kgDM)	c (g/kgDMh)	PD(g/kgDM)	ED(g/kgDM)
First rumen environment: Veld grass hay only					
MS	194^{b}	445^{ab}	0.049^{a}	639^{ab}	645^{b}
ML	158^{d}	454^{ab}	0.049^{a}	612^{ab}	637^{b}
WS	17^{l}	373^{ab}	0.033^{a}	391^{b}	351^{f}
EC	86^{e}	518^{a}	0.048^{a}	604^{ab}	622^{b}
ECC	43^{i}	491^{ab}	0.037^{a}	534^{ab}	454^{c}
KK	76^{f}	430^{ab}	0.047^{a}	506^{ab}	339^{cd}
VGHD	53^{k}	475^{ab}	0.027^{a}	499^{ab}	405^{de}
VGHC	44^{h}	400^{ab}	0.032^{a}	445^{ab}	398^{de}
VGHP	39^{j}	446^{ab}	0.026^{a}	486^{ab}	385^{e}
VGHA	174^{c}	439^{ab}	0.029^{a}	613^{ab}	351^{f}
P (value)	0.0001	0.0059	0.5302	0.0017	0.0001
RMSE	2.110	6.429	0.064	6.429	1.362
Coeff Var	7.73	15.4	125.7	12.2	2.7
Second rumen environment: Veld grass hay and 1.5kg/d Lucerne					
MS	194^{b}	592^{bcd}	0.039^{b}	786^{abc}	531^{b}

ML	158^{c}	623^{abcd}	0.043^{b}	780^{abc}	524^{b}
WS	16^{k}	534^{cd}	0.016^{cb}	556^{c}	201^{g}
EC	87^{d}	726^{abc}	0.033^{cb}	813^{abc}	467^{c}
ECC	44^{l}	818^{abc}	0.017^{cb}	819^{abc}	289^{e}
KK	76^{e}	577^{bcd}	0.017^{cb}	652^{abc}	272^{ef}
VGHD	24^{j}	869^{ab}	0.008^{c}	894^{ab}	212^{fg}
VGHC	43^{h}	622^{abcd}	0.018^{cb}	665^{abc}	258^{efg}
VGHP	51^{g}	521^{cd}	0.029^{cb}	572^{bc}	285^{e}
VGHA	28^{i}	647^{abcd}	0.017^{cb}	676^{abc}	265^{efg}
P (Value)	0.0001	0.0021	0.0011	0.0161	0.0001
RMSE	1.686	8.588	0.008	8.588	2.117
Coeff Var	10.4	13.2	30.1	11.6	5.9
Third rumen environment: Veld grass hay and 3kg/d Lucerne					
MS	194^{b}	607^{bc}	0.052^{a}	801^{a}	579^{b}
ML	158^{d}	659^{b}	0.051^{a}	817^{a}	572^{b}
WS	16^{l}	489^{d}	0.033^{bcd}	505^{d}	269^{f}
EC	87^{e}	727^{a}	0.042^{abc}	814^{a}	512^{c}
ECC	44^{h}	647^{b}	0.029^{bcd}	691^{b}	365^{d}
KK	76^{f}	507^{d}	0.030^{bcd}	582^{c}	329^{e}
VGHD	24^{k}	593^{bc}	0.019^{d}	616^{c}	256^{f}
VGHC	43^{i}	591^{bc}	0.024^{cd}	634^{c}	299^{ef}
VGHP	40^{j}	543^{cd}	0.025^{cd}	583^{c}	285^{f}
VGHA	173^{c}	428^{e}	0.030^{bcd}	600^{c}	387^{d}
P (value)	0.0001	0.0001	0.0006	0.0001	0.0001
RMSE	1.034	2.472	0.006	2.472	1.578
Coeff Var	4.4	4.3	15.6	3.7	3.8

MS: Maize stover; ML: Maize leaves; WS: Wheat straw; EC: Erograstis curvula; ECC: Erograstis curvula at bloom stage; KK: Kikuyu; VGHD: Veld grass hay from Dundee; VGHC: Veld grass hay Camperdown; VGHP: Veld grass hay below sheep pens; VGHA: Veld grass hay from the Airport; VGHU: Veld grass hay from Ukulinga research farm
a: Soluble fraction
b: Insoluble but potential degradable fraction
c: Degradation rate
PD: Potential degradability
ED: Effective degradability
^{a,b}Means in the same columns with different superscripts are significantly different ($P < 0.05$).
RMSE: Root mean square error
Coeff Var: Coefficient of variation

The solubility or instantly degradable fractions (*a*-fraction) were similar for all roughages in all rumen environments. Consequently, the *a*-fraction is completely utilized in any rumen environment irrespective of roughage quality. Dry matter solubility (*a* fraction), insoluble but slowly degradable fraction (b fraction), the rate of degradation (c), the potential and effective degradability differed ($P<0.0001$) among roughages. For DM solubility, MS had the highest followed in order by VGHA and ML, then by EC, KK, VGHD, VGHC, ECC, VGHP and WS. These values on solubility are wide apart from those reported by Tesfayohannes (2003) for WS (184 g/kgDM), Kikuyu (218) and MS (227 g/kgDM) in the study that was also conducted at the University of Natal's Ukulinga Research Farm outside Pietermaritzburg. The quality of the feed which is affected by season and stage of harvest could be possible reason to support these outcomes (Van *et al*., 2002). Hence, feed quality may limit microbial activity preventing roughages from being degraded according to their potential (Fonseca *et al*., 1998). In the first rumen environments presented in (Table 3.3), dry matter (*a* fraction) for maize stover was the highest as compared to other feed; possibly because OM and CP were readily soluble in the rumen (Chumpawadee *et al*., 2006).

The slowly but potentially degradable fraction (*b* fraction) for all feeds ranged between 173-518 g/kg and the corresponding potential degradability ranged from 249-639 g/kg. Maize Stover had the lowest b-fraction but with the highest PD that compared to maize leaves. However, the potential degradability of MS was higher than reported by Fon (2011). Fonseca *et al*. (1998) reported high potential degradability of wheat straw than it is reflected in the results of this study. This may be caused by the quality of roughages varies greatly because of maturity at harvest, soil and climate changes which are influenced by either tropical or temperate regions (Antongiovanni & Sargentini., 1991; Abdou., 2010).

The potentially degradable fraction (*b* fraction) for all feeds ranged from 521 to 869 g/kg. The potential degradability ($a+b$) of dry matter differed significantly among feeds ($P<0.0161$). Unlike the results found by Manyuchi *et al*. (1997) when groundnut hay (GN) and napier hay

(Nap) at various incremental levels, the potential degradabilities of grass hays in this study were very high at 15% of lucerne inclusion in the rumen environment. Navaratne & Ibrahim (1988) found similar results in the potential degradability of kikuyu (KK) when 5% of concentrate was supplemented. This implies that the inclusion of 15% lucerne in the diet may impose the same effect to the degradability of roughage in the rumen like the concentrate. In addition, the *b* fraction and the corresponding potential degradabilities of native grasses in the study by Thu & Uden (2001) when supplemented with 700g of urea molasses cake are similar with the results of grasses hays found from this study because molasses in high in energy than nitrogen. This reveals that high level molasses would impose the same effect in the rumen as low level of nitrogen supplement (lucerne) supplemented would.

Degradation rate (*c*) of dry matter varies among roughages (P<0.0001). According to the results found in this study feeds may be placed in three groups based on the rate of degradation: The fastest (MS & ML), intermediate (WS, EC & KK) and the slowest (ECC, VGHA, VGHC, VGHD & VGHP).This pattern of degradation rate may be due to NDF and content presented in Table 3.2 that feeds with high fibre content are slowly degradable vice versa for low fibrous feeds. Hence, the degradability of feed decreases as NDF increases (Defoor *et al*., 2002; Galyean & Defoor, 2003). Maize stover degradation rate in this study slightly increased to 0.039 (g/kgDMh) on the use of 15% lucerne compared to 0.03 (g/kgDMh) obtained on the use of 30% of groundnut hay (GN) and cowpea hay (CW) in the rumen environment (Chakerendza *et al*., 2002). The degradation rate of veld grasses from this study corroborates with the results found by Manyuchi *et al*. (1997) because the digestibility of roughages across these species (cattle and sheep) is the same (Schlecht *et al*., 2007). In addition, the type of roughage and stage at which forage is harvested affect degradability through the degree of lignification (Ibrahim *et al*., 1995;

Van *et al*., 2002), also the condition of the rumen environment in relation to N content also impacts the degradation rate. Ultimately, results from the study by Nsahlai & Umanna (1996) particularly on MS revealed that N supplement increase the degradability of *b* fraction at an increasing degradation rate while concentrate increases the degradability of *b* fraction at a decreasing degradation rate.

The potentially degradable fraction (*b* fraction) for all feeds ranged from 428 to 727 g/kg and the corresponding potential degradation ($a + b$) of dry matter differed among feeds ($P<0.0001$). The effect of 30% lucerne inclusion level in the diet showed two groups of roughages in the rumen environment; crop residues and grass hays with each group having approximately same potential degradability values. Similar results were found by Chakerendza *et al*. (2002) on MS where 30% of GN, CW and CSM were supplemented without much change in the degradation kinetics of MS. These results may be further explained by the fact that increased degradable protein in the diet may be desired for microbial synthesis to improve forage degradability on special (high) producing condition of the animal (Hristov *et al*., 2004). Therefore, degradability is predominantly influenced by the type of forage, the protein supplemented and their interaction in the rumen (Masama *et al*., 1995; Promkot *et al*., 2007; Ruiz *et al*., 2009). Increased PD and ED indicated that rumen fermentation was improved by supplementation.

Degradation rate (*c*) of dry matter differed ($P<0.0006$) among roughages. The *c* values of feeds in this study are approximately the same according to their categories such as crop residues (ML & MT) and grass hays (ECC, VGHA, VGHC, VGHD, VGHP & KK) except WS and EC which had unique *c* values. This may be due to incremental levels of forage legume (30% lucerne) that has high CP contents, high digestibility and desirable fibre levels, with excellent degradation standards and ruminal characteristics, such as pH and ammonia concentration, favouring the quality of ruminal environment (Fernandes *et al*., 2013). This suggests that forages of the same group would be utilized approximately equally in the rumen as demonstrated in Table 3.3. This agrees with the supported opinion by Venkateswarlu *et al*. (2013) that upon supplementation good quality roughages can make up 75% or more of a ruminant diet, while low quality roughages might make up only 50% of diet. However, the degradation rate of maize stover supplemented with 30% lucerne from this study was far greater than the results found by Chakerendza *et al*. (2002) when the same level (30%) of nitrogen supplements (GN, CW, CSM) were used. Compared to the results of Chakeredza *et al*. (2002) & Hindrichsen *et al*. (2004), lucerne is a powerful N supplement to improve the degradability of poor quality roughages than other N supplements.

3.3.3 pH levels & NH_3-N concentration

Table 3. 4 Effects of levels of lucerne supplement on rumen ammonia concentrations and rumen pH in Jersey cows

Parameters	N Supplement (%)			Root MSE	P value
Level	0	30	50		
NH_3 mgl^{-1}	24.81	89.60	122.50	31.925	<0.0001
pH	7.3	6.6	7.2	0.531	0.0087

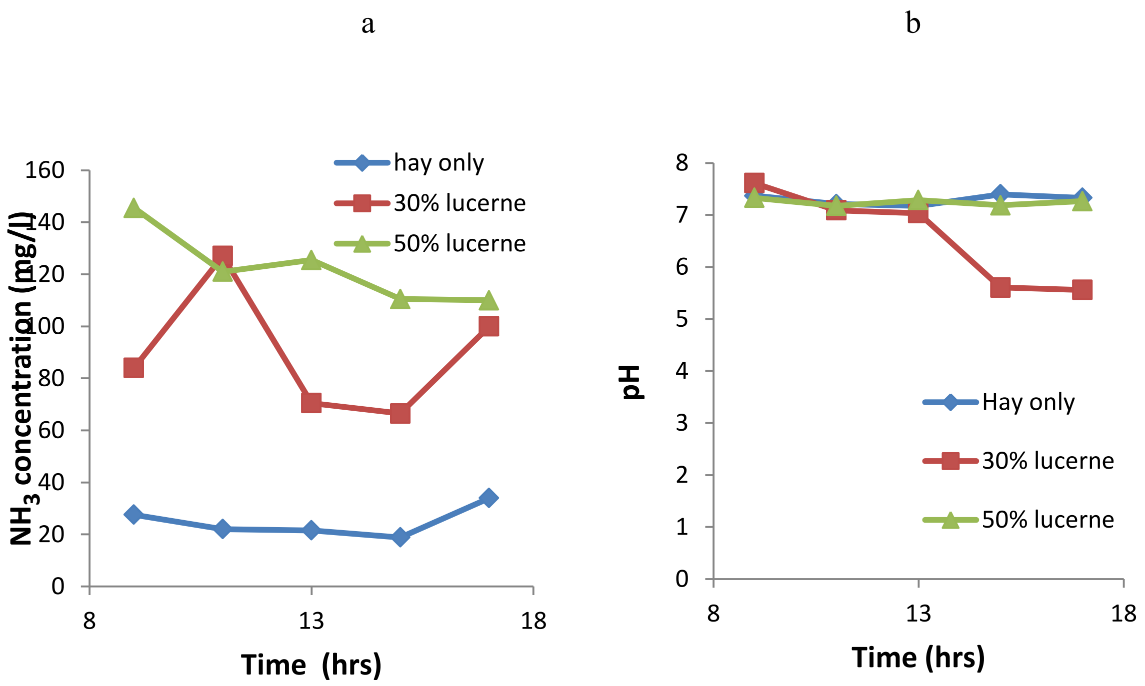

Figure 3.2 Effect of levels of lucerne supplement on (a) ammonia concentration and (b) rumen pH in of jersey cows.

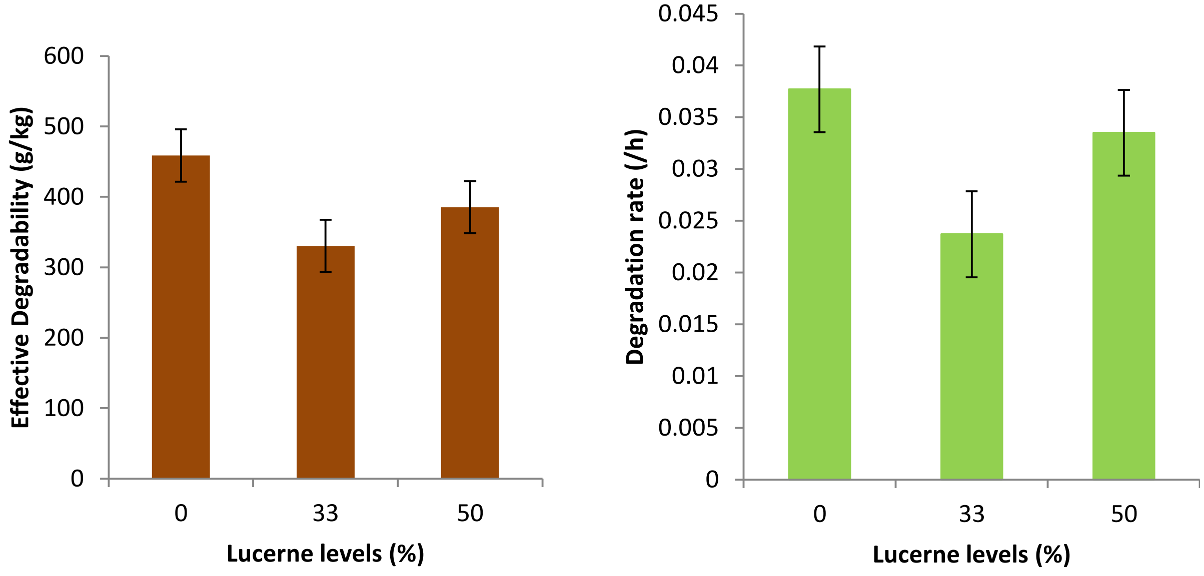

Figure 3.2 Significance of effective degradability and degradation rate from different rumen environments

3.3.4 Rumen ecology

The effect of lucerne in rumen environments is presented in Figure 3.1 and the least square means are given in Table 3.4. Ammonia concentrations (P<0.0001) increased with the increase in level of lucerne supplement. The pH in the rumen environments was almost neutral. It is possible that the diet fed to animals triggered a lot of saliva secretions through mastication and the rumen environments were buffered (Mohamed & Chaudhry, 2008). There is a significant difference between degradation rate and effective degradability from non-supplemented rumen and the rumen supplemented with low (33%) levels of lucerne (Figure 3.2). However, comparing between a non-supplemented rumen and rumen supplemented with high (50%) levels of lucerne the difference was not significant. Hence, the degradation of roughages would be effective in specific rumen environment with suitable supply of nitrogen and good pH level (McAllister, *et al*., 1994). In all rumen environments there was an order in degradation parameters among roughages; meaning that a sustained favourable rumen environment drives roughages to be degraded according to their quality. However, retention time is an important factor for each feed to be effectively degraded (Weyenberg *et al*., 2006; Schlecht *et al*., 2007).

3.5 Conclusion

Significant variations of *in sacco* degradability parameters were reported among roughages incubated in different rumen environments (First rumen environment: Veld grass hay only; Second rumen environment: Veld grass hay and 1.5kg/d Lucerne & Third rumen environment: Veld grass hay and 3kg/d Lucerne). These variations are more related to the chemical composition of roughages and the suitability of the rumen ecology (pH & ammonia concentrations). This study suggests that nitrogen supply in the basal feed is a factor that favours the utilization of low quality roughages. Therefore, these results may be linked with other studies and be used to find a relationship between degradation rates of low quality roughages.

CHAPTER 4

MODELING DEGRADATION RATE OF DIFFERENT ROUGHAGES USING PROPERTIES OF DIET AND INCUBATED FEEDS

ABSTRACT

The aims of this study were (a) to establish a regression model for degradation rate and (b) to simulate intake and total dry matter digestibility of non-supplemented low quality roughages. Data from fourty suitable studies was used for developing regression models. Data from four suitable studies that reported all requisite data needed to predict intake and total digestibility were used for validation purpose. These studies had degradability measurements obtained from studies using cattle, sheep, goats and wild ruminant animals (Buffalo). Regression relationships were established between degradation parameters with various feed and dietary properties under non-supplemented and supplemented rumen environments. The outcome produced six regression models and strong correlations ($P<0.0001$) between degradation parameters, diet properties and feed properties. The rate of degradation (kdo) of roughages in non-supplemented rumen had a meaningful root mean square error (RMSE) = 0.00803 and coefficient determination (R^2) value ranging from 60% to 96%. The predicted kdo was then used in the model produced in the laboratory to simulate intake and digestibility. Results showed small chances of predicting intake pertaining relationships in all observations with values of coefficient of determination (R^2) ranging from 10% to 24%, suggesting that some unknown variables may be affecting predicted intake. The best R^2 for the digestibility relationship were 82% and 44% for two studies out of four meaning that there are possible chances that digestibility can be predicted by degradation rate. It was concluded that a good relationship between degradation parameters, diet properties and incubated feed properties enables modelling degradation rate. More work is required to predict intake together with digestibility.

Keywords: Intake, digestibility, chemical composition, model, degradation kinetics

4.1 Introduction

Continuous improvement in animal performance is the interest of any livestock producers but knowledge about efficient utilization of feeds is the key because feed is the single most costly input into livestock production enterprise (Nsahlai & Apaloo, 2007). However, degradation of forages in the rumen is crucial in terms of dietary nutrients available to meet the nutrient requirements of anaerobic microbes and body tissues of ruminants (Mohamed & Chaudhry, 2008). The ability of a ruminant to meet its metabolic and production requirements depend on soluble fraction, insoluble but potential degradable fraction and degradation rate of given roughage ingested (Shem *et al*., 1995). Low quality roughages are low in crude proteins and soluble carbohydrates. Fewer studies have been done on degradation kinetics of low quality roughages thus less available information for livestock feed production industry (Campos *et al*., 2004).

Models have been used to predict intake and degradation of forages but they still need data from either the *in sacco* method or the rumen fluid-based *in vitro* methods for comparison and validation (Mohamed & Chaudhry, 2008). Continuous use of models may provide technical ways of using different quality roughages as feed for ruminants because models would allow integration of knowledge about supplementation, rumen fill and type of forage. The complexity of interaction amongst supplement, ruminal fill and forage type governs voluntary feed intake thus simple regression relationships have been inadequate to predict forage intake (Hyer *et al*., 1991). Attempts have been made to predict intake of roughage diets in ruminants using deterministic regression models. But, sound clarifications for the effects of roughage on feed intake are not fully understood since these models do not take advantage of both the animal and plant factors that affect intake (Galyean & Detour, 2003; Defoor *et al*., 2002). These regression models are state-specific and have only been valid under similar circumstances for which they have been developed (Nsahlai & Apaloo, 2007). Hence, simulation modeling should be widely excesized as a strategy for pursuing the goal of predicting intake of roughage diets for ruminant species. The aim of this study was to establish a regression model for degradation rate of roughages in non-supplemented diets; and to validate this model by simulating intake and digestibility as suggested by Nsahlai & Apaloo (2007).

4.2 Materials and methods

4.2.1 Modeling degradation rate

Empirical data from fourty suitable studies (i.e. studies that reported all requisite data needed to create a model) in which different quality roughages were fed to ruminants was used to relate diet quality, processing and the quality of the tested feeds on their degradation rate obtained in the nylon bag studies. Details of these data are presented in appendix 2. The crude protein (CP) (6.25*N) and neutral detergent fibre (NDF) of diets were calculated based on information given in each paper. The potential degradability (PD), effective degradability (ED) and hemicellulose were calculated for the papers that did not give them to complete the table. All values in percentages (%) were converted to grams per kilogram (g/kgDM). All missing data were sourced amongst collected set of studies or calculated when the necessary information was available. For example, Umunna *et al*. (1995); Bengaly (1996); Nsahlai & Umanna (1996a) and Abdou (2010) were used to source undetermined data values on common variables for the following literature Shem *et al*. (1995); Orden *et al*. (2000) and Ngele *et al*. (2009) lacking dietary information. Chemical information of feeds for sourced data was partitioned into dry matter (DM), CP, Ash, NDF, acid detergent fibre (ADF) and hemicellulose (Van Soest *et al*., 1991) and non-fibre, CP free fraction. Studies that qualified for evaluation had 419 degradability measurements obtained using cattle, sheep, goats and wild ruminant animals (Buffalo). In these studies animals were offered feed *ad libitum* with a quantified amount of supplement in specific studies (Table 4.1).

The supplementary information, ingredient composition for each study and diet chemical composition (CP, NDF & NF-NDS (Nitrogen free- neutral detergent soluble)) were quantified. All the key components of data such as DM solubility (*a*), slowly degradable fraction (*b*), rate of degradation (*c*), potential degradability (PD), effective degradability (ED), neutral detergent fibre (NDF) and crude protein of the diet together with the incubated feeds were checked to identify and correct errous entries. Analysis of variance was carried out according to the Statistical Analysis System (SAS, 2013) using the Reg procedure to determine the relationship between degradation parameters from non-supplemented and supplemented rumen environments. Hence, regression models and correlation matrix were obtained.

Table 4. 1 Feeding programme during *in sacco* feed evaluation experiments used in this study

Source	Animal	Type (S)	kg DM/day	Urea treament	Screen size
Empirical	Cattle	None	-	0	2
		L	1.5	0	2
		L	2	0	2
		L	3	0	2
Tesfayohannes , 2003	Cattle	Conc	-	1	2
		Conc	-	0	2
		None	-	1	2
		Conc	-	0	2
Nsahlai & Umanna, 1996	Sheep	Conc	0.2	0	2
Khazaal *et al*., 1995	Sheep	None	-	0	2.5
Shem *et al*., 1995	Cattle	CSC	1	0	3.1
Fonseca *et al*., 1998	Sheep	SBM	-	0	4
Chakeredza *et al*., 2002	Sheep	None	-	0	3
Abule *et al*., 1995	Cattle	CSC	2.45	0	2
Nsahlai *et al*., 1998b	Sheep	FLs	0.175	0	2
Hindrichsen *et al*., 2004	Sheep	MPTs	0.2	0	2
Nsahlai *et al*., 1999	Cattle	RSM	-	0	3
Abdou, 2010	Sheep	L	2	0	2
Navaratne & Ibrahim, 1988	Buffalo	Conc	0.5	0	1.5

Alcaide *et al*., 2000	Sheep/Goats	Suppl	-	0	2
Ibrahim *et al*., 1995	cattle	None	-	0	5
Bonsi & Osuji, 1997	Sheep	Suppl	-	0	2
Ngwa *et al*., 2001	Sheep	Suppl	-	0	2
Umunna et al., 1995	Sheep	Suppl	-	0	2
Bonsi *et al*., 1994	Sheep	Suppl	-	0	2
Kamalak *et al*., 2005	Sheep	Suppl	-	0	3
Khazaal *et al*., 1993	Sheep	None	-	0	2.5
Silva *et al*., 2008	Cattle	None	-	0	3.1
Bengaly, 1996	Sheep	La	2.05	0	3.1
Tang *et al*., 2011	Goats	Conc	3	0	3.1
Tolera & Sundstøl, 2001	Sheep	Conc	1	0	2
Ngele *et al*., 2009	Cattle	GnH	4.5	1	2
Chumpawadee *et al*., 2006	Cattle	Conc	-	0	1
Ikhimioya *et al*., 2005	Sheep	None	-	0	2.5
Jalilvand *et al*., 2008	Sheep	Conc	-	0	1
Chumpawadee *et al*., 2005	Cattle	Conc	-	0	1
Orden *et al*., 2000	Sheep	RB	-	1	2
Tahseen *et al*., 2014	Sheep	Conc	-	0	2
Nouala *et al*., 2004	Cattle	Conc	1.5	0	3
Verbic *et al*., 1995	Sheep	None	-	0	5
Karsli & Russell, 2002	Sheep	Suppl	-	0	3.1
Kabatange & Shayo, 1991	Cattle	None	-	0	3.1
Kariuki *et al*., 2001	Cattle	De	-	0	3
Chaudhry, 2000	Sheep	None	-	0	4
Bogoro *et al*., 2006	Cattle	None	-	0	3.1
Bamikole & Babayemi, 2008	Cattle	None	-	0	2.5
Lanyasunya *et al*., 2006	Goat	L	-	0	2.5

L: Lucerne; CSC: cottonseed cake; La: lablab; RSM: rapeseed meal; MPTs: multipurpose trees; FLs: forage legumes; 1: urea treated; 0: urea untreated; None: not defined; Conc: concentrate; GnH: groundnut haulms; RB: rice bran; Suppl: supplements

4.2.2 Predicting intake and digestibility

Data from four suitable studies that reported all requisite data (type of animal, type of supplement & feeding levels) needed to predict intake and total digestibility using results from the above predicted degradation rate was used. All observations were used. Roughages and forage legumes were by Umunna *et al.* (1995). Small ruminants (twelve sheep & twenty five goats) were housed in individual pens during the intake phase but they were transferred to metabolism crates during the digestibility phase of the study. However, cattle were housed in tie-stalls during the entire duration of the study and faeces were immediately removed from concrete floors and placed in collection buckets until weighed. Details are given for each of these studies (Table 4.2 & 4.3). The intake and digestibility values were predicted based on the new rumen load and the above predicted degradation rate. Values of the observed and predicted intake were regressed using regression procedure in SAS (2013).

Table 4. 2 Feeding programme during intake and digestibility experiments used in each study

	Feeding level and supplement (S) used during the intake and digestibility studies		
Reference	Animal	Feeding level	Type (S)
Nsahlai & Umunna, 1996	Sheep	*Ad libitum*	None
Kibon & Ørskov, 1993	Goats	*Ad libitum*	None
Nsahlai *et al.*, 1996	Cattle	*Ad libitum*	None
Umunna *et al.*, 1995	Cattle	*Ad libitum*	None

Table 4. 3 Characteristics of the animals and feeds used in digestibility and intake studies.

		Animal attributes		Feed attributes		
Reference	Feed type	Type	Wt range (kg)	k_{dig} (/h)	CP (g/kg)	Ash (g/kg)
Nsahlai & Umunna, 1996	Chickpea straw	Sheep	25.6	0.051	87.5	85
	Cowpea hay (regrowth)	Sheep	25.6	0.066	218.8	150
	Cowpea hay (first cut)	Sheep	25.6	0.037	162.5	330
	Desmodiun intortum (hay)	Sheep	25.6	0.010	212.5	116
	Haricot bean straw	Sheep	25.6	0.048	62.5	94
	Lablab hay (first cut)	Sheep	25.6	0.057	137.5	87
	Lablab hay	Sheep	25.6	0.064	193.8	131
	Leucaena leucocephala	Sheep	25.6	0.017	250.0	95
	Barley straw	Sheep	25.6	0.014	37.5	103
	Cynodon hay	Sheep	25.6	0.019	62.5	127

	Debre Zeit native hay	Sheep	25.6	0.016	50.0	98
	Maize cowpea intercropped roughage	Sheep	25.6	0.039	118.8	106
	Maize lablab intercropped roughage	Sheep	25.6	0.026	75.0	86
	Maize stover	Sheep	25.6	0.010	37.5	108
	Oat hay	Sheep	25.6	0.029	50.0	94
	Oat straw	Sheep	25.6	0.024	31.3	78
	Oat/vetch intercropped roughage	Sheep	25.6	0.029	68.8	89
	Sorghum stover	Sheep	25.6	0.012	56.3	126
	Sululta native hay	Sheep	25.6	0.024	50.0	79
	Teff straw	Sheep	25.6	0.008	50.0	102
	Wheat straw	Sheep	25.6	0.045	31.3	105
	Wheat/trifolium intercropped roughage	Sheep	25.6	0.026	68.8	152
Kibon & Ørskov, 1993	*Acacia albida*	Goats	19.08	0.022	188.8	136
	Tamarindus indica	Goats	19.36	0.047	152.5	136
	Etanda africana	Goats	18.744	0.009	91.3	136
	Anogeissus leiocarpus	Goats	18.352	0.011	130.6	136
	Sterculia setigera	Goats	19.472	0.077	130.0	136
Nsahlai *et al.*, 1996	Barley straw	Calf	56-153	0.019	38.1	90
	Debre Zeit native hay	Calf	75-144	0.019	65.6	90
	Debre Zeit native hay	Oxen	217-330	0.019	65.6	90
	Napier grass 2	Calf	55-142	0.021	43.1	90
	Napier grass 2	Oxen	236-341	0.021	43.1	90
	Oat hay	Calf	67-141	0.017	36.9	90
	Oat hay	Oxen	237-373	0.017	36.9	90
	Pea straw	Calf	46-145	0.029	56.3	90
	Sorghum straw (bird resistant)	Calf	70-133	0.013	48.8	123
	Sorghum straw (bird resistant)	Oxen	213-336	0.013	48.8	123
	Sorghum straw (non-bird resistant)	Calf	64-137	0.015	50.0	118
	Sorghum straw (non-bird resistant)	Oxen	216-305	0.015	50.0	118
	Sululta native hay	Calf	68-144	0.024	63.8	108
	Sululta native hay	Oxen	205-320	0.024	63.8	108
	Teff straw	Oxen	214-283	0.014	33.8	96
Umunna *et al.*, 1995	Oat/vetch intercropped roughage	Calf	135-195	0.022	64.0	96
	Oat/vetch intercropped roughage	Oxen	208-249	0.022	64.0	99

Oat/vetch intercropped roughage 2	Calf	105-196	0.024	64.0	99
Oat/vetch intercropped roughage 2	Oxen	206-226	0.024	64.0	99
Teff straw	Calf	94-200	0.021	41.0	99
Teff straw	Oxen	204-227	0.021	41.0	86

Wt: Weight; k_{dig}: Rate of digestion; CP: Crude protein content of the diet

4.3 Results & Discussion

Table 4. 4 Correlations and level of significance (*P*-value) between degradation parameters, diet properties and incubated feed properties

	dmlo	bo	kdo	pdo	edo	tlo
Diet properties						
Diet-CP	-0.06304	0.21989	-0.12999	0.12873	-0.00787	-0.03490
	0.4831	0.0134	0.1469	0.1508	0.9303	0.7137
Diet-NDF	-0.35590	-0.37884	0.04850	-0.51733	-0.42233	0.61063
	<0.0001	<0.0001	0.5897	<0.0001	<0.0001	<0.0001
CPF_FF	0.38629	0.36410	-0.02991	0.52534	0.44741	-0.64642
	<.0001	<0.0001	0.7396	<0.0001	<0.0001	<0.0001
Con	0.49530	0.44817	0.07805	0.65926	0.62151	-0.59026
	<0.0001	<0.0001	0.3850	<0.0001	<0.0001	<0.0001
For	-0.49530	-0.44817	-0.07805	-0.65926	-0.62151	0.59026
	<0.0001	<0.0001	0.3850	<0.0001	<0.0001	<0.0001
Feed properties						
NDF	-0.69136	-0.02480	-0.49743	-0.45890	-0.61386	0.61948
	<0.0001	0.7828	<0.0001	<0.0001	<0.0001	<0.0001
CP	0.60489	0.04427	0.67531	0.41884	0.65255	-0.27204
	<0.0001	0.6226	<0.0001	<0.0001	<0.0001	0.0036
Ut	0.29709	0.30356	0.01006	0.42213	0.38283	-0.35628
	0.0007	0.0005	0.9110	<0.0001	<0.0001	0.0001
Ash	0.26761	-0.07928	0.36269	0.10929	0.22637	-0.17556
	0.0024	0.3776	<0.0001	0.2231	0.0108	0.0629

dml: soluble fraction; b: insoluble but potential degradable fraction; kd: Degradation rate; pd: Potential degradability; ed: Effective degradability; tl: lag time; NDF: Neutral detergent fibre; CP: Crude Protein; Ut: Urea treatment; Diet-NDF: Diet Neutral detergent fibre; Diet-CP: Diet Crude Protein; For: Forage legume; Con: Concentrate; CPF_FF: Crude protein free & fibre free; o: non-supplemented rumen environment;

Results of the correlation analysis between degradation parameters, diet properties and incubated feed properties are presented in Table 4.4. Degradation parameters of non-supplemented roughage were very strongly (*P*<0.0001) related to corresponding parameters in supplemented environments (dml vs dmlo, r = 0.97; b vs bo, r = 0.74; kd vs kdo, r = 0.78; pd vs pdo, r = 0.85; ed vs edo, r = 0.94; tl vs tlo, r = 0.91). These results revealed that there is inter-relation between supplemented and non-supplemented rumen environments such that degradation parameters or roughages can be modeling with reasonable accuracy. Moreover, the study by Kaitho *et al.* (1997) yielded results with minimum values of coefficients of determination similar to this study, subsequently, positive opinions were made. Whereas, Nsahlai *et al.* (1995) believed that high R^2 values (0.75-0.92) shows high capacity to estimated degradabilities. This implies that the behavior of roughage utilization (intake and digestibility) can be predicted.

There was a strong correlation ($P<0.0001$) between degradation parameters from non-supplemented rumen environments and degradation parameters in supplemented rumen environments. Correlations between kdo and diet properties were not significant ($P>0.05$). But dmlo, bo, pdo and edo had mostly good correlations ($P<0.0001$) with diet properties. Logically, diet properties refer to effect of nitrogen or energy supplement and basal feed which causes fluctuation in rumen pH and ammonia. Supplements have been used in many studies to create different rumen environments to study *in sacco* degradability of low quality roughages to come up with new strategies to improve utilization by ruminants. Hence, there would be a positive correlation between supplementation and the degradability of low quality roughages as found by others (Tolera & Sundstøl, 2001; Kariuki *et al.*, 2001). However, the level of contribution of supplements upon the degradation of low quality roughages has never been equal (Ngwa *at al.*, 2001; Vinil & Balakrishnan, 2008).

The relationship between NDF and bo together with tlo was not significant ($P>0.05$). All other degradation properties (dmlo, kdo, pdo, edo) sustained strong correlation ($P<0.0001$) with all feed properties. These findings agrees with the results of Tolera & Sundstøl (2001) and Tang *et al.* (2011) where new genotype maize varieties had higher nutritive value than conventional varieties based on *in sacco* degradation parameters. Values of correlation coefficient for all that were significant contained few negative (Diet-NDF vs dmlo, bo, pdo, edo, r = -0.36, -0.38, -0.52,-0.42; NF_FF vs tlo, r = -0.65; Con vs tlo, r = -0.59; For vs dmlo, bo, pdo, edo, r = -0.50, -0.45, -0.66, -0.62; NDF vs dmlo, bo, kdo, pdo, edo, r = -0.69, -0.02, -0.50, -0.46, -0.6; CP vs tlo, r = -0.27; Ut vs tlo, r = -0.36) meaning that degradability parameters are inversely related to diet properties (rumen environment) than feed properties but more positive (Diet-CP vs bo, r = 0.22; Diet-NDF vs tlo, r = 0.61; NF_FF vs dmlo, bo, pdo, edo, r = 0.39, 0.36, 0.53, 0.45; Con vs dmlo, bo, pdo, edo, r = 0.50, 0.45, 0.66, 0.62; For vs tlo, r = 0.59; NDF vs tlo, r = 0.62; CP vs dmlo, kdo, pdo, edo, r = 0.60, 0.68, 0.42, 0.65; Ut vs dmlo, bo, pdo, edo, r = 0.30, 0.30, 0.42, 0.38; Ash vs dmlo, kdo, edo, r = 0.27, 0.36, 0.23) correlations. The correlation obtained from this study reveals the possibility of modelling the degradation of low quality roughages in different rumen environment.

Table 4. 5 Degradation relationships of low quality roughages in non-supplemented rumen environments from degradation parameters in supplemented rumen environments

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
Dependent variable	kdo	tlo	edo	pdo	bo	dmlo
Supplemented corresponding parameter estimates	0.473 (0.0616)	0.62 (0.617)	0.888 (0.0405)	0.646 (0.0739)	0.6604 (0.0737)	0.980 (0.0215)
Diet-NDF	-	-	-	-	-0.177 (0.0592)	-
CPF_FE	-	-	-	0.266 (0.0614)	-	-
G-supp	-	-	0.671 (0.1780)	-	-	-
For-supp	-	1.269 (0.2590)	-	-	-	-
CP	0.000074 (0.000017)	0.0055 (0.0022)	-	-	-	-
Ut	-0.0053 (0.0019)	-	-35.207 (10.616)	-	-	-

Ash	-0.000061	-	-0.694	-	-0.652	-
	(0.000033)		(0.1749)		(0.3141)	
ADF	-	0.0099	-0.177	-0.396	-0.310	-
		(0.0019)	(0.0553)	(0.0944)	(0.0906)	
Hem	-	-	-	-	-	-0.024
						(0.0281)
Intercept	0.018	-4.311	189.373	340.958	469.0254	9.8578
	(0.0024)	(0.9731)	(45.235)	(93.608)	(77.729)	(8.6581)
RMSE	0.0080	1.1615	41.2937	75.8676	78.1665	24.5927
R- Square	0.6911	0.9059	0.9304	0.7939	0.6198	0.9535
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

dml: soluble fraction; b: insoluble but potential degradable fraction; kd: Degradation rate; pd: Potential degradability; ed: Effective degradability; tl: lag time; CP: Crude Protein; Ut: Urea treatment; Diet-NDF: Diet Neutral detergent fibre; For: Forage legume supplement; CPF_FF: Crude protein free & fibre free; G-supp: Grain supplement; ADF: Acid detergent fibre; o: non-supplemented rumen environment;

Models in Table 4.5 are not as expected since there were good relationships from results in Table 4.4. Dietary properties did not ($P>0.05$) affect edo, pdo and bo models (Table 4.5). Only kdo and dmlo models indicated preferences to predict intake and digestibility because they showed significant ($P<0.05$) outcomes. Modelling degradation parameters revealed that feed properties and supplementation are more related to the degradability of the feed than diet properties (Table 4.5). Appropriate equations that can be used to predict degradation properties of non-supplemented roughages are presented in Table 4.5. The amount of variation (R^2 Value) contributed by various variables in these equations ranged from 60% to 96%.

The kd and CP from the model are directly proportional to the kdo. These results are in agreement with studies where increasing levels of nitrogen (N) supplementation improved microbial degradation and rumen fermentation resulting to improved estimated dry matter degradability (DMD) (Nsahlai *et al*., 1998b; Tolera & Sundstøl, 2001; Kariuki *et al*., 2001). Furthermore, supplements such as forage legumes provide concentrations of rumen metabolites (NH_3,-N, VFA, minerals) that improve degradation in the rumen (Bonsi *et al*., 1995). Generous access to other supplements reduces ruminal pH leading to depressed rumen degradation rate of the fibre constituents (Nsahlai *et al*., 1998b). In contrast, other forage legumes (*Lablab*, *Sesbania sesban* & *Tagasaste*) have a tendency to increase rumen particulate outflow rate instead of DMD depending on the level of supplementation (Umunna *et al*., 1995). So the selection of an appropriate supplement and the level of supplementation would results to cost effective input of feeding.

The Ut and Ash from the model are inversely proportional to the kdo. The Ut has been found to enhance the soluble fraction (a) of ruminants feeds significantly (Tesfayohannes e*t al*., 2013), while insoluble but potential degradable fraction (b) and potential degradability (PD) increased but not significantly in the urea treated sugarcane bagasse (Ahmed *et al*., 2013). However, it has been pointed out that treating of roughages with less than 6% (urea) does not affect the degradation rate (Hameed *et al*., 2012). Some studies have shown that rice straw may contain biogenic silica which would decrease the availability of cellulose for rumen microbial degradation (Shen e*t al*., 1998). The negative relationship of urea treatment with degradation rate suggest that urea treatment would not increase the soluble fraction only, but would have little or no effect on rate of degradation of the potentially degradable insoluble fraction.

Likewise, the ash content of the feed (in the model) had a negative effect as Ut. Ash refers to all inorganic components of the feed such as minerals. Minerals in ruminants are supplemented as salt licks or as molasses (which is concentrated plant juice rich in minerals) (Leng, 1990). Minerals are classified in the manner of their requirement in animal nutrition namely; macro and micro minerals. Macro minerals include calcium, magnesium, phosphorus, potassium, sodium, chlorine, and sulfur. Micro minerals include chromium, cobalt, copper, iodine, iron, manganese, molybdenum, nickel, selenium, and zinc. Mineral availability to goats and sheep differ because goats graze and browse while sheep graze; eventually soil, plant type and season influence the mineral availability (Haenlein & Ramirez, 2007). Ruminant mineral requirement is met when microbes are fulfilled with their mineral requirements (Leng, 1990). Urea-mineral lick block was used as a supplement and did not greatly influence rumen degradation of either dry matter or crude protein in treated roughages but improves fibre digestion and effective in increasing nutrient digestibility of untreated low quality roughages (Yue-ming *et al*., 2005). However, minerals are necessary at required proportions to ruminant rations thus overfeeding or underfeeding may lead to nutritional and reproductive disorders (Bhanderi *et al*., 2011). This implies that ash does not have significant contribution in the model but it supports the nutrition of micro-organisms which greatly affect degradation.

Hemicellulose is the component of digestible cell contents of the feed. It is one of the reasons for the treatment of low quality roughages to break bonds with lignin that make it difficult to be utilized by rumen microbes (Tesfayohannes, 2003). Subsequently, this tendency would be due to the stage of maturity of the plant, plant part, harvesting regime, season, location and type of the roughage plant. The negative sign on the dmlo model tells that hemicellulose does greatly affect the digestible fraction of the feed though it is a structural carbohydrate (Fon, 2006).

Table 4. 6 The coefficient of determination (*R^2*) and residual standard deviations of relationships between observed and predicted intake and total digestibility

	Intake			Total digestibility		
Source	Observation study	Simulation study	Simulation RMSE	Observation study	Simulation study	Simulation RMSE
1	0.16410	0.13336	5.7556	0.34342	0.25849	0.1040
2	0.22553	0.11160	2.5415	0.85811	0.44129	0.0420
3	0.22458	0.19638	5.3958	0.00925	0.00017	0.0677
4	0.22654	0.21957	2.2458	0.88769	0.82903	0.0106

RMSE: root mean square error; 1= Nsahlai & Umunna, 1996a; 2= Kibon & Ørskov, 1993; 3= Nsahlai *et al*., 1996b; 4= Umunna *et al*., 1995

Results obtained in using degradation rate as tool to predict digestibility and intake are presented in Table 4.6. A comparison was made between the coefficients of determination (R^2) obtained from predicted and observed intake and digestibility values (Table 4.6). Similarly to Nsahlai & Apaloo (2007) R^2 values were generally higher in the observation studies than in the simulation study. The R^2 for the intake relationship were poor for all studies, having all ranging from 10% to 24%. The best R^2 for the digestibility relationship were 82% for the study by Umunna *et al.* (1995) and 44% for the study by Kibon & Ørskov (1993). This is related to the type of feeds in these studies (Table 4.6). Similarly, it has been demonstrated that supplementation of N-deficient roughage with forage legumes can result in an almost two-fold increase in the rate of degradation (Nsahlai *et al.*, 1998a).

In relation to results found in this study though they were slightly poor there is a link between degradation characteristics and intake (Khazaal *et al.*, 1995; Kibont & Ørskov, 1993). In addition, in the study by Shem *et al.* (1995) it was found that degradation rate improved prediction of intake. Likewise, results found by Shem *et al.* (1995) revealed that eliminating one feed type resulted in a shift from poor to very good correlations between dry matter intake (DMI) and dry matter digestibility (DMD). However, these results leave the gap to identify some unknown variables to be compromised for better intake and digestibility predictions.

The poor performance of the model in this wider range of roughage diets may be due to the following reasons. The retention time of digesta that differs, with cattle having a significantly longer retention of feed than small ruminants thus intake and total degradability would be affected (Hadjigeorgiou *et al.*, 2003; Alcaide *et al.*, 2000). This suggests that ruminant species are unique in digesting the same type of roughage fed to them; so, one type of roughage may be efficiently or poorly utilized by different ruminant species. Moreover, it was found that the efficiency of digestibility in relation to retention time between species is mostly revealed as the quality of available vegetation decreases (Alcaide *et al.*, 1997). Furthermore, the reason for these outcomes of the model may be that goats have been found to possess a great ability to select quality feed and chew efficiently with specific quantities of intake, digestibility and mean retention time (MRT) compared to the sheep (Van *et al* 2002; Hadjigeorgiou *et al*., 2003). There may not be a concrete conclusion on this study because Fonseca *et al*. (1998) found that digestible dry matter intake was best predicted by a multiple regression equation where degradation constants such as soluble fraction and rate of degradation accounted for 89% of the variation observed.

4.4 Conclusion

There were good relationships between degradation parameters, diet properties and incubated feed properties that predominantly confirmed the degradation rate model to be established. For example; the rate of degradation (kdo) of roughages in non-supplemented rumen had a meaningful root mean square error (RMSE) = 0.00803 and coefficient determination (R^2) value ranging from 60% to 96%. Apparently, the behaviour of degradation rate regression model was difficult to justify biologically. Intake was poorly predicted but 50% of digestibility was well predicted with degradation rate. Therefore, it is clear that some unknown variables may be affecting predicted intake meaning that caution is needed when analyzing degradation profile data from forages, forage-based and other low-quality feeds. In conclusion, the inclusion of a variables like retention time and other factors that significantly affects intake in addition to diet and incubated feed properties, may improve simulation of intake and total digestibility of non-supplemented low quality roughages.

CHAPTER 5

CONCLUSIONS & RECOMENDATIONS

5.1 Introduction

The key problem to the effective use of roughages in livestock production may be referred to seasonal changes that influence the availability of good quality. Eventually, as the nutritive value of roughage from pastures and crop residues depreciate in relation to harvest time, region and age there would be low intake and digestibility. Experiments were therefore designed to: (a) determine degradation properties of roughages in three different rumen environments (First rumen environment: Veld grass hay only; Second rumen environment: Veld grass hay and 1.5kg/d Lucerne & Third rumen environment: Veld grass hay and 3kg/d Lucerne), (b) inter-relate the degradation properties from three different rumen environments, and (c) determine the effect of re-calculated roughage properties on intake and digestion in ruminants. Results of this work have confirmed other reports that N supplement improved degradation rate, effective degradability and potential degradability of DM of roughages. Other results of this work gave good correlations between degradation parameters, feed properties and diet properties such that degradation rate may be used to predict feed intake and total digestibility of low quality roughages.

5.2 Conclusions

Selected roughages for this study showed a great variation in chemical composition and degradability. Ruminal disappeared characteristic of selected roughages differed among each other in all rumen environments. Result from this study indicated that manipulating rumen conditions (NH_3 and pH) through supplementation would improve efficiency of utilizing low quality roughages. Hence, low quality roughages should be primarily used to feed livestock to economise cost effective input of feeding in production. Supplementation is a main practical strategy to increase production potentials in livestock production systems through the improvement of intake and digestibility of diet.

Good correlations between diet properties, incubated feed properties and degradation parameters leads to the acceptance of the hypothesis that degradation properties of roughages from different rumen environments are related. Subsequently, degradation rate for non-supplemented rumen was successfully modelled from degradation properties in supplemented rumen.

The findings of predicting intake and digestibility using degradation rate did not entirely justify to accept the hypothesis that predicted intake is equal to the observed intake. However, regression models revealed that it is possible to use degradation parameters to predict feed intake and digestibility. More work should be done to identify the unexplained portion that should have affected predicted intake. Eventually, several statistical evaluations should be done on chemical properties and biological characteristics that would affect both intake and digestibility. The overall results of this work confirms the need to do more research in order to establish regression models capable of predicting intake and digestibility. Lastly, the outcomes of this thesis could serve as a platform for future research and adoption by researchers to fulfil the will of producers.

5.3 Recommendations

Ruminants play a significant role in the livelihood of rural people in developing countries and they are able to do well in most regions because of their ability to feed on diverse types of plant species, mainly browses and grasses. It is therefore necessary to, assess and estimate the intake and digestibility of ruminant feeds. To maximize profitability of livestock enterprises, it is recommended that other factors that affect intake and digestibility for example retention time and other related animal factors such as gut capacity should be considered for economic importance in livestock feeding programs. To estimate the intake and digestibility of low quality roughages, there should be a collaboration research between nutritionists and statisticians in order to put the knowledge and ideas together to come up with auspicious outputs. It is wise to apply more than one evaluation method when predicting intake of low quality roughages since a single method can show misleading results. It is recommended that information from *in vitro* and *in sacco* techniques should compared to identify accuracy when modeling degradation parameters and predicting intake together with digestibility. Further research should focus on ways to relate *in vitro* and *in sacco* degradation parameters to make accurate intake and digestibility predictions of low quality roughages.

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Appendix

Appendix 1: List of abbreviations

DM = Dry matter

DMI = Dry matter intake

DMD = Dry matter digestibility

OMD = Organic matter digestibility

PD = Potential degradability

ED = Effective degradability

NDF = Neutral detergent fibre

ADF = Acid detergent fibre

ADL = Acid detergent lignin

CF = Crude fibre

CP = Crude protein

N = Nitrogen

NPN = Non-protein nitrogen

HC = Hemicelluloses

CELL = Cellulose

MPTs = Multipurpose trees

HCN = Hydrocyanic acid

GIT = Gastro-intestinal tract

MS = Maize stover

ML = Maize leaves

MT = Maize stalks

WS = Wheat straw

KK = Kikuyu

EC = *Erograstis curvula*

VGH = Veld grass hay

SBM = Soybean meal

GN = Groundnut hay

CW = Cowpea hay

CSM = Cotton seed meal

LLM = Leucaena leaf meal

BS = Barley straw

ETH = *Erograstis curvula*

K11 = Coast cross hay

OH = Oat hay

OS = Oat straw

RG = Rye grass

VH = Veld hay

TS = Teff straw

SS = Sorghum stover

FS = Field pea straw

CH = Cynodon hay

DZH = DZ native hay

HbS = Horse bean straw

SnH = Sululta native hay

M_CP = Maize/cowpea

M_L = Maize/lablab

O_V = Oat/vetch

W_T = Wheat/trifolium

IRGHPB = Italian rye grass hay pre bloom

THEB = Triticale hay early bloom

THMB = Triticale hay mid bloom

THS = Triticale hay in seed

RYHEB = Rye grass hay early bloom

RYHMB = Rye grass hay mid bloom

RYHS = Rye grass hay in seed

OHEB = Oat hay early bloom

OHMB = Oat hay mid bloom

OHS = Oat hay in seed

GKMS = Green Kilima maize stover

UTMSM = Urea treated maize stover Malawi

UTMSK = Urea treated maize stover Kilima

MSM _30U = 30g/kg on Malawi maize stover

MSK_30U = 30g/kg on Kilima maize stover

DKMS = Dry Kilima maize stover

GMMS = Green Malawi maize stover

DMMS = Dry Malawi maize stover

MST = Maize stover tops

GG = Guatemala grass

SG = Setaria grass

NG = Napier grass

CWS = Canadian wonder straw

BBS = Belabela bean straw

RGH = Rhodes grass hay

RGG = Rhodes grass green

BL = Banana leaves

BP = Banana pseudostems

RS = Rice straw

MIS = Millet stover

GNH = Groundnut haulms

MB = millet bran

WB = Wheat bran

GG = Guinea grass

RB = Rice bran

AH = Alfalfa hay

SBP = Sugar beet pulp

OG = Oat grain

RU = Ruzi

SG = Signal

GLY = Glyricidia

LEU = Leucaena

ERY = Erythrina

JL = Jack leaves

CM = Coconut meal

SCH = Sweet clover hay

PCH = Persian clover hay

EG = Elephant grass

CS = Corn stover

EB = Early bloom

MB = Mid bloom

IS = In seed

PB = Pre bloom

MSHOMSP = Maize stover HOM Spring

MSSMSS = Maize stover SM Summer

URS = Untreated rice straw

UTRS = Urea- treated Rice Straw

PLTRS = Poultry Litter Treated Rice Straw

WH = Water hyacinth

KP = kraphanghom

CH = Cassava hay

SC = Sugar cane top

CN = Chinese spinach

CC = Cavalcade hay

FE = *Ficus exasperata*

SM = *Spondias monbin*

TG = *Tectonia grandis*

TC = *Terminalia catappa*

GnH = Groundnut husk

PP = Pineapple peels

PLP = Plantain peels

RO = Rice offal

RPO = Rice pollard

ARS = Ammoniate rice straw

BCS = Baby corn stover

BV = Beans Vines

PV = Peas Vines

STN = Stalks N

LN = Leaves N

LBC = Leaves BC

HN = Husk N

HBC = Husks BC

CN = Cobs N

CBC = Cobs BC

OBR = Oat/Berseem clover

NG = Napier grass

WSCaO = Wheat straw treated with Calcium oxide

WSNaOH = Wheat straw treated with sodium hydroxide

WSAHP = Wheat straw treated with alkaline hydrogen peroxide

PCL = Palm calyx leaves

PPF = Palm press fiber

POS = Palm oil sludge

CdL = *Commelina diffusa* L.

Appendix 2: Recalculated attributes of intake and degradability of diets and degradability properties together with chemical composition of different quality feeds tested as feeds for ruminants

Source	Obs	Animal	Graz	G-supp %	For-supp %	Diet CP (g/kg)	Diet NDF	ftype	dml	b	kd	tl	pd	ed	DM	CP	Ash	NDF	ADF	HEM
Eperical study	1	cattle	0	0	0	69	795	EC	86	509	0.048	8.00	595	421	931	107	95	815	503	312
	2	cattle	0	0	0	69	795	ECC	43	493	0.037	9.00	536	336	925	128	35	874	615	259
	3	cattle	0	0	0	69	795	VGHA	174	439	0.029	9.00	613	409	936	37	54	876	609	267
	4	cattle	0	0	0	69	795	VGHC	44	398	0.031	9.00	442	265	929	41	63	834	564	270
	5	cattle	0	0	0	69	795	VGHD	24	483	0.026	9.00	506	269	932	41	45	885	629	256
	6	cattle	0	0	0	69	795	VGHP	40	440	0.026	10.00	480	263	932	51	55	849	619	230
	7	cattle	0	0	0	69	795	VGHU	53	525	0.049	9.00	579	400	933	69	66	795	603	192
	8	cattle	0	0	0	69	795	KK	76	101	0.019	8.00	177	120	919	99	86	778	666	112
	9	cattle	0	0	0	69	795	ML	159	454	0.050	8.00	612	461	925	102	104	645	559	86
	10	cattle	0	0	0	69	795	MS	194	431	0.049	8.00	625	480	930	96	102	718	614	104
	11	cattle	0	0	0	69	795	MT	398	283	0.049	6.00	681	586	913	71	65	648	594	54
	12	cattle	0	0	0	69	795	WS	17	373	0.033	10.00	391	230	878	42	78	764	691	73
	13	cattle	0	0	30	98	703	EC	87	617	0.033	6.00	704	438	931	107	95	815	503	312
	14	cattle	0	0	30	98	703	ECC	1	727	0.017	7.00	728	298	925	128	35	874	615	259
	15	cattle	0	0	30	98	703	VGHA	28	556	0.017	6.00	585	254	936	37	54	876	609	267
	16	cattle	0	0	30	98	703	VGHC	43	522	0.018	7.00	565	258	929	41	63	834	564	270
	17	cattle	0	0	30	98	703	VGHD	24	804	0.008	7.00	828	225	932	41	45	885	629	256
	18	cattle	0	0	30	98	703	VGHP	51	448	0.027	7.00	498	282	932	51	55	849	619	230
	19	cattle	0	0	30	98	703	VGHU	53	799	0.017	6.00	852	379	933	69	66	795	603	192
	20	cattle	0	0	30	98	703	KK	76	507	0.016	6.00	583	275	919	99	86	778	666	112
	21	cattle	0	0	30	98	703	ML	158	535	0.043	5.00	693	497	925	102	104	645	559	86
	22	cattle	0	0	30	98	703	MS	194	510	0.040	5.00	703	507	930	96	102	718	614	104
	23	cattle	0	0	30	98	703	MT	398	319	0.065	4.00	717	629	913	71	65	648	594	54

	24	cattle	0	0	30	98	703	WS	16	488	0.016	7.00	504	204	878	42	78	764	691	73
	25	cattle	0	0	35	103	687	EC	87	599	0.016	9.00	686	321	931	107	95	815	503	312
	26	cattle	0	0	35	103	687	ECC	44	466	0.070	9.00	510	387	925	128	35	874	615	259
	27	cattle	0	0	35	103	687	VGHA	173	385	0.029	10.00	557	381	936	37	54	876	609	267
	28	cattle	0	0	35	103	687	VGHC	43	433	0.024	10.00	476	254	929	41	63	834	564	270
	29	cattle	0	0	35	103	687	VGHD	168	467	0.019	10.00	635	373	932	41	45	885	629	256
	30	cattle	0	0	35	103	687	VGHP	40	499	0.016	10.00	539	235	932	51	55	849	619	230
	31	cattle	0	0	35	103	687	VGHU	53	459	0.051	9.00	512	360	933	69	66	795	603	192
	32	cattle	0	0	35	103	687	KK	76	355	0.033	9.00	431	278	919	99	86	778	666	112
	33	cattle	0	0	35	103	687	ML	158	403	0.064	8.00	561	448	925	102	104	645	559	86
	34	cattle	0	0	35	103	687	MS	194	388	0.057	8.00	581	463	930	96	102	718	614	104
	35	cattle	0	0	35	103	687	MT	398	247	0.069	7.00	646	580	913	71	65	648	594	54
	36	cattle	0	0	35	103	687	WS	16	389	0.025	10.00	404	211	878	42	78	764	691	73
	37	cattle	0	0	50	117	641	EC	87	468	0.042	8.00	555	381	931	107	95	815	503	312
	38	cattle	0	0	50	117	641	ECC	44	540	0.029	10.00	584	334	925	128	35	874	615	259
	39	cattle	0	0	50	117	641	VGHA	173	388	0.030	10.00	561	384	936	37	54	876	609	267
	40	cattle	0	0	50	117	641	VGHC	43	469	0.023	9.00	512	267	929	41	63	834	564	270
	41	cattle	0	0	50	117	641	VGHD	24	469	0.019	10.00	492	228	932	41	45	885	629	256
	42	cattle	0	0	50	117	641	VGHP	16	423	0.026	10.00	463	229	932	51	55	849	619	230
	43	cattle	0	0	50	117	641	VGHU	53	531	0.044	9.00	584	392	933	69	66	795	603	192
	44	cattle	0	0	50	117	641	KK	76	367	0.030	10.00	443	276	919	99	86	778	666	112
	45	cattle	0	0	50	117	641	ML	158	470	0.051	9.00	628	473	925	102	104	645	559	86
	46	cattle	0	0	50	117	641	MS	194	436	0.052	8.00	629	488	930	96	102	718	614	104
	47	cattle	0	0	50	117	641	MT	398	296	0.053	7.00	694	599	913	71	65	648	594	54
	48	cattle	0	0	50	117	641	WS	16	353	0.033	11.00	369	216	878	42	78	764	691	73
Tesfayohannes, 2003	49	cattle	0	0	0	88	754	BS	161	555	0.031	3.18	716	467	930	37	55	795	541	254
	50	cattle	0	0	0	88	754	ETH	158	645	0.026	1.16	803	488	936	71	58	765	426	339

51	cattle	0	0	0	88	754	KK	218	450	0.034	3.81	668	476	930	76	77	692	365	327
52	cattle	0	0	0	88	754	K11	152	584	0.031	1.73	736	474	951	118	70	767	398	369
53	cattle	0	0	0	88	754	MS	227	499	0.028	0.67	725	492	929	86	46	720	448	272
54	cattle	0	0	0	88	754	OH	426	461	0.066	1.28	886	760	905	97	108	487	302	185
55	cattle	0	0	0	88	754	OS	171	477	0.030	2.54	648	431	937	43	69	769	531	239
56	cattle	0	0	0	88	754	RG	385	572	0.096	2.02	957	839	924	303	136	438	233	206
57	cattle	0	0	0	88	754	VH	158	660	0.029	4.05	818	511	945	65	79	698	454	245
58	cattle	0	0	0	88	754	WS	184	421	0.027	2.18	604	402	935	45	57	752	521	230
59	cattle	0	25	0	102	598	BS	161	559	0.032	1.87	719	476	930	37	55	795	541	254
60	cattle	0	25	0	102	598	ETH	158	679	0.026	1.21	837	501	936	71	58	765	426	339
61	cattle	0	25	0	102	598	KK	218	469	0.033	3.01	686	486	930	76	77	692	365	327
62	cattle	0	25	0	102	598	K11	152	602	0.033	1.79	755	494	951	118	70	767	398	369
63	cattle	0	25	0	102	598	MS	227	524	0.024	0.84	751	485	929	86	46	720	448	272
64	cattle	0	25	0	102	598	OH	426	462	0.075	1.43	888	772	905	97	108	487	302	185
65	cattle	0	25	0	102	598	OS	171	493	0.029	2.25	664	435	937	43	69	769	531	239
66	cattle	0	25	0	102	598	RG	385	572	0.087	0.87	957	830	924	303	136	438	233	206
67	cattle	0	25	0	102	598	VH	158	677	0.026	2.53	835	500	945	65	79	698	454	245
68	cattle	0	25	0	102	598	WS	184	483	0.021	1.99	667	405	935	45	57	752	521	230
69	cattle	0	50	0	115	442	BS	161	576	0.028	2.87	737	463	930	37	55	795	541	254
70	cattle	0	50	0	115	442	ETH	158	628	0.025	-0.24	786	472	936	71	58	765	426	339
71	cattle	0	50	0	115	442	KK	218	445	0.034	2.57	662	473	930	76	77	692	365	327
72	cattle	0	50	0	115	442	K11	152	602	0.026	1.37	754	456	951	118	70	767	398	369
73	cattle	0	50	0	115	442	MS	227	450	0.034	1.49	677	485	929	86	46	720	448	272
74	cattle	0	50	0	115	442	OH	426	455	0.061	1.09	881	749	905	97	108	487	302	185
75	cattle	0	50	0	115	442	OS	171	476	0.029	2.50	647	425	937	43	69	769	531	239
76	cattle	0	50	0	115	442	RG	385	579	0.078	1.13	964	824	924	303	136	438	233	206

77	cattle	0	50	0	115	442	VH	158	646	0.028	3.60	804	497	945	65	79	698	454	245
78	cattle	0	50	0	115	442	WS	184	447	0.023	2.44	631	396	935	45	57	752	521	230
79	cattle	0	75	0	129	286	BS	161	558	0.020	0.74	719	409	930	37	55	795	541	254
80	cattle	0	75	0	129	286	ETH	158	577	0.026	0.39	735	451	936	71	58	765	426	339
81	cattle	0	75	0	129	286	KK	218	439	0.029	3.28	656	451	930	76	77	692	365	327
82	cattle	0	75	0	129	286	K11	152	536	0.030	0.88	688	444	951	118	70	767	398	369
83	cattle	0	75	0	129	286	MS	227	478	0.021	-0.18	705	447	929	86	46	720	448	272
84	cattle	0	75	0	129	286	OH	426	455	0.063	1.91	881	751	905	97	108	487	302	185
85	cattle	0	75	0	129	286	OS	171	424	0.031	1.23	595	404	937	43	69	769	531	239
86	cattle	0	75	0	129	286	RG	385	553	0.087	1.89	939	816	924	303	136	438	233	206
87	cattle	0	75	0	129	286	VH	158	631	0.023	2.59	789	460	945	65	79	698	454	245
88	cattle	0	75	0	129	286	WS	184	429	0.021	1.02	613	378	935	45	57	752	521	230
89	cattle	0	0	0	64	752	BS	209	599	0.025	1.50	808	509	938	79	53	739	523	217
90	cattle	0	0	0	64	752	ETH	125	711	0.038	1.49	836	555	923	10	59	772	432	340
91	cattle	0	0	0	64	752	KK	204	578	0.029	-0.59	782	517	909	118	79	659	381	279
92	cattle	0	0	0	64	752	K11	186	591	0.033	3.25	778	524	924	153	70	758	419	339
93	cattle	0	0	0	64	752	MS	205	577	0.038	1.37	782	551	912	124	47	720	434	287
94	cattle	0	0	0	64	752	OH	429	465	0.044	0.21	894	725	887	178	105	479	318	162
95	cattle	0	0	0	64	752	OS	209	589	0.021	1.46	799	480	938	80	69	724	516	208
96	cattle	0	0	0	64	752	RG	392	574	0.064	1.20	966	805	913	349	139	495	247	248
97	cattle	0	0	0	64	752	VH	140	747	0.025	1.87	887	514	924	106	61	721	492	230
98	cattle	0	0	0	64	752	WS	216	471	0.028	2.48	687	464	932	76	48	727	518	209
99	cattle	0	25	0	84	596	BS	209	617	0.027	2.97	826	530	938	79	53	739	523	217
100	cattle	0	25	0	84	596	ETH	125	745	0.029	1.91	870	528	923	10	59	772	432	340
101	cattle	0	25	0	84	596	KK	204	555	0.048	0.78	760	569	909	118	79	659	381	279
102	cattle	0	25	0	84	596	K11	186	634	0.031	1.77	820	539	924	153	70	758	419	339
103	cattle	0	25	0	84	596	MS	206	603	0.032	1.39	809	543	912	124	47	720	434	287

	104	cattle	0	25	0	84	596	OH	429	482	0.053	1.41	911	755	887	178	105	479	318	162
	105	cattle	0	25	0	84	596	OS	209	580	0.022	-0.16	790	484	938	80	69	724	516	208
	106	cattle	0	25	0	84	596	RG	392	567	0.096	2.12	959	842	913	349	139	495	247	248
	107	cattle	0	25	0	84	596	VH	140	755	0.029	3.32	896	549	924	106	61	721	492	230
	108	cattle	0	25	0	84	596	WS	216	552	0.022	0.03	768	472	932	76	48	727	518	209
	109	cattle	0	50	0	103	441	BS	209	563	0.029	3.15	772	510	938	79	53	739	523	217
	110	cattle	0	50	0	103	441	ETH	125	699	0.030	2.94	824	507	923	10	59	772	432	340
	111	cattle	0	50	0	103	441	KK	204	528	0.046	1.56	733	548	909	118	79	659	381	279
	112	cattle	0	50	0	103	441	K11	186	638	0.031	3.66	825	541	924	153	70	758	419	339
	113	cattle	0	50	0	103	441	MS	206	575	0.033	2.23	718	535	912	124	47	720	434	287
	114	cattle	0	50	0	103	441	OH	429	486	0.058	0.95	915	769	887	178	105	479	318	162
	115	cattle	0	50	0	103	441	OS	209	540	0.025	1.02	750	482	938	80	69	724	516	208
	116	cattle	0	50	0	103	441	RG	392	573	0.079	2.04	966	828	913	349	139	495	247	248
	117	cattle	0	50	0	103	441	VH	140	749	0.026	4.04	890	520	924	106	61	721	492	230
	118	cattle	0	50	0	103	441	WS	216	530	0.021	1.29	746	457	932	76	48	727	518	209
	119	cattle	0	75	0	123	285	BS	209	621	0.022	1.30	830	501	938	79	53	739	523	217
	120	cattle	0	75	0	123	285	ETH	125	744	0.023	1.44	869	480	923	10	59	772	432	340
	121	cattle	0	75	0	123	285	KK	204	517	0.040	1.70	721	522	909	118	79	659	381	279
	122	cattle	0	75	0	123	285	K11	186	612	0.032	2.21	798	529	924	153	70	758	419	339
	123	cattle	0	75	0	123	285	MS	206	606	0.024	0.97	811	503	912	124	47	720	434	287
	124	cattle	0	75	0	123	285	OH	429	489	0.045	-0.76	918	743	887	178	105	479	318	162
	125	cattle	0	75	0	123	285	OS	209	592	0.018	-1.19	802	458	938	80	69	724	516	208
	126	cattle	0	75	0	123	285	RG	392	561	0.085	1.72	953	826	913	349	139	495	247	248
	127	cattle	0	75	0	123	285	VH	140	703	0.025	2.77	843	491	924	106	61	721	492	230
	128	cattle	0	75	0	123	285	WS	216	505	0.021	2.19	721	444	932	76	48	727	518	209
Nsahlai & Umanna, 1996	129	Sheep	0	38	0	176	146	BS	117	574	0.014	9.10	622	323	.	38	103	769	480	289
	130	Sheep	0	45	0	193	134	WS	146	403	0.045	-2.00	587	405	.	31	105	724	471	253

	131	Sheep	0	45	0	193	134	TS	131	757	0.008	5.30	857	315	.	50	102	793	424	369
	132	Sheep	0	34	0	166	153	SS	281	601	0.012	-3.00	800	476	.	56	126	697	410	287
	133	Sheep	0	.	0	.	.	FS	118	418	0.039	6.80	439	373	.	69	69	732	594	138
	134	Sheep	0	38	0	176	146	OS	265	357	0.024	5.30	577	440	.	31	78	738	492	246
	135	Sheep	0	39	0	179	144	MS	199	694	0.010	0.50	883	397	.	38	108	720	436	284
	136	Sheep	0	20	0	132	177	OH	360	332	0.029	4.80	649	538	.	50	94	636	402	234
	137	Sheep	0	27	0	149	165	CH	193	404	0.019	8.80	534	367	.	63	127	700	405	295
	138	Sheep	0	30	0	156	160	DZH	172	485	0.016	8.60	596	361	.	50	98	729	448	281
	139	Sheep	0	.	0	.	.	HbS	115	243	0.026	15.80	276	239	.	50	54	745	715	30
	140	Sheep	0	38	0	176	146	SnH	193	401	0.024	-6.70	662	389	.	50	79	713	425	288
	141	Sheep	0	29	0	154	161	M_CP	292	508	0.039	3.90	728	602	.	119	106	551	471	80
	142	Sheep	0	27	0	149	165	M_L	273	538	0.026	3.40	765	547	.	75	86	571	353	218
	143	Sheep	0	27	0	149	165	O_V	214	360	0.029	2.20	555	407	.	69	89	599	348	251
	144	Sheep	0	28	0	151	163	W_T	125	402	0.026	2.20	500	330	.	69	152	670	428	242
Khazaal *et al.*, 1995	145	Sheep	0	0	0	98	679	IRGHPB	271	374	0.051	.	645	522	.	98	81	679	447	232
	146	Sheep	0	0	0	123	650	THEB	366	493	0.033	.	859	647	.	123	115	650	410	240
	147	Sheep	0	0	0	75	696	THMB	370	448	0.039	.	818	643	.	75	93	696	439	257
	148	Sheep	0	0	0	51	727	THS	170	533	0.028	.	703	452	.	51	67	727	503	224
	149	Sheep	0	0	0	188	583	RYHEB	302	514	0.052	.	816	649	.	188	104	583	339	244
	150	Sheep	0	0	0	132	678	RYHMB	249	471	0.037	.	720	530	.	132	96	678	447	231
	151	Sheep	0	0	0	70	667	RYHS	238	367	0.036	.	605	455	.	70	54	667	426	241
	152	Sheep	0	0	0	100	478	OHEB	362	431	0.055	.	793	658	.	100	83	478	357	121
	153	Sheep	0	0	0	70	608	OHMB	343	373	0.043	.	716	579	.	70	69	608	373	235
	154	Sheep	0	0	0	68	635	OHS	327	407	0.025	.	734	531	.	68	66	635	421	214
Shem *et al.*, 1995	155	cattle	0	0	26	162	659	GKMS	213	543	0.036	5.30	756	532	380	73	74	773	.	.

	156	cattle	0	0	19	159	723	UTMSM	218	566	0.036	1.10	784	552	750	98	57	814	.	.
	157	cattle	0	0	24	162	715	UTMSK	219	534	0.037	6.70	753	536	870	81	71	835	.	.
	158	cattle	0	0	26	174	698	MSM _30U	221	513	0.031	5.30	734	503	750	89	59	826	.	.
	159	cattle	0	0	32	187	678	MSK_30U	205	497	0.033	6.40	702	489	760	79	62	840	.	.
	160	cattle	0	0	35	173	690	DKMS	183	522	0.028	1.70	705	459	860	41	60	881	.	.
	161	cattle	0	0	23	164	656	GMMS	224	543	0.044	5.80	767	570	353	88	68	752	.	.
	162	cattle	0	0	31	163	700	DMMS	203	534	0.026	1.80	737	475	850	49	59	864	.	.
	163	cattle	0	0	25	137	733	MST	218	548	0.031	3.30	766	519	380	43	70	866	.	.
	164	cattle	0	0	25	186	672	GG	219	512	0.038	4.30	731	527	233	109	86	784	.	.
	165	cattle	0	0	24	168	679	SG	227	542	0.041	5.40	769	563	198	90	82	788	.	.
	166	cattle	0	0	27	196	649	NG	225	526	0.034	4.50	751	529	188	114	95	765	.	.
	167	cattle	0	0	22	143	726	CWS	218	564	0.031	2.10	782	531	840	66	86	836	.	.
	168	cattle	0	0	28	151	716	BBS	208	541	0.028	2.40	749	495	860	48	75	864	.	.
	169	cattle	0	0	28	148	717	RGH	217	549	0.026	4.10	766	499	850	44	53	866	.	.
	170	cattle	0	0	23	148	720	RGG	225	535	0.034	4.10	760	532	300	67	62	835	.	.
	171	cattle	0	0	39	240	532	BL	237	380	0.017	3.40	617	390	230	127	63	659	.	.
	172	cattle	0	0	41	193	376	BP	459	415	0.042	9.00	874	719	70	38	29	405	.	.
Fonseca *et al.*, 1998	173	Sheep	0	0	8	135	749	UTRYS2	118	642	0.027	5.70	760	451	.	104	34	799	502	297
	174	Sheep	0	0	10	153	729	UTWS2	150	585	0.034	5.00	735	487	.	115	51	791	510	281
	175	Sheep	0	0	19	125	579	RS	161	528	0.037	4.40	689	476	.	39	145	675	493	182
	176	Sheep	0	0	25	143	654	RYS1	124	507	0.020	3.20	631	349	.	27	39	815	530	285
	177	Sheep	0	0	19	111	706	RYS2	98	583	0.017	1.80	681	334	.	22	34	832	501	331
	178	Sheep	0	0	20	132	667	WS1	107	568	0.022	1.40	675	373	.	42	50	791	451	340
	179	Sheep	0	0	21	125	681	WS2	100	549	0.028	4.20	649	390	.	28	54	817	491	326
	180	Sheep	0	0	17	157	650	MH1	198	555	0.029	1.00	753	496	.	89	50	748	431	317
	181	Sheep	0	0	17	130	635	MH2	210	505	0.029	3.90	715	481	.	56	46	730	427	303

	182	Sheep	0	0	12	118	582	OH1	243	497	0.024	2.00	740	486	.	67	42	638	362	276
	183	Sheep	0	0	20	140	563	OH2	296	509	0.025	3.10	805	551	.	52	44	662	399	263
	184	Sheep	0	0	8	136	624	IRG	248	482	0.046	4.00	730	560	.	105	77	664	376	288
Chakeredza *et al.*, 2002	185	sheep	0	0	34	228	651	MS3	84	589	0.024	.	673	372	950	435	78	283	171	112
	186	sheep	0	0	34	108	626	MS4	94	534	0.026	.	628	367	949	79	20	211	52	159
	187	sheep	0	0	0	94	840	MS	71	586	0.030	.	657	390	923	38	61	839	591	248
	188	sheep	0	0	30	113	725	MS2	96	535	0.027	.	631	374	918	101	122	457	430	27
	189	sheep	0	0	30	125	740	MS1	81	509	0.034	.	591	375	909	142	89	507	386	121
Abule *et al*., 1995	190	cattle	0	0	0	56	683	TS	118	718	0.014	.	836	376	942	33	79	781	428	353
	191	cattle	0	0	34	196	569	TS_CW	95	613	0.027	.	708	414	935	87	100	673	413	260
	192	cattle	0	0	36	204	562	TS_L	112	607	0.026	.	720	421	934	88	93	651	404	248
Nsahlai et al., 1998	193	Sheep	0	0	0	44	804	TS	141	649	0.012	0.70	790	351	951	44	89	804	478	326
	194	Sheep	0	0	24	66	737	TS_L	141	596	0.025	0.90	736	439	951	44	89	804	478	326
	195	Sheep	0	6	24	69	580	TS_L_MG	141	542	0.024	-1.30	683	406	951	44	89	804	478	326
	196	Sheep	0	7	24	74	718	TS_L_WB	141	575	0.020	-0.60	716	397	951	44	89	804	478	326
	197	Sheep	0	0	22	87	687	TS_S	141	523	0.029	0.90	664	422	951	44	89	804	478	326
	198	Sheep	0	6	21	88	661	TS_S_MG	141	506	0.020	-0.20	647	366	951	44	89	804	478	326
	199	Sheep	0	6	24	98	660	TS_S_WB	141	621	0.020	3.20	762	417	951	44	89	804	478	326
	200	Sheep	0	0	23	72	715	TS_T	141	596	0.018	2.40	737	390	951	44	89	804	478	326
	201	Sheep	0	6	23	75	684	TS_T_MG	141	572	0.018	0.50	713	380	951	44	89	804	478	326
	202	Sheep	0	7	25	83	689	TS_T_WB	141	590	0.046	0.80	731	523	951	44	89	804	478	326
Hindrichsen et al., 2004	203	Sheep	0	0	25	75	646	MS_Lp	238	532	0.025	.	772	504	931	35	93	737	.	.
	204	Sheep	0	0	27	79	627	MS_C	232	569	0.019	.	800	478	931	35	93	737	.	.
	205	Sheep	0	0	33	92	611	MS_Ld	220	513	0.035	.	733	519	931	35	93	737	.	.
Nsahlai *et al*., 1999	206	cattle	0	0	75	171	.	BS	156	547	0.047	1.70	703	513	898	77	1	.	.	.
	207	cattle	0	0	76	223	.	BS	150	560	0.049	1.00	710	521	898	77	1	.	.	.

	208	cattle	0	0	76	274	.	BS	153	551	0.049	1.23	704	518	898	77	1	.	.	.
abdou , 2010	209	Sheep	0	0	35	122	676	MIS	152	260	0.058	.	412	334	938	46	65	859	532	327
	210	Sheep	0	0	35	122	676	GNH	319	412	0.156	.	731	674	937	94	76	565	422	142
	211	Sheep	0	0	35	122	676	MB	439	408	0.215	.	847	805	953	138	61	383	71	312
	212	Sheep	0	0	35	122	676	WB	456	353	0.077	.	809	722	946	164	53	482	140	342
	213	buffalo	0	10	0	86	540	US1	-13	609	0.025	.	596	292	.	41	130	736	.	.
Navaratne & Ibrahim, 1988	214	buffalo	0	10	0	86	540	US2	-70	642	0.028	.	572	269	.	47	121	774	.	.
	215	buffalo	0	10	0	86	540	SS1	-50	702	0.036	.	652	364	.	74	108	744	.	.
	216	buffalo	0	10	0	86	540	SS2	-59	645	0.036	.	586	322	.	64	124	745	.	.
	217	buffalo	0	10	0	86	540	TS1	18	683	0.026	.	701	366	.	52	128	749	.	.
	218	buffalo	0	10	0	86	540	TS2	47	641	0.032	.	688	407	.	55	119	761	.	.
	219	buffalo	0	10	0	86	540	GG	157	641	0.041	.	798	555	.	96	100	.	.	.
	220	buffalo	0	10	0	86	540	KK	178	662	0.040	.	840	585	.	178	58	760	.	.
	221	buffalo	0	10	0	86	540	RB	239	132	0.039	.	371	319	.	95	295	.	.	.
Alcaide et al., 2000	222	Sheep	0	0	100	181	390	AH1	64	677	0.087	.	741	589	899	181	131	390	294	96
	223	Sheep	0	0	80	166	402	AH2	200	472	0.095	.	672	574	899	181	131	390	294	96
	224	Sheep	0	0	80	166	402	SBP	112	842	0.031	.	954	578	919	106	116	490	244	246
	225	Sheep	0	0	60	153	410	OG	647	284	0.029	.	931	800	858	108	.	310	149	161
	226	goats	0	0	100	181	390	AH1	22	678	0.091	.	700	554	899	181	131	390	294	96
	227	goats	0	0	80	166	402	AH2	258	375	0.086	.	633	549	899	181	131	390	294	96
	228	goats	0	0	80	166	402	SBP	107	815	0.047	.	922	639	919	106	116	490	244	246
	229	goats	0	0	60	153	410	OG	526	425	0.025	.	951	739	858	108	.	310	149	161
Ibrahim et al., 1995	230	cattle	0	0	0	87	810	RU	524	229	0.041	2.20	753	666	.	77	80	615	322	293
	231	cattle	0	0	0	87	810	NB12	614	228	0.039	1.90	842	753	.	86	124	647	364	283
	232	cattle	0	0	0	87	810	SG	530	319	0.031	1.70	849	707	.	78	98	686	377	309
	233	cattle	0	0	0	87	810	GU	609	253	0.031	3.10	862	749	.	127	118	686	368	318

	234	cattle	0	0	0	87	810	GLY	486	121	0.108	4.00	607	584	.	302	102	331	197	134
	235	cattle	0	0	0	87	810	LEU	543	129	0.063	2.80	672	635	.	380	101	354	164	190
	236	cattle	0	0	0	87	810	ERY	514	182	0.139	4.60	696	668	.	383	117	399	216	183
	237	cattle	0	0	0	87	810	JL	569	171	0.071	10.70	740	695	.	126	88	391	279	112
	238	cattle	0	0	0	87	810	CM	560	57	0.110	4.90	617	606	.	238	59	475	247	228
	239	cattle	0	0	0	87	810	RB	309	467	0.086	1.00	776	671	.	107	208	455	303	152
Bonsi & Osuji, 1997	240	Sheep	0	0	0	44	455	TS1	79	649	0.028	3.80	728	423	951	44	89	804	478	326
	241	Sheep	0	6	25	157	685	TS2	126	646	0.017	2.20	772	389	952	44	89	804	478	326
	242	Sheep	0	5	24	95	652	TS3	128	509	0.024	1.57	637	376	953	44	89	804	478	326
	243	Sheep	0	5	25	95	645	TS4	117	519	0.026	2.20	636	380	954	44	89	804	478	326
Ngwa *at al*., 2001	244	Sheep	0	0	0	15	701	MS1	117	642	0.013	-2.88	759	337	943	55	71	523	360	163
	245	Sheep	0	0	50	117	552	MS2	117	613	0.013	-5.39	730	327	943	55	71	523	360	163
	246	Sheep	0	0	50	131	555	MS3	117	780	0.007	-6.90	897	288	943	55	71	523	360	163
	247	Sheep	0	0	50	82	463	MS4	117	442	0.016	-3.61	559	289	943	55	71	523	360	163
	248	Sheep	0	0	50	95	534	MS5	117	555	0.016	-1.10	672	334	943	55	71	523	360	163
	249	Sheep	0	0	0	15	701	ALF1	288	426	0.053	-1.51	714	577	927	220	101	402	341	61
	250	Sheep	0	0	50	117	552	ALF2	288	432	0.045	-2.88	720	566	927	220	101	402	341	61
	251	Sheep	0	0	50	131	555	ALF3	288	432	0.037	-3.85	720	546	927	220	101	402	341	61
	252	Sheep	0	0	50	82	463	ALF4	288	403	0.044	-2.61	691	545	927	220	101	402	341	61
	253	Sheep	0	0	50	95	534	ALF5	288	428	0.036	-4.62	716	541	927	220	101	402	341	61
Umunna *et al*., 1995	254	Sheep	0	0	22	157	654	OH1	235	336	0.025	0.20	571	403	888	49	110	615	.	.
	255	Sheep	0	0	22	157	654	OH2	232	285	0.030	0.40	517	387	888	49	110	615	.	.
	256	Sheep	0	0	22	157	654	OH3	218	338	0.032	1.00	556	408	888	49	110	615	.	.
	257	Sheep	0	0	22	157	654	OH4	210	305	0.041	0.30	515	399	888	49	110	615	.	.
	258	Sheep	0	0	22	157	654	OH5	220	227	0.021	4.50	447	324	888	49	110	615	.	.
	259	Sheep	0	0	22	157	654	OH6	206	323	0.035	3.10	529	394	888	49	110	615	.	.
	260	Sheep	0	0	22	157	654	OS1	143	475	0.014	-0.90	618	314	892	24	91	727	.	.

	261	Sheep	0	0	22	157	654	OS2	91	409	0.030	4.20	500	314	892	24	91	727	.	.
	262	Sheep	0	0	22	157	654	OS3	101	568	0.017	4.30	669	331	892	24	91	727	.	.
	263	Sheep	0	0	22	157	654	OS4	130	439	0.021	-0.90	569	330	892	24	91	727	.	.
	264	Sheep	0	0	22	157	654	OS5	125	501	0.016	1.60	626	321	892	24	91	727	.	.
	265	Sheep	0	0	22	157	654	OS6	93	395	0.031	3.80	488	312	892	24	91	727	.	.
Bonsi *et al*., 1994	266	Sheep	0	0	0	34	790	TS1	26	532	0.015	3.31	558	221	909	34	170	790	449	341
	267	Sheep	0	0	76	191	346	TS2	37	540	0.019	1.89	577	268	910	34	170	790	449	341
	268	Sheep	0	0	69	176	387	TS3	24	561	0.025	1.46	585	303	911	34	170	790	449	341
	269	Sheep	0	0	61	160	434	TS4	43	446	0.021	0.04	489	245	912	34	170	790	449	341
Kamalak *et al*., 2005	270	Sheep	0	40	60	209	270	WS	154	428	0.042	.	582	422	922	31	58	756	543	212
	271	Sheep	0	40	60	209	270	BS	146	461	0.040	.	607	430	918	42	74	727	532	195
	272	Sheep	0	40	60	209	270	LH	279	398	0.035	.	676	511	915	184	107	424	274	150
	273	Sheep	0	40	60	209	270	MS	280	543	0.022	.	823	534	253	79	56	448	241	207
Khazaal *et al*., 1993	274	Sheep	0	0	60	150	427	LH_EB	36	39	0.082	.	76	66	.	150	75	427	314	113
	275	Sheep	0	0	0	100	471	LH_MB	30	35	0.071	.	65	56	.	100	66	471	368	103
	276	Sheep	0	0	0	88	522	LH_IS	31	26	0.038	.	58	47	.	88	52	522	437	85
	277	Sheep	0	0	0	106	474	SCH_EB	29	38	0.059	.	67	55	.	106	86	474	388	86
	278	Sheep	0	0	0	100	515	SCH_MB	16	31	0.068	.	47	39	.	100	81	515	403	112
	279	Sheep	0	0	0	50	625	SCH_IS	18	38	0.049	.	56	43	.	50	44	625	542	83
	280	Sheep	0	0	0	150	373	PCH_EB	42	38	0.107	.	80	73	.	150	104	373	312	61
	281	Sheep	0	0	0	81	523	PCH_MB	31	38	0.025	.	69	50	.	81	71	523	442	81
	282	Sheep	0	0	0	100	407	PCH_IS	26	44	0.083	.	70	59	.	100	80	407	347	60
	283	Sheep	0	0	0	75	519	IRG_PB	27	37	0.051	.	65	52	.	75	62	519	342	177
Silva et al., 2008	284	cattle	0	0	0	170	670	EG	33	503	0.040	1.70	536	343	148	91	.	728	451	277
	285	cattle	0	0	0	170	670	CS	58	372	0.050	5.50	430	306	204	77	.	638	418	220
Bengaly, 1996	286	sheep	0	0	5	44	831	MS	142	449	0.025	1.90	591	367	934	40	60	845	541	304
	287	sheep	0	0	5	44	831	USMS	134	479	0.027	1.70	613	383	934	40	60	845	541	304

	288	sheep	0	0	5	44	831	MS__L	302	317	0.089	2.50	619	549	934	40	60	845	541	304
Tang *et al*., 2011	289	Goats	0	40	0	88	644	MSCMSP1	333	432	0.022	0.49	765	537	135	89	79	618	389	229
	290	Goats	0	40	0	88	644	MSCMSP2	343	384	0.022	0.73	727	521	253	87	81	606	383	223
	291	Goats	0	40	0	88	644	MSCMS1	367	407	0.025	0.61	774	571	157	78	72	594	359	235
	292	Goats	0	40	0	88	644	MSCMS2	362	402	0.031	0.81	764	583	204	79	57	600	346	254
	293	Goats	0	40	0	88	644	MSFMSP1	365	272	0.022	0.29	637	491	156	103	72	640	379	261
	294	Goats	0	40	0	88	644	MSFMSP2	406	341	0.031	0.67	747	595	251	97	102	573	344	229
	295	Goats	0	40	0	88	644	MSFMS1	413	414	0.022	0.65	827	605	160	86	64	542	343	199
	296	Goats	0	40	0	88	644	MSFMS2	379	405	0.018	0.30	784	550	176	82	70	608	361	247
	297	Goats	0	40	0	88	644	MSHOMSP1	312	352	0.031	1.04	664	506	169	101	68	617	381	236
	298	Goats	0	40	0	88	644	MSHOMSP2	359	404	0.022	1.20	763	548	284	88	74	583	364	219
	299	Goats	0	40	0	88	644	MSHOMS1	345	382	0.027	1.25	727	543	188	98	57	585	348	237
	300	Goats	0	40	0	88	644	MSHOMS2	375	314	0.027	1.00	689	539	229	88	63	577	346	231
	301	Goats	0	40	0	88	644	MSSMSP1	357	379	0.023	1.00	736	537	134	106	82	596	365	231
	302	Goats	0	40	0	88	644	MSSMSP2	411	295	0.030	0.37	706	572	218	105	102	551	356	195
	303	Goats	0	40	0	88	644	MSSMSS1	379	422	0.024	0.83	801	584	185	93	61	564	316	248
	304	Goats	0	40	0	88	644	MSSMSS2	372	462	0.021	0.44	834	582	190	95	74	600	365	235
	305	Goats	0	40	0	88	644	MSWMSP1	365	434	0.027	1.60	799	589	165	92	72	581	351	230
	306	Goats	0	40	0	88	644	MSWMSP2	294	456	0.019	0.71	750	492	293	87	87	651	418	233
	307	Goats	0	40	0	88	644	MSWMS1	396	420	0.017	0.86	816	564	162	104	63	560	314	246
	308	Goats	0	40	0	88	644	MSWMS2	394	417	0.018	0.18	811	570	241	75	58	590	340	250
Tolera & Sundstøl, 2001	309	Sheep	0	7	0	122	539	1MS1	146	638	0.018	1.10	784	413	934	36	74	772	455	317
	310	Sheep	0	7	0	122	539	1MS2	170	586	0.026	1.40	756	469	934	36	74	772	455	317
	311	Sheep	0	7	0	122	539	1MS3	187	551	0.032	1.60	738	496	934	36	74	772	455	317
	312	Sheep	0	7	0	122	539	1MS4	207	507	0.040	1.90	714	519	934	36	74	772	455	317
	313	Sheep	0	7	0	122	539	2MS1	129	670	0.017	0.70	799	400	937	33	69	790	483	307
	314	Sheep	0	7	0	122	539	2MS2	160	605	0.027	1.10	765	474	937	33	69	790	483	307

	315	Sheep	0	7	0	122	539	2MS3	181	561	0.033	1.40	742	500	937	33	69	790	483	307
	316	Sheep	0	7	0	122	539	2MS4	198	524	0.038	1.70	722	514	937	33	69	790	483	307
	317	Sheep	0	7	0	122	539	3MS1	119	599	0.023	1.80	718	406	937	33		790	483	307
	318	Sheep	0	7	0	122	539	3MS2	152	555	0.031	1.90	707	459	934	31	69	801	531	270
	319	Sheep	0	7	0	122	539	3MS3	174	526	0.035	2.00	700	481	934	31	69	801	531	270
	320	Sheep	0	7	0	122	539	3MS4	193	501	0.040	2.10	694	501	934	31	69	801	531	270
Ngele *et al*., 2009	321	cattle	0	0	80	74	817	URS	73	547	0.027	.	620	357	928	44	161	698	581	117
	322	cattle	0	0	80	74	817	UTRS	106	665	0.032	.	771	480	900	124	195	657	445	212
	323	cattle	0	0	80	74	817	PLTRS1	102	672	0.028	.	774	457	989	205	195	699	572	126
	324	cattle	0	0	80	74	817	PLTRS2	58	615	0.024	.	673	359	972	197	200	551	368	183
Chumpawadee *et al*., 2006	325	cattle	0	25	0	45	616	WH	201	687	0.011	.	888	411	150	129	143	692	427	265
	326	cattle	0	25	0	45	616	KP	276	615	0.025	.	891	583	217	166	86	502	453	49
	327	cattle	0	25	0	45	616	CS	309	530	0.022	.	840	558	233	63	63	674	384	290
	328	cattle	0	25	0	45	616	CH	207	676	0.020	.	882	507	240	158	87	509	514	-5
	329	cattle	0	25	0	45	616	SC	180	535	0.018	.	715	404	367	58	53	799	546	253
	330	cattle	0	25	0	45	616	CN	391	488	0.051	.	879	719	156	264	233	401	199	202
	331	cattle	0	25	0	45	616	RS	133	625	0.018	.	758	394	915	30	136	721	533	188
	332	cattle	0	25	0	45	616	CC	295	554	0.016	.	849	512	945	109	76	599	416	183
Ikhimioya *et al*., 2005	333	Sheep	1	0	0	.	.	FE	516	297	0.025	.	813	664	945	123	21	.	.	.
	334	Sheep	1	0	0	.	.	SM	494	473	0.012	.	967	647	962	96	27	.	.	.
	335	Sheep	1	0	0	.	.	TG	293	367	0.018	.	659	446	967	111	16	.	.	.
	336	Sheep	1	0	0	.	.	TC	269	467	0.012	.	736	420	945	88	37	.	.	.
	337	Sheep	1	0	0	.	.	GnH	164	349	0.021	.	513	323	967	106	16	.	.	.
	338	Sheep	1	0	0	.	.	PP	339	344	0.019	.	683	487	953	127	21	.	.	.
	339	Sheep	1	0	0	.	.	PLP	373	365	0.018	.	738	526	961	113	19	.	.	.
	340	Sheep	1	0	0	.	.	RO	235	334	0.023	.	569	395	961	116	18	.	.	.

Jalilvand *et al*., 2008	341	Sheep	0	50	0	174	434	AH	315	416	0.061	.	731	610	933	152	96	466	.	.
	342	Sheep	0	50	0	174	434	MSI	314	428	0.036	.	742	565	376	89	86	591	.	.
	343	Sheep	0	50	0	174	434	WS	228	346	0.042	.	574	445	953	32	74	786	.	.
Chumpawadee *et al*., 2005	344	cattle	0	25	0	45	616	GC	290	710	0.027	.	1000	659	922	85	17	133	36	96
	345	cattle	0	25	0	45	616	CC	751	222	0.032	.	973	875	934	19	20	69	64	6
	346	cattle	0	25	0	45	616	BR	131	867	0.065	.	998	757	921	78	7	93	7	86
	347	cattle	0	25	0	45	616	RB	351	399	0.182	.	749	701	917	143	63	203	81	122
	348	cattle	0	25	0	45	616	RPO	231	224	0.107	.	455	412	905	85	141	612	460	152
Orden *et al*., 2000	349	Sheep	0	15	0	53	576	URS	219	436	0.018	.	655	402	889	40	221	640	407	232
	350	Sheep	0	15	0	95	548	ARS	240	502	0.035	.	742	533	882	89	184	607	393	214
	351	Sheep	0	15	5	51	369	T1	325	341	0.038	.	666	530	894	91	175	499	310	189
	352	Sheep	0	15	0	95	548	T2	290	479	0.035	.	769	569	878	94	172	543	374	169
Tahseen *et al*., 2014	353	Sheep	0	60	0	132	384	GHW	161	558	0.020	.	719	409	882	175	31	430	270	160
	354	Sheep	0	60	0	132	384	OC	72	476	0.030	.	548	332	890	95	14	490	330	160
Verbič *et al*., 1995	355	sheep	0	0	0	122	563	STN	329	296	0.037	1.34	625	506	.	.	.	601	391	210
	356	sheep	0	0	0	122	563	STBC2	272	338	0.030	4.44	610	456	.	.	.	685	437	248
	357	sheep	0	0	0	122	563	STBC8	267	289	0.059	2.19	556	470	.	.	.	645	420	225
	358	sheep	0	0	0	122	563	STD	385	292	0.028	4.30	677	539	.	.	.	605	391	214
	359	sheep	0	0	0	122	563	STM	255	351	0.027	0.81	606	437	.	.	.	668	451	217
	360	sheep	0	0	0	122	563	STBC3	229	341	0.044	3.70	570	446	.	.	.	707	452	255
	361	sheep	0	0	0	122	563	STBC18	248	349	0.044	3.47	597	471	.	.	.	680	422	258
	362	sheep	0	0	0	122	563	STEva	282	295	0.040	3.32	577	464	.	.	.	650	415	235
	363	sheep	0	0	0	122	563	LN	177	565	0.067	4.18	742	588	.	.	.	677	373	304
	364	sheep	0	0	0	122	563	LBC2	143	597	0.049	3.70	740	538	.	.	.	727	398	329

	365	sheep	0	0	0	122	563	LBC8	169	575	0.061	3.73	744	577	.	.	.	692	370	322
	366	sheep	0	0	0	122	563	LD	196	596	0.041	2.94	792	566	.	.	.	687	362	325
	367	sheep	0	0	0	122	563	LM	190	543	0.047	2.87	733	544	.	.	.	664	359	305
	368	sheep	0	0	0	122	563	LBC3	118	626	0.051	3.94	744	538	.	.	.	752	404	348
	369	sheep	0	0	0	122	563	LBC18	183	574	0.058	3.15	757	584	.	.	.	677	358	319
	370	sheep	0	0	0	122	563	LEva	168	549	0.048	3.27	717	529	.	.	.	692	370	322
	371	sheep	0	0	0	122	563	HN	173	647	0.039	1.03	820	567	.	.	.	737	357	380
	372	sheep	0	0	0	122	563	HBC2	146	659	0.042	3.21	805	559	.	.	.	787	387	400
	373	sheep	0	0	0	122	563	HBC8	128	682	0.040	2.62	810	548	.	.	.	795	363	432
	374	sheep	0	0	0	122	563	HD	183	636	0.033	2.94	819	545	.	.	.	753	368	385
	375	sheep	0	0	0	122	563	HM	145	615	0.057	2.97	760	573	.	.	.	776	378	398
	376	sheep	0	0	0	122	563	HBC3	142	675	0.048	1.59	817	586	.	.	.	779	379	400
	377	sheep	0	0	0	122	563	HBC18	142	655	0.039	1.61	797	541	.	.	.	758	376	382
	378	sheep	0	0	0	122	563	HEva	195	594	0.043	1.06	789	571	.	.	.	782	379	403
	379	sheep	0	0	0	122	563	CN	121	554	0.035	1.85	675	444	.	.	.	776	398	378
	380	sheep	0	0	0	122	563	CBC2	132	591	0.030	1.23	723	454	.	.	.	798	431	367
	381	sheep	0	0	0	122	563	CBC8	112	496	0.029	0.15	608	378	.	.	.	798	429	369
	382	sheep	0	0	0	122	563	CD	123	539	0.031	2.05	662	421	.	.	.	820	442	378
	383	sheep	0	0	0	122	563	CM	121	585	0.029	3.65	706	435	.	.	.	810	447	363
	384	sheep	0	0	0	122	563	CBC3	137	685	0.026	2.05	822	486	.	.	.	800	442	358
	385	sheep	0	0	0	122	563	CBC18	120	518	0.030	1.38	638	403	.	.	.	799	442	357
	386	sheep	0	0	0	122	563	CEva	109	487	0.023	0.00	596	342	.	.	.	811	446	365
Karsli & Russell, 2002	387	sheep	0	0	0	.	757	CS	145	485	0.038	.	630	437	.	.	.	757	433	324
	388	sheep	0	0	100	.	622	OBR	244	454	0.030	.	698	493	.	.	.	622	374	248

	389	sheep	0	0	100	.	420	Alf	284	433	0.028	.	717	514	.	.	.	420	284	136
	390	sheep	0	5	16	.	659	CS_Suppl	185	513	0.030	.	698	466	.	.	.	659	369	290
	391	sheep	0	8.3	22.7	.	645	CS_BrL_Supl	194	511	0.029	.	705	470	.	.	.	645	359	286
	392	sheep	0	5	40	.	610	CS_BrH_Supl	216	505	0.028	.	721	482	.	.	.	610	339	271
	393	sheep	0	10.3	26	.	628	CS_Alf_Supl	194	511	0.030	.	705	471	.	.	.	628	356	272
	394	sheep	0	20	35	.	554	CS_Alf_Supl	230	498	0.027	.	728	489	.	.	.	554	315	239
Kabatange & Shayo, 1991	395	cattle	0	0	0	24	733	MS1	30	135	0.022	.	165	93	919	24	79	733	.	.
	396	cattle	0	0	35	64	594	MS2	140	270	0.034	.	410	296	919	24	79	733	.	.
	397	cattle	0	0	50	82	534	MS3	100	270	0.043	.	370	271	919	24	79	733	.	.
	398	cattle	0	15	35	79	556	MS4	75	215	0.032	.	290	196	919	24	79	733	.	.
	399	cattle	0	0	0	.	.	MS5	80	205	0.028	.	285	188	919	24	79	733	.	.
Kariuki *et al.*, 2001	400	cattle	0	0	0	91	603	NG1	197	492	0.044	.	689	511	150	91	158	603	311	292
	401	cattle	0	0	10	97	591	NG2	189	481	0.043	.	670	493	150	91	158	603	311	292
	402	cattle	0	0	20	108	583	NG3	186	488	0.046	.	674	502	150	91	158	603	311	292
	403	cattle	0	0	30	117	575	NG4	190	453	0.045	.	643	481	150	91	158	603	311	292
	404	cattle	0	0	0	89	614	NG5	202	462	0.044	.	664	497	150	91	158	603	311	292
	405	cattle	0	0	10	99	581	NG6	201	463	0.044	.	664	496	150	91	158	603	311	292
	406	cattle	0	0	20	109	573	NG7	211	480	0.048	.	691	527	150	91	158	603	311	292
	407	cattle	0	0	30	120	565	NG8	198	477	0.046	.	675	507	150	91	158	603	311	292
Chaudhry, 2000																				
	408	Sheep	0	0	0	160	390	WS	108	433	0.015	.	541	270	.	42	.	841	582	259
	409	Sheep	0	0	0	160	390	WSCaO	279	644	0.021	.	923	573	.	42	.	676	647	29
	410	Sheep	0	0	0	160	390	WSNaOH	278	599	0.049	.	877	675	.	42	.	781	714	67
	411	Sheep	0	0	0	160	390	WSAHP	383	559	0.054	.	942	765	.	42	.	776	753	23

Bogoro *et al*., 2006	412	cattle	0	0	0	122	475	GnHa	292	662	0.010	.	954	481	916	135	94	545	309	236
	413	cattle	0	0	0	122	475	GnHa	277	690	0.009	.	967	460	916	135	94	545	309	236
	414	cattle	0	0	0	122	475	SS	65	343	0.005	.	408	122	941	34	60	528	465	63
	415	cattle	0	0	0	122	475	SS	70	317	0.004	.	387	114	941	34	60	528	465	63
Bamikole & Babayemi, 2008	416	cattle	1	0	0	.	.	PCL	192	288	0.001	.	480	200	885	54	45	615	491	124
	417	cattle	1	0	0	.	.	PPF	242	461	0.016	.	704	420	960	70	41	448	321	128
	418	cattle	1	0	0	.	.	POS	279	559	0.026	.	838	564	676	100	58	254	203	51
Lanyasunya *et al*., 2006	419	Goats	0	0	25	108	.	*CdL*	201	462	0.057	.	663	522	893	177	205	360	227	133

Obs: Observations; Graz: Grazing; G-supp: Grain supplement; For-supp: Forage supplement; Diet CP: Diet crude protein; Diet NDF: Diet neutral detergent fibre; ftype: Feed type; *a*: instantly degradable fractions; b: insoluble but slowly degradable fraction; c: rate of degradation PD: Potential degradability; ED: Effective degradability; CP: Crude protein; NDF: Neutral detergent fibre; ADF: Acid detergent; Hem: Hemicellul