COURSE GUIDE

ANP 502
RUMINANT NUTRITION

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Printed: 2020

ISBN: 978-978-970-186-5

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INTRODUCTION

Introduction to Ruminant Nutrition is a 500 level two unit course leading to B.Sc Agriculture degree. The course can also be offered by any other student of agriculture who may be interested in ruminant animal production. This course is concerned with the nutrition and digestive processes of ruminant animals. This entails knowing the accurate feed and water requirement of the animal. This course will therefore, enable you acquire the knowledge of the physiology and microbial environment of the ruminant and the different processes involved in nutrient evaluation.

This course offers you a thorough understanding of the group of animals that chew the cud. These set of animals are those that feed on plant materials and utilize them for the production of various products like meat, milk, hides and skin and so many other agro-based products and by-products. The course teaches about the importance of this class of animals, the various breeds, and how to manage them. The management of the weaners or the weaned animals to maturity and other production purposes in terms of their feeds and feeding was also addressed. It also teaches about the various types of housing and equipment available as well as the management practices you need to carry out in order to maintain healthy animals on the farm. The course material also teaches about the common ruminant disease that could be encountered on a farm and how they could be treated or controlled. Processing of the various products and there marketing procedures were also discussed. This course also prepares you for the advanced level courses such as Beef Production, Dairy Cattle Production and Sheep and Goat Production which you may do if you choose to specialize in Animal Science.

COURSE AIM

Ruminant Nutrition is designed to provide you with the knowledge of the nutrient requirements of the ruminant animal and the processes and pathways through which these nutrients are properly utilized by the animal in the digestive tract.

COURSE OBJECTIVES

On successful completion of the course, you should be able to:

- Explain the rumen environment, physiology and metabolic pathways
- Explain the different systems of energy and protein partitioning

- Formulate rations for ruminant and carry out proximate analysis
- Mention the different food additives, nutritional disorders and how to manage them.

WORKING THROUGH THIS COURSE

You are expected to study and understand the content of this course. Each unit must be properly studied for good comprehension of the contents. By the end of each unit, you are expected to answer the questions therein and submit as appropriate when directed by the administration of the University. These questions are like continuous assessment. You are expected to sit for an examination on completion of the course. The course duration shall take about 17 weeks of learning. Therefore, you must be able to organise your time to achieve this successfully. Tutorial session will be available and it is advisable for you to attend in order to be able to assess and compared yourself with your peers and clarify any area that you do not properly understand.

THE COURSE MATERIAL

Major components of the course material are:

- The Course Guide
- Study Units
- The References/Further Reading, that will be provided at the end of each unit are necessary supplements to the course material.
- For further studies on Youtube:

https://www.youtube.com/watch?v=LVQJNrYBQVs
https://www.youtube.com/watch?v=muf8ZA3F2mA
https://www.youtube.com/watch?v=3xQ83mbfn5s
https://www.youtube.com/watch?v=YK6e_6QhsJo
https://www.youtube.com/watch?v=5OsmJ_ERO3g
https://www.youtube.com/watch?v=_6NDYaFZ9fs
https://www.youtube.com/watch?v=OWIktxwPTzo

STUDY UNITS

Module 1 Rumen Environment, Physiology and Metabolic Pathways

Unit 1 Microbiology of the Rumen
Unit 2 Physiology of Rumen Action

Unit 3 Metabolic Processes and Pathways

Module 2 Nutrients Evaluation and Formulation of Rations for Ruminant

Unit 1 Determination of Digestive Coefficients and Balance Trials
Unit 2 Systems of Energy Partitioning
Unit 3 Systems of Protein Partitioning
Unit 4 Proximate Analysis
Unit 5 Ration Formulation

Module 3 Water Metabolism, Nutritional Disorders and Feed Additives in Ruminants

Unit1 Water in Relation to Nutrition and Water Metabolism, Requirements and Their Interrelationship in Nutrition
Unit 2 Feed Additives
Unit 3 Nutritional Disorders

ASSESSMENT

The assessment of the course shall be in two parts. The Tutor-Marked Assignments (TMAs) will take a part while the end of course written examination takes the second part. As a result, you must do the TMAs applying the knowledge and techniques learnt in each unit. The assignment must be submitted to your tutor/facilitator for assessment in accordance with the set time in the presentation schedule. The TMAs assessment will constitute 30% while the written examination account for 70% of the total mark for the course.

TUTOR-MARKED ASSIGNMENT

The TMA is a continuous assessment component of your course. It carries 30% of the total score. You will be given four TMAs to answer. Three of these must be answered before you are allowed to sit for the end of the course examination. The TMA would be given to you by your facilitator and you should submit after you have done the assignment.

END OF COURSE EXAMINATION

The examination concludes the assessment for this course. It constitutes 70% of the mark for the whole course. You will be informed of the time for the examination.

SUMMARY

Ruminant Animal Production is a course that gives you a good understanding of the care and management of cattle, sheep and goats. It teaches the skills of rearing ruminants animals and covers areas such as types of ruminant animals, their importance, management practices, breeding, housing and equipments as well as disease control of these animals. Your knowledge, understanding and skill acquired in this course will enable you to venture into cattle, sheep and goat production either on subsistence or commercial scale.

Best wishes.

MAIN COURSE

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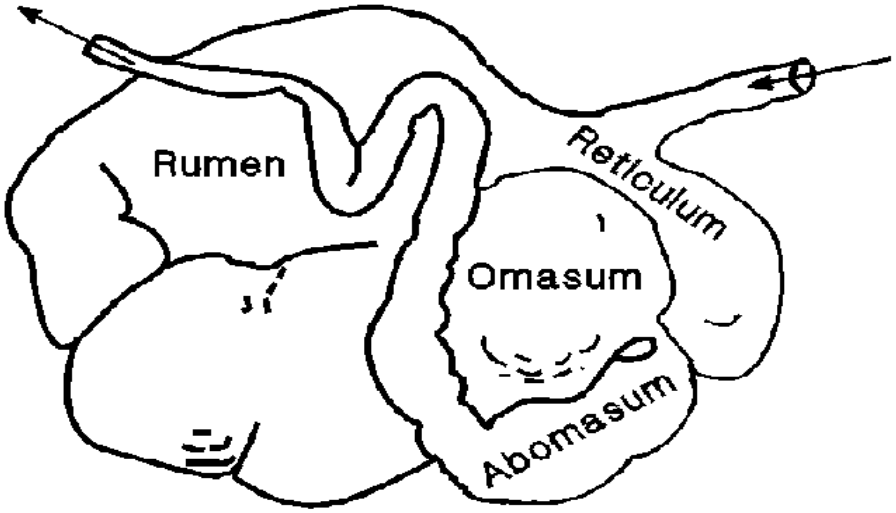
MODULE 1 RUMEN ENVIRONMENT, PHYSIOLOGY AND METABOLIC PATHWAYS

UNIT 1 MICROBIOLOGY OF THE RUMEN

1.0 INTRODUCTION

In your previous lectures on the introduction to animal production, you might have learnt about the difference between ruminant and non-ruminant animal. The herbivorous mammal is those that consume plants. In Many mammals are herbivorous and consume plant material high in cellulose. Consequently, these animals have evolved a close symbiotic relationship with the microorganisms which reside in their gut which aid the digestion of highly fibrous plant material for the host. The ruminant animal has evolved a specially adapted digestive system to enable, relatively efficient breakdown of feedstuffs and is split into four different compartments, the reticulum, rumen, omasum and abomasum.



The rumen is the main site of microbial digestion and is perhaps best described as a large fermentation vat which contains a complex array of different microorganisms which act synergistically to break down feed for the host animal. After extensive fermentation by the resident microbes, the products of fermentation, mainly organic volatile fatty acids (VFAs) and microbial protein then become available to the host. Up to 80% of an animal's energy requirements may be met by the production of VFAs and, depending on the diet, microbial protein leaving the rumen may account from between 50 and 90% of the protein that enters the small intestine which is available to the host. Conditions in the rumen are strictly anaerobic, although small trace amounts of oxygen may be found, particularly in close proximity to the rumen wall and in ruminal gas. Temperature is maintained between 38 to 42°C which enables optimum growth of the microbes present and if animals are fed a balanced ration of forage and grain the pH lies between 5.8 and 6.4 which is a favourable environment for the growth of a wide variety of different microorganisms.

Problems may occur however, if there is a sharp decrease in pH which may cause a marked change in the composition of the microflora. This may have significant consequences for the productivity and health of the host animal and in some instances these effects may not be realised until several weeks after the initial change.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- describe the rumen environment and different microorganisms present in the rumen
- explain their nutrient requirements and metabolism
- explain what roles they play

- describe how a perturbation or an imbalance in the microbial population may lead to several metabolic disorders which can have a direct impact on productivity and health.

3.0 MAIN CONTENT

3.1 The Rumen

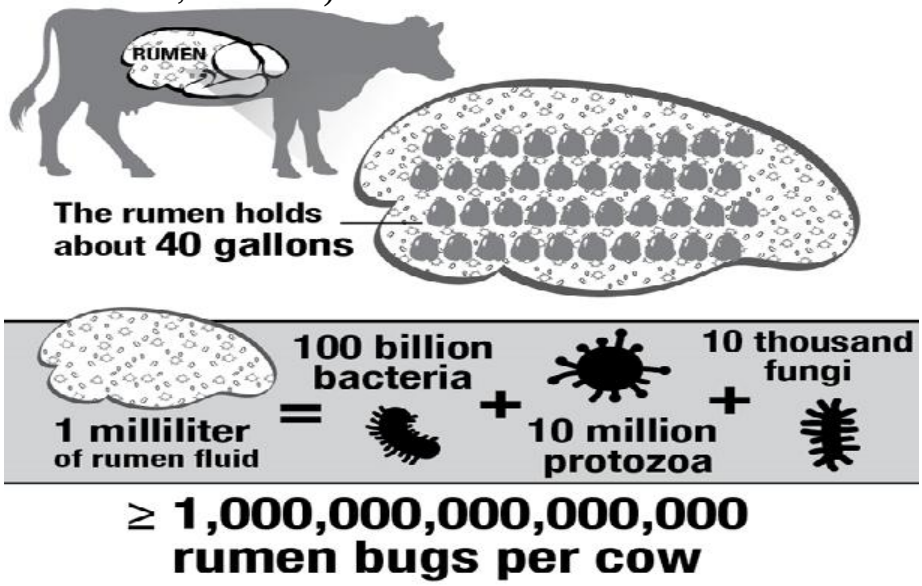
The rumen is the largest portion of the "stomach“. It is a fermentation vat filled with microbial populations which collaborate to digest cellulose and other polysaccharides, producing carbon dioxide, methane and organic acids. The rumen is an anaerobic environment; i.e. no oxygen. Ingested food first enters the rumen (pH 6.5, temperature of 30^0C) where it is microbially digested for 9 hours. The gaseous products of the microbial degradation are expelled from the animal (eructation). The material from the rumen, called the cud, is regurgitated. This regurgitated mixture of microorganisms and partially digested materials then travels through the abomasum, the omasum (pH ~ 2), and the rest of the digestive tract, for further digestion. Microbes are also capable of producing protein from simple nitrogenous compounds. Microbes produce B-complex vitamins. Microbes eventually die and are digested and absorbed for nutrients in the Small Intestine. Microbes are very useful for the digestion of forages but inefficient in the use of starches and proteins digestion. The abundant volatile fatty acids produced by fermentation in the rumen are readily absorbed across the rumen epithelium.

3.2 The Rumen Microbial Ecosystem

You have learnt the various components of the ruminant animal digestive system. The rumen is perhaps the best characterised gut microbial ecosystem of all, and for many years, nutritionists, microbiologists and physiologists have been studying the rumen with the aim of maximising productivity and improving overall host health through manipulating the rumen and its microbial ecosystem. The rumen contains a complex and diverse array of anaerobic bacteria, archaea, ciliate protozoa, anaerobic fungi, bacteriophage (viruses) and mycoplasmas. The role of the bacteria, protozoa and fungi in the breakdown of feedstuffs have been well documented, particularly for the bacteria, and although the bacteriophage and mycoplasmas have no known role in feed breakdown, due to their parasitic nature they can have a direct effect on the composition, dynamics and activity of the bacterial community.

3.2.1 Bacteria

Now let us look at the various types of microbes that are found in the rumen. The majority of bacteria found in the rumen are strictly anaerobic and the total number of bacteria present in the rumen is in excess of 1010 cells/ g of rumen contents. Only a very small percentage of bacteria from the rumen (1 to 10% depending on diet) may be cultivated under present laboratory conditions which may lead to a misrepresentation of the true ruminal bacterial community using culture based techniques which tend to select for Gram negative organisms from the *Cytophaga- Flexibacter- Bacteroides* phylum. However, due to the development of molecular techniques and the use of clone libraries this may now be corrected. To date more than 200 different species have been identified and this list is growing as more information is derived from non-culture based microbial community analysis and these organisms are added to the list. Most bacteria are classified on the basis of their fermentative capability - even those which cannot be cultured may be assigned putative roles on the basis of their relatedness to known microorganisms. The main substrates of digestion in the rumen are non-structural carbohydrates (starch, sugar, pectin), structural carbohydrates (hemicellulose, cellulose) and nitrogen containing compounds (protein, peptides, amino acids, ammonia).



Thus the main classifications on the basis of fermentative capacity are amylolytic (starch-degrading), cellulolytic (fibre degrading) and proteolytic (protein degrading) organisms. Other hydrolytic, fermentative and hydrogenotrophic bacteria are also present. It should be noted that no single species of bacterium has the ability to display all of the enzymatic properties required to degrade all dietary components, although many have evolved so that they can utilise more than one substrate. During the fermentation process one organism may produce several different fermentation products which may in turn be utilised as

a growth substrate by another organism, resulting in a cascade event, where everything is interlinked. This has led to interspecies dependence and interaction in the rumen with each microorganism carrying out a specific role and filling a particular ecological niche. Interactions between dietary particles, other microorganisms and even the host animal are therefore important factors which may affect the composition of the microbial population.

Any perturbation or sudden alteration of the composition of the microbial community can have very far-reaching consequences in terms of overall host health and productivity. Diet in particular can have a significant effect upon the diversity and population sizes of different groups of bacteria and can affect the relative proportions of Gram negative to Gram positive organisms. Bacterial numbers tend to be higher on high grain diets than on high forage diets, although this may be a simple reflection on ease of enumeration as bacteria attached to feed particles can be more difficult to count than bacteria associated with the liquid phase. When a high amount of concentrate is included in the diet, the Gram positive amylolytic bacteria can also tend to proliferate.

3.2.2 Protozoa

The protozoa are found at concentrations of 104 – 106 cells/ ml rumen contents and due to their relatively large size can account for up to 50% of the biomass. They primarily play a role in predation of other microorganisms, resulting in a contribution to nitrogen recycling, although some are able to digest starch and plant particles. Twenty-five different genera have been identified to date and divided into two different groups on the basis of their morphological traits, the holotrichs (*Isotrichidae*) and the entodiniomorphs (*Orphyroscolecidae*). Protozoa are of particular interest because they live in a symbiotic relationship with the methanogenic archaea, the methanogens profiting from hydrogen produced by the protozoa and the protozoa profiting by hydrogen removal. Ciliate protozoa, unlike the bacteria, are not essential for ruminal fermentation, as defaunation (removal of the protozoal population) has no drastic effect on overall fermentation. Consequently, defaunation has been examined as a potential method for either reducing methane production or of improving the flow of nitrogen from the rumen to the small intestine due to a decrease in nitrogen recycling. Protozoa are generally more sensitive to dietary changes than the bacterial population and there appears to be greater host animal to animal variation in the protozoal population than with bacterial populations. Protozoal diversity also tends to be reduced in browsing ruminants. This is thought to be due to these animals feeding on more

fibrous foods. It is perhaps also interesting to note that the protozoa are the last microorganisms to colonise the rumen of young animals and as a consequence their presence is taken as a sign of rumen maturity.

3.2.3 Fungi

Although the anaerobic fungi only make up a very small percentage of the total microbial population they are thought to act as the initial colonisers of plant material and play an important role in plant cell wall weakening due to their high hemicellulase and cellulose activity and the use of their rhizoids to pull apart the plant fibre. In so doing, they increase the rate of cellulose digestion by the bacteria as the bacteria are able to gain access more easily. Numbers generally are in the region of 103-105 zoospores/ml and they are particularly numerous on fibrous diets although they tend to be sensitive to sharp decreases in pH and therefore tend to be reduced on high concentrate diets.

3.2.4 Essential Nutrient Requirement of the Microbes

Water

- Cows require up to 100 L of drinking water/cow/day.
- Water maintains the rumen liquid environment, supports microbe metabolism, dilutes acids in the rumen.

Energy

Most energy for microbes to grow and multiply is sourced from:

- Starches (e.g. cereal grains)
- Sugars (e.g. lush forages, molasses, citrus pulp)
- Digestible fibre (e.g. forages, cottonseed hulls, palm kernel extract brewer’s grain).

Protein
Microbes use both true protein (e.g. protein meal pastures) non-protein nitrogen (e.g. urea) for growth and reproduction. Rumen microbes in turn become the largest source (>70%) of dietary protein for the cow.

Minerals
Calcium, phosphorus, sulphur and magnesium are essential for microbes to grow multiply.

Other microorganism classified based on food nutrients they degrade include:

1. Amylolytic bacteria
A large number of ruminal bacteria, protozoa and fungi are able to use starch or the intermediate products of starch degradation. Many species of ruminal bacteria actively degrade starch and/ or utilize the intermediate products of starch degradation (amylodextrins, maltose, and glucose), forming lactate as an end product of fermentation. In some instances, particularly in animals fed a high concentrate diet, the proportion of amylolytic bacteria can account for as much as 90% of the total culturable bacterial population, although it is hard to say at this moment the exact contribution that each genus or species makes to overall amylolytic activity and the formation of lactic acid. The numerically predominant starch degrading organisms with the highest amylolytic activity and the fastest growth rates are *Ruminobacter amylophilus*, *Streptococcus bovis* and *Selenomonas ruminantium*. In addition, isolates of *Bifidobacterium*, *Butyrivibrio fibrisolvens*, *Clostridium*, *Eubacterium ruminantium*, *Lactobacillus*, *Mituoskella*, *Prevotella*, *Succinimonas*, and *Succinivibrio* may all exhibit amylolytic, amylodextrinase and/or maltose utilising activity.

However, not a single one of these bacteria is equipped with the complete array of digestive enzymes for complete starch breakdown and thus the maximal digestion of starch to monosaccharides requires synergistic interaction among several bacterial species. Co-culture of *S. bovis*, *B. fibrisolvens* or *Prevotella ruminicola*, with *S. ruminantium* led to high growth rates and complete digestion of starch, again demonstrating the degree of interspecies interaction and dependence which may be found in the rumen. Most of these organisms involved in starch breakdown are relatively easy to grow under laboratory conditions and experiments with gnotobiotic lambs fed starchy diets in which a defined bacterial flora was established and normal growth and ruminal function was achieved, led to the suggestion that it is probable that the major bacteria involved in starch digestion have been identified and isolate. These experiments also demonstrated that amylolytic

protozoa and fungi are not essential elements for ruminal starch utilisation to occur as they were not included in the inoculum.

S. bovis has been implicated as the "bad guy" in terms of excessive lactic acid production in the rumen. A sudden increase in rapidly fermentable carbohydrate in the diet may in some instances cause the proliferation of this Gram positive organism which when energy is readily available will switch to the production of lactate. Even though this population can increase, it does not maintain high levels for a long period of time, so is probably best regarded as an initiator organism in that it can produce the conditions whereby an increase in the lactic acid bacteria can occur, and an increase in its numbers is generally regarded as the first step in the chain of events which can lead to the downward spiral into acute lactic acidosis. It should be noted however, that if the animal is allowed to adapt to the inclusion of concentrate in the diet, or active dry yeast is included in the diet, this organism will not get the chance to proliferate to the same extent.

Even though not essential for starch breakdown to occur, ruminal protozoa do play a role in engulfing and ingesting starch particles which may also have bacteria attached to their surface. This engulfment process is believed to limit access to the starch by the rapidly fermenting amylolytic bacteria and slows its degradation and the consequent lowering of ruminal pH. The rate of starch uptake varies greatly with species, with *Entodinium* spp. engulfing starch grains very rapidly. Nearly all of the larger entodiniomorph protozoa are amylolytic. Starch is broken down to maltose and then glucose and either used as an energy source or stored in the ectoplasm. The rate of starch uptake and breakdown is governed by the concentration of starch or amylopectin inside the protozoa.

2. Fibrolytic bacteria, fungi and protozoa

Fibre breakdown in the rumen is catalysed by a complex community of fibrolytic microorganisms. Fibrolytic bacteria tend to degrade the more readily digestible fibrous structures and rely on help from the ruminal fungi to weaken the plant cell wall. Thus optimal fibre degradation and ruminal fermentation will occur when ruminal conditions produce an environment conducive to the growth of these organisms.

The major fibrolytic bacteria include the Gram negative organism *Fibrobacter succinogenes* and two species of Gram positive bacteria, *Ruminococcus albus* and *Ruminococcus flavefaciens*. Fibrolytic activity and growth of these organisms are severely affected by low pH. *In vitro* incubations have shown that below pH 6 the growth and enzymatic activity of these major fibrolytic bacteria is inhibited. This is of

particular note when animals are fed high concentrate diets where ruminal pH is regularly below pH 6. Unlike most ruminal bacteria which can ferment carbohydrates and are capable of using numerous monosaccharides and disaccharides as growth substrates, *F. succinogenes* and the ruminococci are nearly solely restricted to cellulose and its hydrolytic products as growth substrates.

F. succinogenes possesses a complex battery of fibrolytic enzymes and is one of the few microorganisms isolated from the rumen which is capable of digesting crystalline cellulose. Endocellulase, endoxylanase and licheninase activity from several glycosyl hydrolase families have all been identified in this organism. This organism can interact synergistically with non-cellulolytic bacteria during forage digestion. Co-culture of *F. succinogenes* with the hemicellulolytic bacterium *Prevotella ruminicola* resulted in a 2-fold increase in the breakdown of orchard grass. *Ruminococcus albus* and *Ruminococcus flavefacie*ns also possess a large number of glycosyl hydrolases involved in the breakdown of cellulose and hemicellulose, several which have been isolated, purified or cloned. Both *R. albus* and *R. flavefaciens* have high xylan degrading activity. At least seven different endoglucanases have been identified in *R. albus* as well as a β-glucosidase. The cellulose system of *R. flavefaciens* is composed of several endoglucanases, an exoglucanase and a cellodextrinase.

Other important bacteria involved in fibre breakdown include the *Butyrivibrio* and *Prevotella* spp. Although cellulolytic strains of *Butyrivibrio* have been isolated from the rumen, this trait is generally lost upon cultivation under laboratory conditions. It does however retain its ability to rapidly utilise xylans and an abundance of xylanase genes have been identified. This group of organisms is thought to be one of the most metabolically versatile ruminal bacteria and can use simple sugars, starches, pectic polysaccharides and other non-cellulolytic polymers for growth. It is also one of the main organisms involved in ruminal biohydrogenation and the metabolism of linoleic acid (LA) but again is an organism sensitive to decreases in ruminal pH. *Prevotella* spp. are numerically predominant under several different dietary regimes and in some instances can comprise 60% of the total bacterial population. They can exclusively degrade the non-cellulose components of plant cell walls and possesses several xylanases and are an important contributor to xylan degradation in the rumen. These organisms are also of particular interest in the breakdown of dietary protein and peptides by virtue of their high proteolytic and peptidolytic activity. *Lacnospira multiparus* is the most major pectinolytic bacterium and posseses both an endo-acting pectate lyase and an exo-acting polygalacturanase

digalacturonohydrolase which cleaves polygalacturonate to galacturonate residues.

The fungi have an important role in fibre digestion because they are able to penetrate both the cuticle and cell wall of lignified tissue, suggesting the presence of cutinase activity. When incubated with barley straw, increased degradation was observed by the fungi when compared with fibrolytic bacteria. Filamentous growth by the fungi aids its ability to penetrate plant tissue. These organisms have a broad range of highly active fibrolytic enzymes and are the only rumen microorganisms with exocellulase activity.

They have the capacity to attack all carbohydrate components of the cell wall and can slowly solubilize lignin. However, they are relatively slow growing and their ability to persist in the rumen is limited by their growth rates which are much lower than the rumen dilution rate. The best characterised ruminal fungi are the *Neocallimastix* spp. which is highly efficient at degrading crystalline cellulose. Fibrolytic activity and growth of this organism may be enhanced by co-culture with hydrogen-utilizing methanogens, but may be repressed by *Ruminococcus* spp. This antagonistic effect only affects the cellulases of the fungi but not its growth, therefore only cellulolytic activity is affected and appears to be due to the production of extracellular proteins which bind either to the cellulose substrate or the fungal cellulase. Numbers of anaerobic fungi tend to be highest on highly fibrous diets and diminish with increasing concentrate.

Approximately 25 – 33% of fibre breakdown in the rumen is protozoal. Defaunation, or removal of the protozoa, results in a decrease in fibre breakdown. All of the rumen entodiniomorphid protozoa, except for *Entodinium* spp. possess cellulase activity, with highest activity in *Eudoplodinium maggi*. Xylanases are also present and a broad range of glycosidase activities are observed. Thus fibre breakdown is carried out by a complex consortium of different microorganisms, key members of which can be significantly influenced by changes in diet or by interactions with other microorganisms.

Proteolytic bacteria

The breakdown of dietary protein in the rumen is a complex process that involves many different microbes that provide the necessary enzymes to hydrolyse peptide bonds. The bacteria are the main contributors to protein breakdown, but protozoa and fungi may also play a role. Protein is first broken down to oligopeptides, and then small di- and tripeptides, amino acids and finally ammonia and these substrates are then used as a source of nitrogen for microbial growth and protein synthesis. The

ruminant is relatively unique in that the majority of protein which is actually available to the host is in fact derived from the microbial population. Unfortunately problems can occur when proteolysis occurs in excess of microbial requirements.

Ammonia is formed which, again if in excess of microbial requirements, is absorbed across the rumen wall, metabolized to urea in the liver and excreted, resulting in a loss of nitrogen from the system and a problem in terms of environmental nitrogen pollution. Several factors may affect the rate and extent of protein degradation. These include the type of protein, in terms of its structure and solubility; interactions with other nutrients, particularly carbohydrate availability; the composition of the microbial population which may in turn be affected by diet, ruminal dilution rate and ruminal pH; and plant proteinase activity, which may also contribute to the breakdown of its own cell protein.

One of the key organisms involved in the breakdown of protein in the rumen are the *Prevotella* sp. Not only is this group of organisms numerically predominant but they are involved in every step of the proteolytic cascade and they are the only ruminal organisms which have been identified to date that possess dipeptidyl peptidase (DPP) activity.
This is of particular importance as this is the main mechanism by which oligopeptides are broken down in incubations with whole rumen fluid. Not many bacteria possess this type of activity - even in other microbial ecosystems the common bacterial oligopeptidase activity is aminopeptidase activity whereby the oligopeptide is broken down by sequential removal of a single amino acid from the N-terminus. DPP activity is seen more in mammalian systems and a dipeptide is removed in a sequential manner from the N-terminus of the oligopeptide. This results in the formation of smaller di- and tripeptides which are further degraded by separate di- and tripeptidases to free amino acids. Inhibitors which targeted the DPP activity of the *Prevotella* were effective at reducing peptide breakdown and subsequently ammonia production during *in vitro* incubations.

The Hyper Ammonia Producing (HAP) bacteria are also of particular note due to their high deaminase activity. Although not numerically predominant, they have a real impact on deamination due to their high rates of ammonia formation. The HAP groups of organisms are very diverse but one defining characteristic is that they are all sensitive to monensin and the majorities are assacharolytic and rely on the breakdown of amino acids as a source of carbon and nitrogen for growth. A decrease in their populations leads to a decrease in ammonia production and improved nitrogen retention. As we enter a more environmentally aware era, strategies to reduce excessive proteolysis,

peptidolysis and deamination and improve nitrogen retention and the flow of nitrogen from the rumen to the small intestine are being studied.

SELF-ASSESSMENT EXERCISE

1. Discuss the rumen and rumen microbial ecosystem.
2. Write short notes on the Bacteria, Protozoa and fungi.
3. What are the essential nutrient requirements of the rumen microorganisms?
4. Describe the rumen microorganisms based on food particles the degrade.

4.0 CONCLUSION

In this unit, you have studied the rumen environment and the roles of the different microorganisms contained in it. The nutrient requirement of these organisms was also discussed.

5.0 SUMMARY

In this unit, you have learnt the digestive system of ruminant animal has anatomical features which makes it different from the non ruminant. These features enable the ruminant to digest plant materials and utilise it. The rumen been the largest stomach compartment of the ruminant animal is essential in its digestion as it is populated with a larger number of microorganisms such as the bacteria, fungi and protozoa with ensure food degradation.

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe the rumen environment.
2. List the three microorganisms found in the rumen and four essential nutrients they need.
3. Write short notes on the following i) Proteolytic bacteria ii) Amylolytic bacteria.

7.0 REFERENCES/FURTHER READING

Mackie, R.I., McSweeney, C.S. & Aminov, R.I. (1999). Rumen, In: *Encyclopedia of Life Sciences*, http://www.els.net, London: Nature Publishing Company.

Hungate, R. E. (1966). *The Rumen and its Microbes*. New York: Academic Press.

Preston, T.R. & Leng, R.A. *Matching Ruminant Production Systems with 1987 Available Resources in the Tropics and Sub-Tropics*. Penambul Books: Armidale, Australia Pp. 245.

UNIT 2 PHYSIOLOGY OF THE RUMEN

CONTENTS

1.0INTRODUCTION

Ruminant are herbivorous and are involved in the consumption of plant material high in structural carbohydrates. Consequently, these groups of animals have evolved a close symbiotic relationship with the micro-organisms that reside in their gut which are engaged in the digestion of highly fibrous plant material for the host. The ruminant animal has evolved a specially adapted digestive system to enable, for the best part, a relatively efficient breakdown of feedstuffs and is divided into four different compartments, the reticulum, rumen, omasum and abomasum.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- know the digestion of carbohydrates, proteins and fats
- be familiar with the processes of eructation, rumination, motility of the rumen and reticulum and salivation.

3.0 MAIN CONTENT

3.1 Ruminant Digestion

Digestion of carbohydrates
Plant tissues contain about 75% carbohydrates of one kind or another, and provide the primary source of energy for both the ruminal organisms and the host animal. In ruminants the major part of all carbohydrates, including the complex carbohydrates such as cellulose and hemi-cellulose, is digested by bacterial action in the rumen. During microbial digestion an appreciable amount of methane gas is produced. Approximately 6 to 7% of the food energy of the ruminant is lost as methane. The main end-products of carbohydrate digestion are volatile fatty acids (VFAs). Of these, acetic acid forms the major proportion, followed in declining order by propionic, butyric, and valeric acids. The VFAs are absorbed into the bloodstream through the rumen wall, and constitute 66 to 75% of the energy derived from the feed. Carbohydrates, such as sugars and starches, which escape ruminal digestion, are digested in the abomasum, and the end-products are absorbed through the small intestine.

Volatile Fatty Acids (VFA)
Volatile fatty acids (VFA) are produced in large amounts through ruminal fermentation and are of paramount importance in that they provide greater than 70% of the ruminant's energy supply. Virtually all of the acetic, proprionic and butyric acids formed in the rumen are absorbed across the ruminal epithelium, from which they are carried by ruminal veins to the portal vein and hence through the liver. Continuous removal of VFA from the rumen is important not only for distribution, but to prevent excessive and damaging drops in pH of rumen fluid.

- **Acetic acid** is utilised minimally in the liver, and is oxidized throughout most of the body to generate ATP. Another important use of acetate is as the major source of acetyl CoA for synthesis of lipids.
- **Proprionic acid** is almost completely removed from portal blood by the liver. Within the liver, proprionate serves as a major substrate for gluconeogenesis, which is absolutely critical to the ruminant because almost no glucose reaches the small intestine for absorption.
- **Butyric acid**, most of which comes out of the rumen as the ketone beta-hydroxybutyric acid, is oxidised in many tissues for energy production.

Digestion of protein

Dietary protein, as you know like dietary carbohydrates, is fermented by rumen microbes. The majority of true protein, and non-protein nitrogen (NPN), entering the rumen is broken down to ammonia, which bacteria require for synthesizing their own body protein. Ammonia is most efficiently incorporated into bacterial protein when the diet is rich in soluble carbohydrates, particularly starch. Ammonia, in excess of that used by the micro-organisms, is absorbed through the rumen wall into the blood, carried to the liver, and converted to urea; the greater part is excreted in the urine. Some urea is returned to the rumen *via* the saliva, and also directly through the rumen wall. The undegraded true protein fraction, plus the microbial protein, passes from the rumen to the abomasum, where it is digested, and absorbed into the bloodstream through the walls of the small intestine.

Digestion of fats

Ruminant and non-ruminant animals differ with respect to strategies for lipid digestion, primarily because of the nature of the dietary lipids and the microbial processes within the rumen. Bacteria and protozoa in the rumen hydrolyse complex lipids (glycerides) into their constituent long-chain fatty acids, sugars, organic bases (choline, ethanol-amine, serine) and glycerol with the glycerol and sugars fermented rapidly into volatile fatty acids (mainly acetic, propionic and butyric). Thus, the rumen is the primary site of complex lipid hydrolysis, rather than the small intestine as in non-ruminants and pre-ruminants.

Physiology of the Rumen

Salivation

Ruminants produce prodigious quantities of saliva. Published estimates for adult cows are in the range of 100 to 150 liters of saliva per day. Aside from its normal lubricating qualities, saliva serves at least two very important functions in the ruminant:

(a) Provision of fluid for the fermentation vat

(b) Alkaline buffering - saliva is rich in bicarbonate, which buffers the large quantity of acid produced in the rumen and is probably critical for maintenance of rumen pH.

Reticulorumen motility

Ruminal contractions constantly flush lighter solids back into the rumen, the smaller and more dense material tends to be pushed into the reticulum and cranial sac of the rumen, from where it is ejected with microbe-laden liquid through the reticulo-omasal orifice into the omasum. An orderly pattern of ruminal motility is initiated early in life and, except for temporary periods of disruption, persists for the lifetime

of the animal. These movements serve to mix the ingesta, aid in eructation of gas, and propel fluid and fermented foodstuffs into the omasum. If motility is suppressed for a significant length of time, ruminal impaction may result. A cycle of contractions occurs 1 to 3 times per minute. The highest frequency is seen during feeding and the lowest when the animal is resting.

Rumination

Ruminants are well known for "cud chewing" referred to as rumination. Rumination is regurgitation of ingesta from the reticulum, followed by remastication and reswallowing. It provides for effective mechanical breakdown of roughage and thereby increases substrate surface area to fermentative microbes.

Regurgitation is initiated with a reticular contraction distinct from the primary contraction. This contraction, in conjunction with relaxation of the distal oesophageal sphincter, allows a bolus of ingesta to enter the esophagus. The bolus is carried into the mouth by reverse peristalsis.
Fermentation in the rumen generates enormous, even frightening, quantities of gas, about 30-50 liters per hour in adult cattle and about five liters per hour in a sheep or goat.

Eructation or belching

As you know during fermentation, gases are evolved so eructation or belching is how ruminants continually get rid of fermentation gases. The fluid in the bolus is squeezed out with the tongue and reswallowed, and the bolus itself is remasticated, then reswallowed. Rumination occurs predominantly when the animal is resting and not eating, but that is a considerable fraction of the animal's lifespan. An eructation is associated with almost every secondary ruminal contraction. Eructated gas travels up the oesophagus at 160 to 225 cm per second and, interestingly, a majority is actually first inspired into the lungs, then expired. Anything that interferes with eructation is life threatening to the ruminant because the expanding rumen rapidly interferes with breathing. Animals suffering bloat die from asphyxiation. The processes described above apply to adult ruminants.

SELF-ASSESSMENT EXERCISE

i. Explain the digestion of Carbohydrates, Protein and Fats.
ii. Write short notes on the following: Salivation, Reticulorumen Motility, Rumination and Eructation/belching.

4.0 CONCLUSION

In this unit, you are learnt the digestion of carbohydrates, protein and fats and the different products of this pathways. Also the physiology of the rumen has been explained to you.

5.0 SUMMARY

In this unit, you learnt, the rumen is an essential part of the digestive system of the ruminant animal. In the rumen physiological processes like salivation, rumination and eructation help to make the nutrients easily absorbed in the digestive tract of the ruminant.

6.0 TUTOR-MARKED ASSIGNMENT

1. Explain the digestion of carbohydrate and fats.
2. List the major volatile fatty acids.
3. Discuss the following i) eructation ii) Rumination iii) Reticulorumen motility.

7.0 REFERENCES/FURTHER READING

Allison, Leek, & Bergman (1993). In: "Dukes Physiology of Domestic Animals" by Swenson & Reece (ed.).

Sallholz, J.E., Boylan, L.M. & Driskell, J.A. (1999). Nutrition Chemistry and Biology. (2nd ed.). Published CRC Press, LLC.

Voet, D. & Voet, J.G. (2004). *Biochemistry*. (3rded.) United States of America:Published by Wiley.

UNIT 3 METABOLIC PROCESSES AND PATHWAYS

1.0INTRODUCTION

Metabolism refers to the sum total of the chemical and biochemical reactions occurring in each cell and therefore in the entire animal. Reactions that build and maintain cellular components are called anabolic and those that breakdown cellular components like carbohydrate, protein and fat are called catabolic. The processes involved are therefore called metabolic pathways.

2.0OBJECTIVE

By the end of this unit, you will be able to:

- explain the metabolic processes of carbohydrate, protein and fats digestion.

3.0 MAIN CONTENT

3.1 Carbohydrate Metabolism

Carbohydrates are the most important source of energy and the primary precursors of fat and sugar (lactose) in cows' milk. The microorganisms living in the rumen allow the animal to obtain energy from fibrous carbohydrates (cellulose and hemicellulose) which are bound with lignin in plant cell walls or fiber. Since fiber is bulky it is retained in the rumen where the cellulose and hemicellulose are fermented slowly. As plants mature, the lignin content of fiber increases and the extent of cellulose while hemicellulose fermentation in the rumen decreases. Fiber in the form of long particles is essential to stimulate rumination. Rumination enhances the breakdown and fermentation of fiber. It stimulates ruminal contraction, and it increases the flow of saliva to the rumen. Saliva contains sodium bicarbonate (baking soda) and phosphate salts which help to keep the acidity (pH) of the rumen content almost neutral. Rations lacking fiber generally result in a low percentage of fat in milk and contribute to digestive disturbances (e.g., displaced abomasum, rumen acidosis).

Non-fibrous carbohydrates (starches and simple sugars) are fermented rapidly and almost completely in the rumen. Non- fibrous carbohydrates increase the energy density of a diet, which improves the energy supply and determines the amount of bacterial protein produced in the rumen. However, non-fibrous carbohydrates do not stimulate rumination or saliva production and, in excess, they may impede fiber fermentation. Thus, the balance between fibrous and non-fibrous carbohydrates is important in feeding ruminants. In a lactating dairy cow, the rumen, the liver and the mammary gland are the major organs involved in the metabolism of carbohydrates.

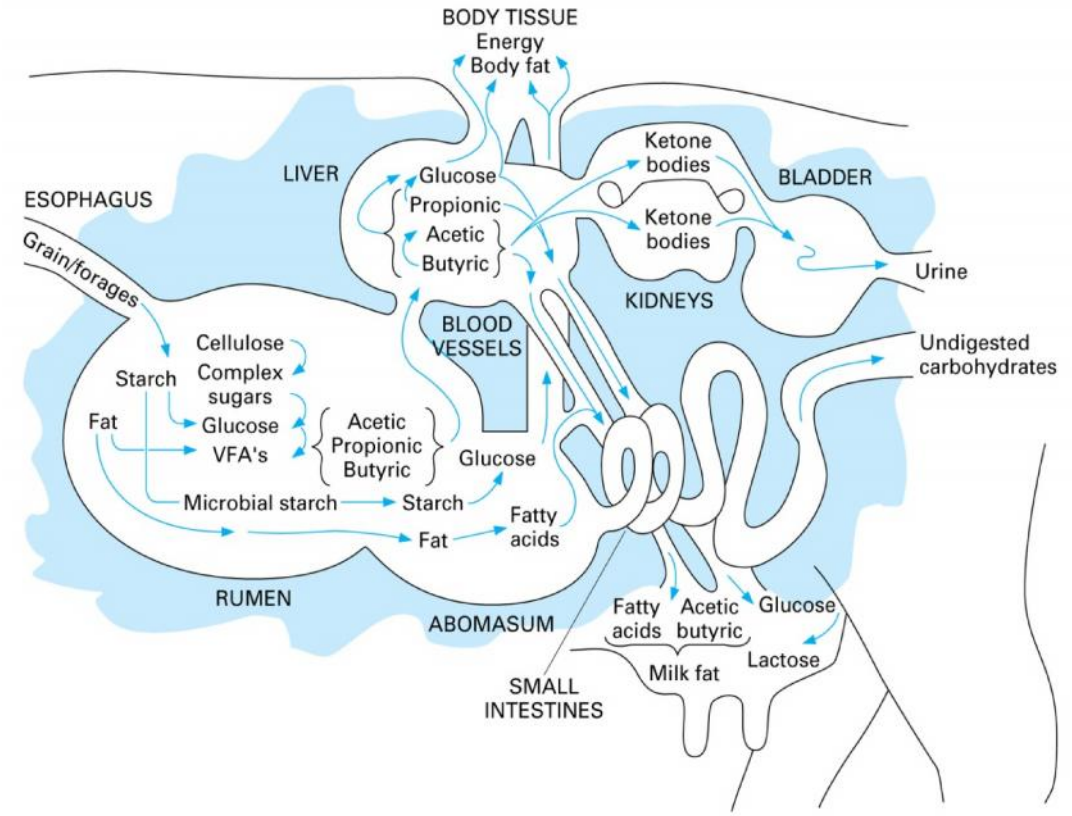


Figure 2: Diagram illustrating Metabolism of Carbohydrate

3.1.1 Volatile Fatty Acid Production and Utilisation in the Rumen

During ruminal fermentation, the population of microorganisms (chiefly bacteria) ferments the carbohydrates to produce energy, gases (methane - CH4 and carbon dioxide - CO2), heat, and acids. Acetic acid (vinegar), propionic acid and butyric acid are volatile fatty acids (VFA) and make up the majority (>95%) of the acids produced in the rumen. The CO_2 and CH_4 are eliminated through belching, and the energy of the CH4 is lost. Unless heat is necessary to maintain body temperature, the heat produced during fermentation is dissipated. The VFA, end-products of microbial fermentation, are absorbed through the rumen wall. Most of the acetate and all the propionate are transported to the liver, but the majority of butyrate is converted in the rumen wall to a ketone body called β-hydroxybutyrate. Ketones are important sources of energy (fuel for combustion) for most tissues in the body. Ketones come primarily from the butyrate produced in the rumen, but in early lactation, they also come from the mobilisation of adipose tissue.

3.1.2 Glucose Production and Utilisation in the Liver

Most of the propionate is converted to glucose by the liver. In addition, the liver can use amino acids for glucose synthesis. This is an important process because there is normally no glucose absorbed from the digestive tract and all the sugar found in the milk must be produced by the liver. An exception arises when animals are fed large amounts of concentrates rich in starch or a source of starch resistant to ruminal fermentation. Then, the starch that escaped fermentation reaches the small intestine. The glucose formed during intestinal digestion is absorbed, transported to the liver and contributes to the supply of glucose to the animal. Lactate is another possible source of glucose in the liver. Lactate is found in well preserved silages, but lactate production in the rumen occurs when there is excess starch in the diet. This is undesirable because the rumen environment become acidic, fiber fermentation stops and in extreme cases the animal stops eating.

3.2 Protein Metabolism in Ruminants

Due to the synthesis of microbial protein in the rumen, the animal has the ability to survive and produce some milk without a source of a dietary protein. Rumen microbes are capable of utilising non-protein nitrogen (primarily ammonia) to synthesise microbial protein. The microbes are subsequently digested by the animal and the amino acids produced will be used to supply the animal's amino acid requirements for various production purposes. The presence of rumen microbes makes it possible for ruminant animals to utilise non-protein sources such as urea to produce a high quality microbial protein.

Dietary protein consumed by the ruminants has three fates:

1 Fermentation in the reticulo-rumen by ruminal microbes
2 Enzymatic hydrolysis in the small intestine
3 Excretion of indigestible protein in feces

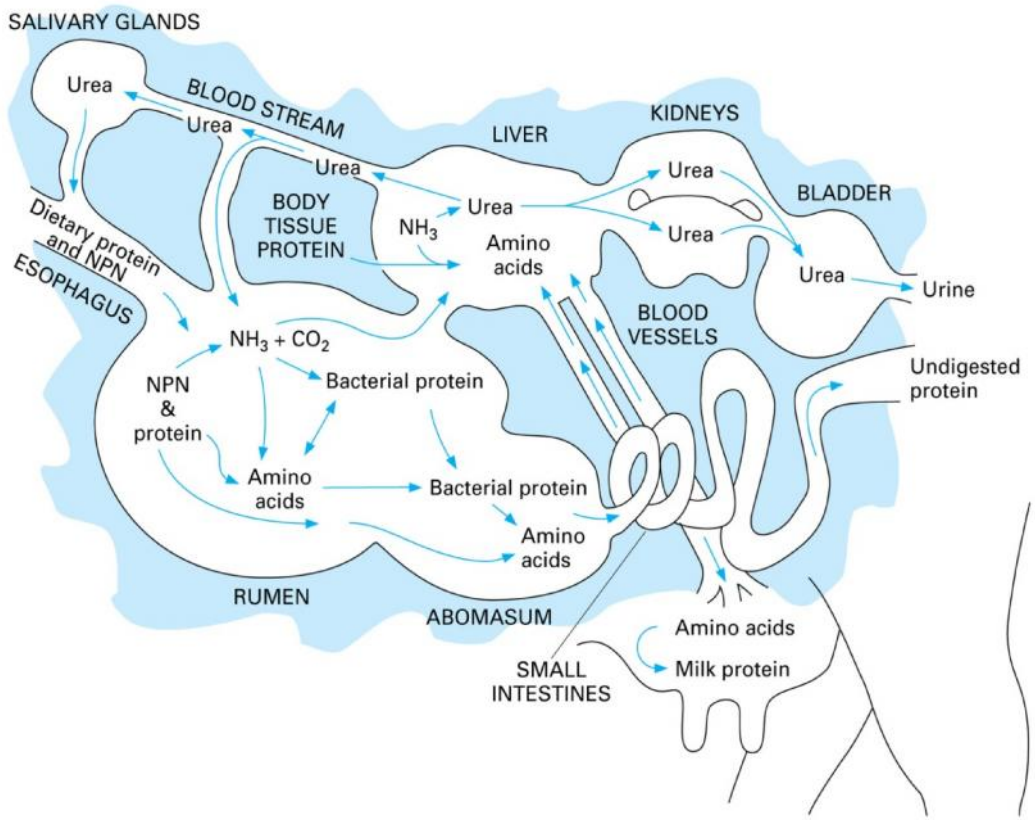


Figure 3: Diagram illustrating Metabolism of Protein

3.2.1 Ruminal protein degradation

Rumen microbes, especially bacteria, degrade most of dietary protein entering the rumen. However, some of dietary protein will escape ruminal degradation (RUP). Some of the RUP will be digested in the small intestine by proteolytic enzymes produced in the pancreas protein and some of it will be excreted in feces. The end product of dietary protein degradation in the rumen is ammonia and microbial protein. The end product of digestion of RUP and microbial protein in the small intestine is amino acids.

Two major steps are involves in protein degradation in the rumen:

1 Hydrolysis of peptide bonds to produce peptides and amino acids.
2 Deamination and degradation of amino acids.

3.2.2 Hydrolysis

Protein hydrolysis is a multi-step process. Insoluble dietary protein is solubilized and then hydrolysed by a variety of endo- and exo-peptidases, which cleave the peptide bonds. The hydrolysis of peptides occurs extracellularly by proteolytic enzymes associated with the

bacterial cell wall. Many of the protease enzymes produced by rumen microbes are "trypsin-like" in nature suggesting that proteolytic activities in the rumen can be reduced by trypsin inhibitors. Free peptides and amino acids are absorbed rapidly by rumen microbes and used as such or deaminated. Non-structural carbohydrate bacteria utilise peptides and amino acids as N sources.

3.2.3 Deamination

Metabolism of amino acids is the next step in protein degradation by rumen microbes. The main end product of amino acid deamination is ammonia. An important byproduct of amino acid deamination is branched chain VFA, which enhance the growth of cellulolytic bacteria. Ammonia produced from deamination of amino acids is used by structural carbohydrate bacteria use as a nitrogen source.

3.2.4 Metabolism of Urea

Urea is broken down rapidly in the rumen to ammonia by urease enzyme. This activity is combined with microbial synthesis from ammonia, enables ruminants to utilise urea entering the rumen either with the feed or in salivary secretion. Recycling of blood urea to the rumen allows ruminant animals to survive on diets very low in nitrogen. The amount of blood urea recycled to the rumen depends on the ammonia concentration in the rumen and plasma urea concentration. Plasma urea enters the rumen with the saliva or by diffusion through the ruminal wall. Microbes adhering to the ruminal epithelium have the ability to produce urease. The enzyme hydrolyses urea as it passes through the rumen to ammonia and CO2. High ruminal ammonia levels reduce recycling by inhibiting urease activity. Recycled nitrogen (urea) is useful only if it is incorporated into microbial protein. Incorporation of recycled nitrogen into microbial protein causes duodenal nitrogen flow to exceed nitrogen intake when the level of protein in the diet is low.

3.2.5 Ammonia Assimilation

Ammonia is the most important source of nitrogen for microbial protein synthesis in the rumen. The first step in ammonia uptake is transportation across the cell membrane. Glutamate is the first amino acid into which ammonia is assimilated. Once nitrogen has been fixed into an appropriate compound such as glutamatic acid, synthesis of amino acid from available energy and carbon sources must occur. Ammonia in excess of microbial protein synthesis in converted to urea

in the liver. Most of the urea will be excreted in the urine. Some however, will be recycled via saliva.

3.2.6 Non-Protein Nitrogen (NPN) Utilisation

As early as in1879 it was reported that NPN compounds may be utilised by ruminant animals as protein replacers (Weiske *et al.*) and it was further added by the findings of Loosli et al., (1949) and Duncan et al., (1953) that almost all the essential amino acids are synthesised in the rumen by the micro-organisms of rumen from NPN compounds. Several NPN compounds have been used experimentally in cattle feeding. These are broken down by the enzyme urease secreted by the rumen bacteria into ammonia and built up into bacterial protein. The bacteria then pass down the animal's (animal with fully functional rumen) digestive tract and are in turn digested by the cow, thus providing her with protein derived originally from relatively simple nitrogenous compounds.

Two NPN compounds have been proved effective and, where proteins are expensive, economic; these are urea and biuret (see table below for other sources). Urea, a constituent of urine, is produced synthetically for use as a fertilizer and animal feedstuff. In the latter, each granule is coated to reduce the hygroscopic nature of urea and make it free-flowing. Feed-grade urea contains about 42% nitrogen (262.5% crude protein equivalent --CPE). Biuret is a condensation product of urea. Feed biuret is not pure but contains some urea. It is more expensive than urea and has a somewhat lower protein equivalent (220%). Its virtue is that it is much less toxic.

Table 1: Non-protein nitrogen sources for ruminants

	Formula	Nitrogen Content	Protein equivalent[1]
			Percent
Ammonium acetate	$CH_3CO_2NH_4$	18	112
Ammonium bicarbonate	NH_4HCO_3	18	112
Ammonium carbamate	$NH_2CO_2NH_4$	36	225
Ammonium lactate	$CH_3CHOHCO_2NH_4$	13	81
Biuret	$NH_2CONHCONH_2H_2O$	35	219
Dicyanodiamide	$NH_2C(:NH)NHCN$	67	419
Glutamine	$NH_2CO(CH_2)_2CHNH_2CO_2H$	19	119
Glycine	$NH_2CH_2CO_2H$	19	119
Urea – pure	$(NH_2)_2CO$	46.7	292
Urea - feed grade	-	42 – 45	262 – 281
Oilseed meals	-	5.8 - 8.0	36 – 50

Where the level of protein in the ration is satisfactorily the addition of NPN is unjustified; where protein is deficient NPN is valuable. Thus, in the season of grass growth, NPN is not likely to have an important role, except possibly for very highly productive dairy cattle. If protein is cheap then, again, the use of NPN is not justifiable. However, during the dry season and whenever the price of protein is high and the feed low in protein, the feeding of NPN may be economically and nutritionally warranted. Nevertheless, NPN is not as *nutritionally* efficient as protein.

The utilisation of urea nitrogen for the synthesis of amino acids and proteins in the rumen is much dependent on the hydrolysis of urea and availability of carbon moiety in the rumen content. Supply of soluble carbohydrates improves its utilisation. Urea is utilised better when fed with molasses or starch. Molasses alone reduces the digestibility of legume cellulose and fibre, but with even small amounts of urea does *not* have this effect and urea/molasses (UM), by speeding up digestion, leads to increased appetite. Hence one important effect of UM in the dry season is a higher intake of rough coarse forages. Urea will dissolve in 1.5 times its own weight of water. It is essential to ensure that all is dissolved before adding molasses. As a supplement to dry-season

grazing, a simple mixture is weight/weight, 4% urea, 6% water, 90% molasses. Such mix will provide about 100 g urea per head per day equivalent to 290g protein. The feeding of NPN mixes can be done by one of several ways: by exposing in open drums, by providing rotating lick surfaces, by spraying on the carrier such as hay, cotton-seed hulls, or maize cobs without the grain or as blocks.

Let us have a look at some precautionary measures to take when feeding NPN

Precautionary measures will include the following:

- Introduce animals to NPN mixes gradually.
- Urea feeding should be spread over as much of the day as possible to reduce the rate at which ammonia is generated in the rumen.
- Effective mixing is essential to prevent any one animal from eating a dangerous quantity.
- Protect UM mixes from rain.
- Urea should not be fed a day before or after the administration of anthelmintics containing carbon tetrachloride.
- Unlike natural proteins NPN contains no sulphur hence a source of sulphur may increase the efficiency of urea feeding.

3.3 Fat Metabolism

Metabolism of fat in the ruminant involves hydrolysis of complex lipids (glycerides) into their constituent long-chain fatty acids, sugars, organic bases (choline, ethanol-amine, serine) and glycerol with the glycerol and sugars fermented rapidly into volatile fatty acids (mainly acetic, propionic and butyric). This process starts from the rumen my the bacteria, fungi and protozoa but is incomplete due to the toxic nature of some fatty acids hence, it is taken down to the lower digestive tract for further breakdown to units that can be absorbed.

3.3.1 Digestion Processes in the Rumen

Bacteria in the rumen split off the fatty acids (and sugars) from the glycerol backbone. The glycerol and the sugars released from glycolipids are fermented to the volatile fatty acids (VFA). The breakdown of dietary lipids by rumen bacteria generally occurs quite rapidly as the lipids are exposed during rumination and bacterial digestion of feed particles.

In addition, the process generally is essentially complete so that no monoglycerides or diglycerides pass to the lower digestive tract. The major exception to this would be when a highly saturated (or hydrogenated) triglyceride is fed. The fatty acids released in the rumen are not absorbed from the rumen, but rather will pass to the abomasum and then the small intestine, which is the primary site for absorption of the fatty acids.

However, the profile of fatty acids that reaches the intestine will be very different from what the animal has consumed. This is because of the extensive *biohydrogenation* that occurs in the rumen as a result of bacterial activity. Unsaturated fatty acids are toxic to many of the species of the rumen bacteria, particularly those that are involved in fiber digestion. Also, because of the anaerobic environment of the rumen, there is an excess of hydrogen that the microbial population is continually interested in getting rid of. From the standpoint of rumen carbohydrate fermentation, biohydrogenation is a favorable process because it reduces potential negative effects of unsaturated fatty acids on rumen fermentation of fiber.

3.3.2 Digestion Processes in the Small Intestine

The lipids that leave the rumen are predominantly free fatty acids (85-90%) and phospholipids (10-15%) found as part of microbial cell membranes. In the rumen, most of the free fatty acids are actually found as potassium, sodium, or calcium salts of fatty acids because of the near-neutral pH in the rumen contents (6.0 – 6.8). After passing through the acid conditions (pH ~2.0) of the abomasum, however, the fatty acid salts are dissociated and the free fatty acids will be found adsorbed (or “stuck”) to the surface of small feed particles that pass as part of the digestive contents. The fatty acids making up the free fatty acid portion will be predominantly saturated (80-90%), with about two-thirds stearic acid and about one-third palmitic acid. Non-ruminants would have a very difficult time trying to absorb such a profile of high-melting point, insoluble fatty acids, but ruminants have developed processes that result in saturated fatty acids being absorbed nearly as well as unsaturated fatty acids, and with much greater efficiency than in non-ruminants.

The key to absorption of fatty acids in both ruminants and non-ruminants is formation in the intestine of complexes called micelles, which are bi-layer disks consisting of bile salts (secreted in bile from the liver into the intestine by way of the gall bladder), phospholipids, and the insoluble lipids in the middle. Micelles are needed to move the fatty acids to the surface of the intestinal cells where they can be absorbed into the cells. In non-ruminants (and also in pre-ruminant calves),

monoglycerides that resultfrom digestion of triglycerides in the small intestine are needed for fat absorption. Bile salts and monoglyceride have portions of their molecular structure that can interact with aqueous systems (like the fluid in the intestinal lumen) as well as portions that can interact with lipids, so they form an "interface" between fat and water. In the absence of monoglycerides, non-ruminants are not able to absorb many fatty acids. In ruminants, however, a compound called lysolecithin takes the place of monoglyceride. Consequently, Mother Nature has ensured ruminants can efficiently absorb the mostly saturated free fatty acids presented to the intestine every day.

3.3.3 Intestinal Processing and Delivery of Dietary Fat

After absorption of fatty acids into intestinal cells, the fatty acids are reconverted to triglycerides by combining with glycerol produced from metabolism of blood glucose. The triglycerides are packaged into lipoprotein particles (chylomicrons or very low density lipoproteins, VLDL) in combination with cholesterol, phospholipids, and specific proteins. These proteins (called apoproteins) serve to direct the trafficking and use of the lipoprotein triglycerides. Because these lipoproteins are too large to pass directly into the venous blood stream draining the intestinal cells, they are secreted into the lymph, which is delivered back into the blood stream near the heart. After the blood is oxygenated through the lungs, the lipoproteins particles are delivered to various organs of the body such as the mammary gland, muscle, and heart that can use the triglycerides.

Triglycerides in chylomicrons or VLDL are broken down to free fatty acids by an enzyme called lipoprotein lipase that is found in the capillaries of these tissues. The free fatty acids then enter the cells where they can be formed back into triglycerides (such as milk fat) or burned to release energy that can fuel cell functions (such as contraction in skeletal or heart muscle). It should be noted from the scheme for lymphatic absorption described here that dietary fats do not reach the liver directly, in contrast to other absorbed nutrients like amino acids or propionate. Consequently, dietary fats do not contribute much to the fat accumulation in the liver (fatty liver) that is often observed around parturition.

In ruminant animals, oxidative or fuel use of long-chain fatty acids is more limited than in most non-ruminants. This may be due, at least in part, to the abundance of acetic acid from rumen fermentation. Acetate (the salt form of acetic acid present at normal body pH) is the most abundant oxidative fuel in ruminants, and seems to be more actively taken up and prepared for fuel use than long-chain fatty acids.

Consequently, the main use for fatty acids from dietary fats and oils will be for triglyceride synthesis. The small amounts of PUFA that escape through the rumen without being hydrogenated are very important for proper structure of membranes. The PUFA cannot be made in the ruminant's body and so must be absorbed from the intestine.

Intestinal cells primarily attach absorbed PUFA to phospholipids and cholesterol esters rather than triglycerides. In this way, the PUFA are protected from being burned for energy and instead are incorporated into cell membrane phospholipids. Here, they maintain normal structure and function of cell membranes. They also can be released and converted into important signaling molecules such as prostaglandins and leukotrienes.

SELF-ASSESSMENT EXERCISE

Discuss the following

i. Carbohydrate Metabolism as it involves i) Volatile Fatty Acid Production and Utilisation in the Rumen ii) Glucose production and utilisation in the liver.
ii. Protein Metabolism as it involves i) Ruminal Protein Degradation ii) Hydrolysis iii) Deamination iv) Metabolism of Urea v) Ammonia Assimilation vi) Non Protein Nitrogen (NPN) Utilisation.
iii. Fat Metabolism as it involves i) Processes in the Rumen ii) Processes in the Small Intestine iii) Intestinal Processes and Delivery of Dietary Fats.

4.0 CONCLUSION

In this unit you learnt how the different products of carbohydrate, protein and fat digestion are absorbed and utilised at different areas of the ruminant's digestive system.

5.0 SUMMARY

In this unit, you have learnt ruminal digestion and metabolism is an exergonic process that converts feedstuffs into short-chain volatile fatty acids (VFA), CO_2, CH_4, NH_3, and heat. Some of the free energy is trapped as ATP, and this energy is used to drive the growth of anaerobic ruminal microorganisms. The ruminants absorb VFAs and digest the microbial protein to obtain energy and amino acids. CH_4 and NH_3 represent losses of energy and nitrogen to the animal.

6.0 TUTOR-MARKED ASSIGNMENT

1. Describe the metabolism of Carbohydrate.
2. What is Deammination?
3. Explain the intestinal Processing and delivery of fat.

7.0 REFERENCES/FURTHER READING

Baldwin, R. L. (1995). Modeling Ruminant Digestion and Metabolism. London, UK:Chapman and Hall.

Kohn, R. A. & Boston, R. C. (2000). *The Role of Thermodynamics in Controlling Rumen Metabolism.* Pages 11-24 In Modelling Nutrient Utilisation in Farm Animals. J. P. Mcnamara, J. France, and D. E. Beever, (Eds.). Wallingford, UK:CABI Publishing.

Murphy, M. (2013). *Advances in Rumen Microbiology*. Pages 527-528 In: Energy and Protein Metabolism and Nutrition in Sustainable Animal Production. Springer.

MODULE 2

UNIT 1 DETERMINATION OF DIGESTIVE COEFFICIENTS AND BALANCE TRIALS

1.0 INTRODUCTION

Earlier in this class (ANP308) you have learnt how nutrients are metabolised. The chemical composition of the feeds gives only the potential value of the food but does not gives the actual nutritive value of the feedstuffs until the losses of nutrients in the faeces, urine, gases etc., from the animals during digestion, absorption and metabolism are also taken into consideration. Nutrients present in the feed stuffs are not completely available to the animal's body. Major portion of the nutrients are excreted in the faeces because of not being digested in the alimentary tract. Therefore, digestibility of the feed stuff is defined as the portion which is not recovered in the faeces, that is, the portion which has been absorbed by the animal. The digestibility expressed in percentage is known as digestibility coefficient. For example, if an adult Sokoto Gudali bull is eating 50kg Gamba grass fodder containing 20% dry matter per day and is voiding 4kg dry matter in the faeces, then (50×20)/100 – 4 = 6kg dry matter is being digested daily. The digestibility coefficient of the Gamba grass for this bull then works out to be 6×100/10 = 60%.

In practice, digestibility coefficients are determined for dry matter, crude protein, crude fibre, ether extract and nitrogen-free extract. For ash, digestibility coefficient is not calculated since most of the minerals are re-excreted in the gut. In the carbohydrates, digestibility of cellulose,

acid detergent fibre and neutral detergent fibre can also be determined. The digestibility coefficients normally determined are the apparent digestibility coefficients since the nutrients found in the faeces contain small proportion of nutrients from the previously utilised food in the form of mucosal debris, unspent enzymes, intestinal microbes etc.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- describe the measurement of digestibility coefficient, factors affecting it and it laboratory coefficient
- explain the balance trails.

3.0 MAIN CONTENT

3.1 The Measurements of Digestibility

In determining the digestibility coefficients of the organic nutrients in a particular feedstuff, you are expected to use four to six adult apparently healthy animals of same age and sex (preferably male because of the ease of urine and faecal collection) are to be used. This is done in order to avoid the variation due to physical states of the animals for estimating digestibility coefficient. The animals in trial studies are fed on the fodder/feedstuff in question for a period of at least three weeks to remove the effect of previous feed. This period is known as pre-experimental or pre-collection feeding or adjustment period and is followed by a collection period of five to 10 days duration during which daily record of feed intake and faeces voided is kept on a 24 hourly basis.

During the digestion trial period you keep the animals in specially constructed metabolism stalls (faeces bags are harnessed on the animals for easy collection of the faeces of the individual animals) where there is an arrangement for the collection of faeces and urine or in the specially fabricated metabolism cages where there is an arrangement for collection of separate faeces and urine. You should be noted that for the determination of digestibility urine collection is not required but for the determination of the balances of energy, nitrogen, calcium, phosphorus etc., urine collection is essential for accounting the nutrients voided in the urine.

During the collection period, daily record of food offered, residue left and faeces voided is maintained on a 24 hourly basis. During this period, representative samples of feed offered, residue left and faeces voided are taken daily and kept in hot air oven at 100^{o}+/-1^{o}C for drying for about

eight hours or overnight. After drying, samples are weighed to constant weight and collected in marked glass jars or plastic bags and at the end all samples are composited and analysed for the proximate principles and/or other individual nutrients. The digestibility coefficient of complete food in terms of dry matter digestibility or individual nutrients is determined with the help of the following equation:

Digestibility coefficient = Feed or Nutrient consumed – feed or nutrient voided in faeces X 100
Feed or nutrient consumed

Laboratory methods of determining digestibility

In determining the digestibility of forages, one has to keep the animals, and daily record of intake and outgo which is not only costly but very laborious. A number of attempts have been made by various workers to determine the digestibility of dry matter, cellulose, protein etc., by the ***in vitro*** digestibility techniques. These *in vitro* digestibility results correspond to those achieved by the ***in vivo*** trials. The microbial digestion occurring in the rumen can be reproduced in the laboratory by incubating the feedstuff with the rumen liquor under anaerobic condition in an artificial rumen. The *in vitro* digestibility coefficients are determined as the proportion of the food digested during 48 hours of incubation with rumen liquor in an almost simulated condition.

Limitations of digestibility coefficients

You should note that there are two main limitations to the interpretation of digestibility coefficient figures. The first limitation is that the faeces should represent the undigested fraction of food residues for which the digestibility coefficients are being determined. But parts of the nutrients excreted in the faeces come from the unspent enzymes, cellular materials abraded from the gut and other secretions of the gut which actually represent the utilised nutrients of previous diets. For an instance, if an animal is fed on nitrogen free diet, the faecal still contains nitrogen which comes from the intestinal secretions and abrasions. This part of nitrogen is called metabolic faecal. Likewise there is secretion of other nutrients also. In practice the digestion coefficients which are determined do not take into account the nutrients coming into the faeces not directly from the food. These digestibility coefficients are called as "Apparent digestibility coefficients" which are under estimates. In true digestibility coefficients the metabolic losses in faeces are taken into account. For all practical purposes, it is customary to give apparent digestibility coefficients of feedstuffs.

The second limitation of the digestibility trial is that the carbohydrates are broken down to volatile fatty acids, carbon dioxide and methane. The latter two do not give any energy to the ruminant animals but are

computed as digestible carbohydrates since they are not recovered in the faeces. This loss leads to the overestimation of digestible carbohydrates.

Factors affecting digestibility coefficients

The following factors affect the digestibility coefficients of various nutrients from the same feedstuffs. Therefore, while utilising digestibility figures for calculation of energy values of feedstuffs these points may be kept into consideration.

(i) **Age of animals.** In young bulls in their early age of less than three months, when the micro flora have not yet established, the digestibility of the roughage is less than the older bulls having functional rumen. At about six months of age the rumen is fully functional and calves are able to digest the feeds and fodders like adult animals.

(ii) **Level of feeding.** The digestibility of feed is dependent upon the rate of passage of digesta from the alimentary tract. If the food stays for a longer time in the tract then it is more exposed to microbial and enzymatic digestion and therefore digestibility is higher. If the food stays for shorter period then the digestibility is low. The rate of passage of digesta depends on the level of feeding besides other factors. If the level of feeding per unit body weight is increased the digestibility of a feeding stuff is decreased due to increased rate of passage of digesta.

(iii) **Processing of feeds and fodders.** Processing of roughages and concentrates affects the digestibility of nutrients. Processing like grinding, chaffing, soaking, cooking, chopping, alkali treatment etc., affects the digestibility coefficients. Grinding of roughages like straws reduces the digestibility since it increases the rate of passage of the straw. Alkali treatment of the straw improves the digestibility of crude fibre by breaking the ligno-cellulose complex of cell wall and thereby permitting the enzymes to act more thoroughly. The digestibility of cereal grains is higher when they are fed crushed rather than fine ground.

(iv) **Feed composition.** With progressive maturity the crude fibre of the forages is gradually lignified. Though pure cellulose is highly digestible but with the association of lignin with cellulose, the crude fibre digestibility is affected and the digestibility of other nutrients is also very much reduced. This is due to the fact unbroken cell walls prevent the action of the enzymes on the cell contents.

(v) **Ration composition.** The digestibility of food is also influenced by the composition of other feeds which are consumed by the animal. This is due to the associative effect of feeds whereby different environment is available to the rumen micro-organisms. The cellulose digestibility is reduced when molasses is added to

the diet. This is because the microbes act on molasses in preference to cellulose as it contains readily available soluble carbohydrates.

Balance trials

At this point you should know that balance trials differ from digestion trials in that they account for losses associated with the urine and respiration and sometimes those associated with the skin, so a more precise measure of intake and excretion can be obtained. This provides a more accurate measure of nutrient retention. For example, if you feed urea feed to a beef steer, the digestibility of the CP (nitrogen-containing fraction) will approach 100%, because it will be completely digested and absorbed by the animal. Unfortunately, if there is not an adequate source of dietary energy, the nitrogen released from the urea will not be converted into microbial protein, but rather into ammonia. When excessive amounts of ammonia are produced in the rumen, the ammonia is absorbed by the animal, converted by the liver to urea, and excreted, resulting in a net retention of near zero. On the other hand, if enough dietary energy is present to produce microbial protein and the microbial protein is converted into amino acids, which are absorbed and used to synthesize tissues, then the net retention of the nitrogen could be as high as 50% to 70%. These results can be greatly influenced by the state that the animal is in: negative (losing weight), positive (gaining weight), and at equilibrium (maintenance).

SELF-ASSESSMENT EXERCISE

1. Describe the measurement of digestibility.
2. Discuss the laboratory methods of determining digestibility.
3. What are the limitations of digestibility coefficient.
4. List and explain the factors affection digestibility Coefficient.
5. What do you understand by balance trial?

1.0 CONCLUSION

In this unit, you learnt how to measure digestibility, limitation of laboratory measurements, factors affecting digestibility and the balance trail.

2.0 SUMMARY

In this unit, you learnt nutrients present in the feed stuffs are not completely available to the animal body. Major portion of the nutrients are excreted in the faeces because of being not digested in the alimentary tract. Therefore, digestibility of the feed stuff is defined as the portion which is not recovered in the faeces, that is, the portion

which has been absorbed by the animal. The digestibility expressed in percentage is known as digestibility coefficient.

3.0 TUTOR-MARKED ASSIGNMENT

1. What is Digestibility Coefficient?
2. List and explain five factors that affect digestibility coefficient
3. Describe Balance Trail

7.0 REFERENCES/FURTHER READING

McDonald, P.,Edwards, R.A., Greenhalgh, J.F.D & Morgan,C.A. (1998). Animal Nutrition. (5th ed.). Published by Longman, Malaysia.

Basic Animal Nutrition and Feeding. (5thed.). Published by John Wiley & Sons, Inc., USA.

UNIT 2 SYSTEMS OF ENERGY PARTITIONING

1.0 INTRODUCTION

Energy is used to express the "fuel value" of feeds for animals and it comprises the three main groups of nutrients, Carbohydrates, Protein and Fat. The word **energy** originates from Greek and means "in work" (en ergon). The work of the cell is to contract itself actively transport molecules or ions and to synthesize macromolecules from smaller molecules. When chemical compounds are transformed from a higher to a lower energy level, parts of their energy can then be released for useful work (free energy = DG). In nutrition, energy is broken down to several components but not all is used up by the animal as some are lost in several forms. The understanding of the principles for bioenergetic processes is fundamental in the science of nutrition – since all the processes that occur in the animal body when the feed is digested and metabolized leads to energy changes.

2.0 OBJECTIVES

By the end of this unit, you will be able:

- identify the different parts of energy
- discuss energy partitioning and its relevance in livestock feeding.

3.0 MAIN CONTENT

Energy Partitioning

3.1 Gross Energy (GE)

When a feed is completely burnt to its ultimate oxidation product (CO_2 H_2 and gasses), the heat given off is known as Gross Energy or Heat of Combustion. Gross energy is determined with the aid of a bomb calorimeter and is just the starting point in determining the energy value of feeds because not all of it is utilised within the animal's body system. The fraction not utilised is wasted as faecal or urine energy.

3.2 Faecal Energy (FE)

This is the energy lost through the faeces i.e. heat of combustion of faeces. It includes energy of metabolic product of the body as well as that of undigested feed. Faecal energy is important because it is used to compute the apparent digestible energy. It can further be used to obtain the True Digestible Energy (TDE) by subtracting the faecal energy of feed origin only from the gross energy.

3.3 Digestible Energy (DE)

This is the difference between the gross energy intake from feed and energy voided in faeces. It is also determined by the use of bomb calorimeter to obtain gross energy of feed and faeces.

3.4 Metabolisable Energy (ME)

This is the proportion of energy ingested by the animal which is actually transformed and used for metabolic processes in the body. It is the apparent digestible energy minus energy lost in gaseous product of digestion and that lost in urine (UE). These gaseous losses (CH4, H2) are particularly very important in ruminant animals and to a lesser extent in monogastric such as man, dog, swine and chicken. These gaseous losses are usually not accounted for when metabolisable energy is being calculated for monogastrics.

3.5 Urinary Energy (UR)

Urine which comes out of urinary tract of animals contains some energy which constitutes further loss to the animal's energy economy. The urine loss result from the excretion of incompletely oxidized nitrogenous products. The urinary loss is both from the blood and body cells. Therefore it is called Endogenous urinary Nitrogen (EUN).

3.6 Heat Energy (HE)

This is energy lost as heat in the body. This heat is used by the body to maintain the thermo-neutral balance of body tissues. Sometimes, small amount of energy are lost in form of perspiration, epidermal loss (loss through epidermal scales) and shed hair. They could also be accounted for and subtracted from gross energy to obtain metabolisable energy. However, they are normally regarded as insignificant for specific dynamic action. As a result of continuous metabolic reaction in the body, which is a manifestation of life processes, heat is produced within the body in form of chemical energy and it is lost as heat energy. This heat increases with the amount and type of food consumed and the increase is known as Heat Increment (HI). This consists of heat of fermentation and heat of nutrient metabolism.

The heat of fermentation is the heat produced in the GIT especially rumen of ruminant animals as a result of microbial action. Thus, it is more relevant in ruminant animals than any other species. The heat energy produced in an animal will therefore depend on:

i) Nature of the diet/ration (whether soluble or insoluble carbohydrate or proteinous feed. Heat is more generated when carbohydrate is fed to ruminant than roughages).
ii) The level at which it is fed (production or maintenance).
iii) The purpose for which it is fed i.e the body functions the feed supposed to support (maintenance, growth, fattening, lactation etc.)
iv) The environment under which it is fed. The ambient temperature will determine the amount of heat generated by the animal's body. For instance, the heat generated within the body of an animal in cold environment will be more than that of animal in hot environment. This is because of the demand of animal in cold environment to generate more heat to keep its body temperature up to normal within the thermo-neutral level. This will call for more chemical reaction and tissue breakdown in the animal.
v) Physiological state of the animal. A sick animal may not have enough appetite to eat food. Consequently, its body metabolism

may not be able to cope with environmental demand. The result of this is heat stress which could bring down the animal.

3.7 Net Energy (NE)

Net energy is the proportion of feed energy which is completely useful to the body and thereby appears as a product in form of energy for tissue maintenance, growth, milk, egg, wool and fur. It can be obtained by subtracting the heat increment expressed in terms of a given unit of intake from metabolizable energy of the same intake. In ruminants fed concentrate, this value must be added to a basal roughage ration to know the actual net energy value. Energy partitioning has given rise to many concepts one of which is Total Digestible Nutrients (TDN) which represents values commonly used in ruminant animal feed evaluation. It is calculated as:

TDN = % DCP + % NFE + %CF + % EE + 2.25
The 2.25 comes from the fact that fats are concentrated source of energy (1g of fat = 2.25g CHO).

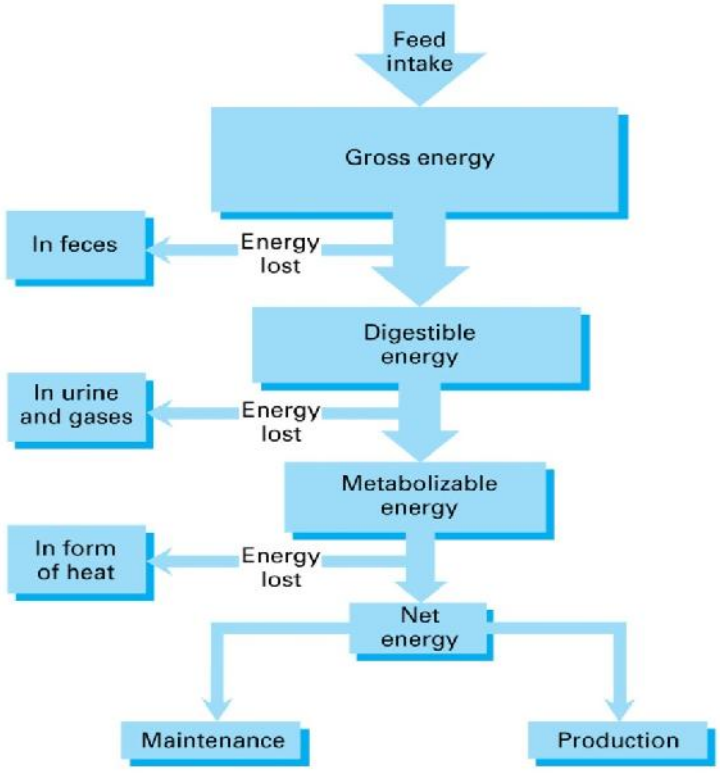


Figure 4: Diagrammatic illustration of Energy Partitioning

SELF-ASSESSMENT EXERCISE

Discuss the following :

i) Gross Energy

ii) Faecal Energy i
iii) Digestible Energy
iv) Metabolisable Energy
v) Urinary Energy
vi) Heat Energy
vii) Net Energy

With the aid of a diagram describe Energy partitioning.

4.0 CONCLUSION

In this unit you have learnt from ingestion of food to excretion as faeces energy is transformed into forms which include Gross energy, Heat energy, Meatbolisable energy, Net energy, Urinary energy and Faecal Energy.

5.0 SUMMARY

In this unit, you have learnt that energy called metabolizable energy is the proportion of energy ingested into the body of the animal and some such as Heat, urinary, faecal, net and gross energy are the other forms energy is lost from the body.

6.0 TUTOR-MARKED ASSIGNMENT

Mention and explain five ways energy is partitioned in ruminant nutrition.

7.0 REFERENCES/FURTHER READING

McDonald, P. Edwards, R.A., Greenhalgh, J.F.D & Morgan,C.A. (1998). *Animal Nutrition*. (5thed.) Published by Longman, Malaysia.

Basic Animal Nutrition and Feeding. (5thed.). Published by John Wiley & Sons, Inc., USA.

UNIT 3 SYSTEMS OF PROTEIN PARTITIONING

CONTENT

1.0 INTRODUCTION

In previous class, you have learn that proteins are chemical compounds of great complexity and high molecular mass containing about 16% nitrogen (N). Nitrogen is the chief element which distinguishes proteins from carbohydrates and fats. Since there is a fairly constant proportion of about 16 % nitrogen in protein, nitrogen is used to estimate the protein content of feeds by determining the nitrogen content of the feed and then multiplying this value by 6.25 (100/16 = 6.25). The estimate of protein obtained from nitrogen determinations is called crude protein (CP). However, the present simple system of expressing the protein content of feeds, according to crude protein content (the CP system) does not take into account the degradability of protein. This system is therefore slowly giving way to other systems which take the role of undegradable protein into account.

1.0 OBJECTIVES

By the end of this unit, you will be able to:

- explain the scheme of protein value
- evaluate the different protein parts.

3.0 MAIN CONTENT

Protein Partitioning

3.1 Crude Protein (CP)

The common practice is for the nitrogen status of livestock feeds and food to be stated in terms of crude protein because most of the feed nitrogen is present as protein and most of the nitrogen required by the animal is used for protein synthesis. Chemically, the protein content of a feed is calculated from its nitrogen content determined by the modification of the classical Kjeldahl technique. This gives a figure which improves most form of nitrogen except nitrite, nitrate and certain cyclic nitrogen compounds which require special techniques for their recovery. The assumption was that all the nitrogen of the feed is present as protein and that all feed protein contain160g N/kg. Thus, the nitrogen content of feed is expressed in terms of crude protein.

CP (g/kg) = gN/kg x 6.25
Cp (g/kg) = gN/kg x 1000
160

With time, these two assumptions were found to be unsound because:

a) Different feed proteins have different N content and therefore different factors should be used in the conversion of N to protein for individual feeds. Factors for converting N to protein for some feeds are as follows:
Feed protein source Nitrogen (g/kg) Conversion factor Maize, egg, meat 160.0 6.25 Barley, Wheat, Oats 171.5 5.83 Milk 156.8 6.38 Soyabean 175.1 5.71 Cotton Seed 188.7 5.30 Although, the use of an average conversion factor of 6.25 for all feed protein is globally in practice, because protein requirement of farm animals is normally expressed in terms of nitrogen x 6.25.

b) Many nitrogenous compounds such as amides, amino acids, glycosides, alkaloids, ammonium salt and compound lipids occur along with feed nitrogen naturally. Only the amides and amino acids are important and these are present in large amount in only a few feeds such as young pasture, silage or immature root crops.

c) The assumption did not take into account the species of animal for which the feeds were intended. In the diets of pigs and poultry, cereals and oil seed predominate which contain little non- protein nitrogen (NPN), thus their nitrogen source may not need to be partitioned but in ruminant animals, variable amount of NPN are fed. Allowance therefore, need to be made for this in the evaluation of ruminant feeds.

3.2 Digestible Crude Protein (DCP)

From what we have learnt eelier, the crude protein figure only provides a measure of the N present in feeds but gives little indication of its value to the animal. Before the feed becomes available to the animal, it must undergo digestion, during which it is broken down into simpler substances which are absorbed into the body system. Thus, the digestible protein in the feed is determined by digestibility trial in which nitrogen intake is measured along with the nitrogen voided in faeces. The assumption is that the difference between the quantities of N in the feed and faeces or digesta represents the quantity absorbed in the utilisable form by the body and that all N which appears in the faeces is of dietary origin. These assumptions are untenable in most cases particularly in ruminant animals because of the presence of nitrogen of metabolic origin in faeces and the production of ruminal ammonia gas. Thus, the figures obtained are called apparently digestible protein. This however, gives a measure of the protein status of a feed for livestock feeding.

3.3 True Protein (TP)

When crude protein is to be determined, it can be separated from NPN compounds by precipitation with cupric hydroxide or heat coagulation in some plant materials. The protein is then filtered off and the residue subjected to a kjeldahl analysis. Determination of the digestibility of true protein (true digestibility) always take account of the contribution of nitrogen of endogenous origin to take of the digesta. The endogenous N is derived from non – food substances entering the intestine such as saliva, bile, gastric and pancreatic secretions, and cell sloughed off the mucous membrane of the gut. This measurement always present difficulties and the result may vary widely with the different techniques employed. Most figures in current use are apparent values minus the metabolic nitrogen which is taken principally as urine nitrogen.

True digestibility = TP- (faecal N + MFN +UN) where MFN = Metabolic faecal Nitrogen and UN= Urinary Nitrogen.
The concept of true protein and its attendant intricacies has given rise to many concepts which are now used more valuably to measure protein quality. These however, differ widely in application between monogastric and ruminant animals. In ruminant nutrition, certain proportion of the intake protein is degraded in the rumen by the microbes while some are lost in their complex compartments. This has made the evaluation of ruminant diets with CP or digestible CP later modified to Protein Efficiency Ratio (PER) unsatisfactory. Thus, estimation of protein quality and digestibility for ruminant animals

which will take into account their microbial and endogenous losses is rather complex.

3.4 Protein Efficiency Ratio (PER)

Digestible protein figure as stated above are not entirely satisfactory measures of the value of a protein to an animal. This is because the efficiency with which the absorbed protein is used differs considerably from one source to another. PER always give the ratio of weight gain of animals to the amount of protein it consumed for each feed.

$$\text{PER} = \frac{\text{Weight gain of animal (g)}}{\text{Protein consumed (g)}}$$

3.5 Net Protein Ratio (NPR)

This entails feeding of a group of animal with protein and compare with another group fed no protein as a ratio of protein consumed
NPR = Wt gain of TPG – Wt loss of NPG
Wt of protein consumed
TPG = Test Protein Group; NPG = Non – Protein Group.

3.6 Biological Value (BV)

Bv is defined as the proportion of the absorbed nitrogen which is retained by the body. It is a direct measure of the proportion of the feed protein which can be utilised by the animals for synthesising body tissues and compounds.

Biological value = N intake – (Faecal N – MFN) - (Urinary N - EUN) N intake – (Faecal N- MFN).
EUN = Endogenous Urinary N; MFN= Metabolic faecal N.
In determining BV, dietary protein should be provided by the feed under test. The protein intake must also be sufficient to allow adequate N intention but must not be in excess of that required for maximum retention.

3.7 Net Protein Utilisation (NPU)

NPU is the product of biological value and digestibility. It is the proportion of feed N that is retained in the animal's body under specified condition. It entails doing a nitrogen balance study and carcass analysis. Hence the higher the retention of a given dietary intake, the better the quality of the protein.

SELF-ASSESSMENT EXERCISE

Discuss the following: i) Crude Protein Digestible ii) Crude Protein iii) True Protein iv) Protein Efficiency Ratio v) Net Protein Ratio vi) Biological Value vii) Net Protein Utilisation

4.0 CONCLUSION

In this study you have learnt that protein is divided into seven portions to be able to properly assess its value ruminant utilisation.

5.0 SUMMARY

The protein in the diet contains intake protein which is normally called crude protein. Immediately it is digested, it is divided into digestible crude protein and undegradable crude protein particularly in ruminant animals.

6.0 TUTOR-MARKED ASSIGNMENT

Mention and explain five ways energy is partitioned in ruminant nutrition.

7.0 REFERENCES/FURTHER READING

McDonald,P. ,Edwards, R.A., Greenhalgh, J.F.D & Morgan,C.A. (1998). Animal Nutrition. (5thed.). Published by Longman, Malaysia.

Basic Animal Nutrition and Feeding. (5thed.). Published by John Wiley & Sons, Inc., USA.

UNIT 4 PROXIMATE ANALYSIS

1.0 INTRODUCTION

For describing various feeds and fodders, about 100 years, researchers at Weende experimental station in Germany proposed a scheme of chemical analysis of feeds and fodders. In this scheme various nutrients and components of feeds and fodders that had some common properties were grouped together and analysed. These nutrients are known as proximate principles of feeds and the scheme of analysis is called proximate analysis of feedstuffs. In this system of analysis, feedstuffs are analyzed into six fractions; viz., water, ether extract, crude protein, crude fibre, nitrogen-free-extract and ash. Although, there are many limitations to this system of analysis, indeed it is widely used in nutritional studies. Five of the six components of feeds are determined and one i.e, nitrogen-free-extract (NFE) is estimated by difference. The crude fibre and NFE together represents the carbohydrate fraction of feed.

According to Weende system of feed analysis total carbohydrates of the forages are partitioned into crude fibre and nitrogen-free-extract. There is a lot of criticism to this partitioning because neither the crude fibre nor the NFE fractions represents any precise chemical constituents or group of constituents. Knowledge of these limitations associated with the determination of crude fibre has stimulated interest in other systems of feedstuff analysis. In 1965 Van Soest and Moore partitioned the whole plant into two parts, the one which is soluble in neutral detergent (cell contents) and the other which is soluble in acid detergent (cell wall). They found high correlations of the *in vivo* digestibility of the cell contents (neutral detergent solubles), of the cell wall (neutral detergent insoluble fibre), and of the lignin with the *in vitro* digestibility data.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- describe the proximate principles of water, crude protein, crude fibre, ether extract, nitrogen free extract and ash.

3.0 MAIN CONTENT

3.1 The Proximate Principles of Feeds

Water (moisture content)
Samples are collected without any form of contamination by dew or rain. They are immediately brought into the lab and grounded. Weighed quantity (say 100g) of the sample is taken into the previously weighed clean dry tray and kept in the hot air oven at 100^{o}C over night for drying. The difference in weight gives the moisture content of the sample which is expressed as percentage.

Crude Protein (CP)
For the determination of crude protein in feeds and fodders nitrogen content is estimated which is multiplied with the factor 6.25 taking into the consideration that protein contains about 16 per cent of nitrogen. The protein content of a feed is important as it gives indirect information about the digestible energy of the feeds. Where the protein content is higher, the crude fibre content is usually lower and in turn the digestibility of the fodder will be higher. Higher digestible fodder would give more digestible energy.

The procedure used in the laboratory is the Kjeldahl method. The nitrogen and other compounds are transformed into ammonium sulfate by acid digestion with boiling sulfuric acid. The acid digest is cooled, diluted with water, and made strongly basic with sodium hydroxide. The released ammonia is distilled into a boric acid solution or standard sulfuric acid solution. When boric acid is used to collect ammonia then it is titrated with standard sulfuric acid or standard hydrochloric acid. When standard sulfuric acid is used to collect ammonia then it is titrated with standard sodium hydroxide solution.

Ether Extract (EE)
The ether extract is that fraction of feed stuffs which is obtained when it is subjected to continuous extraction with petroleum ether. Besides fats, this fraction includes cholesterol, free fatty acids, lecithin, volatile oils, resins, waxes etc. The ether extract is determined by the Soxhlet's ether extraction apparatus/assembly or lab. Con. co. extraction apparatus, where the accurately weighed quantity of the oven dried sample is put in

a filter paper thimble and continuous extraction is made by petroleum ether (40-60^{o}C boiling point) for about 6 hours in Soxhlet's extractor and three hours in laboratory extractor. It should be noted that the Soxhlet extraction assembly consists of three parts: (a) condenser at the top, (b) the soxhlet or extractor in the middle, and (c) the receiver flask at the bottom.

Crude Fibre (CF)

Crude fibre is determined as that fraction of carbohydrates which is not digested after successive boiling with standard solutions of sulfuric acid and sodium hydroxide under carefully controlled conditions. The bulkiness of the feed is correlated with the crude fibre. Bulk for the animal is important since it gives satisfaction to the animal. Crude fibre absorbs moisture in the intestine since it is hydrophilic. This characteristic gives the normal distention to the intestinal tract and helps in the peristaltic movement of intestines with the result that digesta is propelled downward. The mechanical role of crude fibre in the rations of herbivores cannot be ignored. The crude fibre content of feed stuff is also an index of available energy value because of lower digestibility and possible laxative property. In the laboratory crude fibre is estimated when ether extracted oven dried sample is successively digested for 30 minutes each with 1.25% sulfuric acid and 1.25% sodium hydroxide solutions. The residue left after boiling and washing is dried in hot air oven at 100^{o}C, weighed and ignited. Loss in weight is the amount of crude fibre in the sample which is converted into percentage.

Nitrogen-Free Extract (NFE)

It is that fraction of the total carbohydrates of a feed stuff which is obtained when the sum total of percentages of crude protein, ether extract, crude fibre and ash is subtracted from 100. It includes monosaccharides, disaccharides, trisaccharides and some portion of lignin also comes out in this fraction as lignin is soluble in alkali. Lignin is not classed as a carbohydrate but for all practical purposes in Animal Nutrition it is grouped with total carbohydrates or crude fibre. This fraction is more than 40% in most of the feeding stuffs and is important as a source of available energy.

Ash

Ash in feeds is useful for judging nutritional characteristics of the feed because ash has generally constant element composition by feed material type as long as the feed does not contain earth and sand, etc. Ash content in feeds of plant origin is not very good as a nutritional indicator because: it varies widely; silicate accounts for a large percentage of ash; and the other element composition is apt to vary depending on soil and fertilisers. A sample is incinerated by heating to be crude ash. When a sample is incinerated without special treatment,

there always is contamination with charred organic matter, resulting in a blackish color. Therefore, it cannot be considered as pure ash (inorganic salts), and is referred to as crude ash. Crude ash is defined as the weight of a sample measured after heating at 550-600 °C for two hours to incinerate in a crucible. A ceramic crucible can be about 40 mm in inner diameter, and about 37mm in height. For feeds with high sugar content or feeds of animal origin, the sample may be expanded and overflow out of the crucible; heat carefully

SELF-ASSESSMENT EXERCISE

Describe in details the proximate analyses of the following; i) Crude Protein ii) Ash iii) Nitrogen free extract iv) Crude fibre v)Water vi) Ether Extract.

4.0 CONCLUSION

In this unit you have learnt the determination of the amount of water, protein, fat (ether extract), ash, nitrogen free extract and fiber which is known as proximate anaylsis.

5.0 SUMMARY

In this unit, you have learnt proximate analysis is defined as the "determination of a group of closely related components together, e. g. total protein, fat." It conventionally includes determinations of the amount of water, protein, fat (ether extract), ash and fiber, with nitrogen-free extract (sometimes termed Nifext) being estimated by subtracting the sum of these five percentages from 100.

6.0 TUTOR-MARKED ASSIGNMENT

Explain the proximate analysis of:

1. Crude Protein
2. Ash
3. Nitrogen free extract
4. Crude fibre.

7.0 REFERENCES/FURTHER READING

National Research Council. (2001). *Nutrient Requirements of Dairy Cattle.* Vol. (7th Rev. ed.) Natl. Acad. Sci., Washington, DC.

McDonald, P.,Edwards, R.A., Greenhalgh, J.F.D & Morgan, C.A. (1998). *Animal Nutrition*. (5thed.). Malaysia:Published by Longman.

Basic Animal Nutrition and Feeding. (5thed.). Published by John Wiley & Sons, Inc., USA.

UNIT 5 RATION FORMULATION

1.0 INTRODUCTION

Feed or ration formulation is the process of compounding a ration from a range of feed stuff or ingredients that will supply adequately, all the required nutrients for optimum growth, productivity and maintenance of good health of the animal. Diet formulation is an important aspect of animal production. The success of any animal production enterprise depends greatly on proper feeding and nutrition based on economic rations. You should know that the animal production practitioner should have a good knowledge of different aspects of nutrition, feeding, feedstuffs interactions and limitations, as well as the economics of production and feeding. Diet formulation, properly carried out, is the result of this knowledge. Some of the mathematical techniques required in diet formulation are quite simple, although for complex diets they can become complicated. However, with the advent of personal computers and ready access to appropriate software, even the techniques needed for complex rations can be used by almost anyone with proper nutritional knowledge. Some of the simple techniques, as well as basics for complex diet formulation are presented.

2.0 OBJECTIVES

By the of this unit, you will be able to:

- List and describe the basic requirements needed to formulate a ration
- Explain the methods of formulating a ration.

3.0 MAIN CONTENT

3.1 The Formulation of All Types of Diets Must Concern Itself with Six Basic Requirements

- Characteristics of the animal.

- Nutrient requirement of the animal.
- Availability of raw materials (feed ingredients).
- Nutrient composition of the ingredients (note that every batch of feed ingredients varies in nutrient composition).
- Cost of feed ingredients/feedstuffs.
- Restrictions on the diet or ingredients

Characteristics of the animal

- **Age** the usage of each diet may be determined entirely by the age of the animal; for example creep feeding is associated with animals before they are weaned while a lactation diet cannot be prepared for bulls.
- **Sex** different sexes utilize distinct diets. Calcium requirements for lactating dairy cows will be different and higher than that for breeding bulls
- **Body weight** with large bodied, fast growing exotic breeds, the vitamin, mineral and amino acid requirements are greater than for the slower growing breeds in most parts of the tropics
- **Health** unhealthy animals will need fortification in their diet because consumption will be decreased. Medication may also be needed.
- **Environment** standards put forth by various feed program tables must be adjusted to suite the climatic conditions of the animals to be fed. In cool seasons the feed consumption will increase as compared to moderate climate. Hot weather has a detrimental effect on feed consumption and therefore fortification of the diet may be warranted.

Nutrient requirements of the animal the first step is for you to know the nutrient requirements of the animal for which the ration is intended. Nutrient requirements for animals are expressed in terms of energy, protein, mineral elements, vitamins and fibre. Specification of nutrient requirements can be found in different sources. In the USA, the National Research Council (NRC) recommendations are the most commonly used guides for nutrient requirements. It should be borne in mind that these recommendations should be modified if need be to ensure adequacy of nutrients in the feed. For example, when intended to be applied in our hot tropical environment on smaller sized animals. In cold climates, energy needs may be higher than NRC values. In practical feed formulations for ruminants, the most important nutrients usually considered are: protein, energy, calcium, phosphorus and crude fibre.

Available ingredient the next step is to list all the available feedstuffs to be used in the diet for the particular animal in question. An available ingredient is one that is already in the feed mill or is locally available or is on the open market and can with certainty be secured very easily and

quickly. Ingredient availability makes it a necessity to have flexibility in such a way that available ingredients can be used in place of scarce ones. Locality largely determines the ingredients that are available. Abrupt, large changes in the make-up of the diet are not advisable. If a large quantity of feed ingredient cannot be obtained, then it should be used sparingly in the diet at a level of 5-10% and used over a longer period of time than using 30-40% in the diet for a short time. The end choice of any ingredient will also be based on its relative cost and biological availability.

Feedstuffs and feedstuffs analysis The nutrient analysis of the feedstuffs to be used is very essential. How satisfactory the diet will be depends on the reliability of the feedstuff analysis. Government organizations such as NRC of the United States have compiled data while large feed companies do their own analysis. Any ingredient of questionable origin or quality should be analyzed or used at a very low level in the diet. Updated analytical data on feedstuffs are preferred where available; if not, average composition data can be used from reliable nutrient analysis tables. The greatest errors in feed formulation occur in overestimating the value of ingredients. It is generally best to underestimate their value. Furthermore, you must consider whether the feedstuff should be processed and, if so, in what manner and at what cost? Inspection of the ingredients is necessary. The presence of mould, weed seeds, weevils, stones, and other contaminants clearly indicate an inferior product. With each increasing amount of contaminant the table value of protein, etc. should be reduced.

Cost of the Ingredient the cost of the ingredients should include delivery to the feed mill, grinding, rolling or other milling processes. The cost of the ingredient should be judged against its nutrient profile. The expense of the diet should be minimised while at the same time nutritional requirements should be met; in other words, it is not sufficient to formulate a diet which is nutritionally sound without considering cost of feedstuffs and the selling price of the product to ensure that the diet is economically sound as well. An economically sound diet must result in the least cost per kg. of meat or milk produced in a specific period of time, which in most cases should be the shortest period of time. It is important not to confuse the cheapest feed with least-cost feed. The least cost ration is the lowest cost formula that contains all the nutritional elements needed for maximum/optimum performance. To formulate such diets, the use of linear programming with computers becomes a must.

Restrictions in the diet or ingredients it is not unusual for diets to have a maximum, minimum or exact quantity of a certain ingredient due to several nutritional factors. There may also be limitations due to the

availability of an ingredient. For the reason of toxicity, flavor changes, palatability, low digestibility or other reasons, there are many ingredients which should not be used above a certain level. Both salt and premix would be formulated into the diet at an exact level such as one-half percent of each. The quantity of premix may also vary depending upon the concentration of the vitamins and minerals. The use of coccidiostats, antibiotics or other medical products would also necessitate exact levels.

3.2 Mechanisms/methods of Ration Formulation

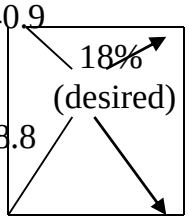
Now you have learnt the basic requirement for feed formulation, we can now go ahead to look at the various methods used in the formulation.
When the number of nutrients specified is small, diet formulation can be adequately carried out through simple calculations. However, as the number of nutrient specifications and/or the number of feedstuffs available increases, the mathematics is quite involved. The various techniques in feed formulation could either be manual/hand or computerised method.

Manual method here, the feed formulator uses his hand and brain to produce acceptable formula. It is usually time consuming, although with experience more time is saved. It allows the formulator to be flexible especially when there is problem of scarcity and price fluctuation. Examples include the pearson's square method, algebraic method and the trail error method.

Computerised method here, all necessary data are fed into the computer which on its own produces a least-cost ration. It saves considerable time although very complicated. It must be emphasised that this method is not a replacement for the manual but a support. Example is the linear programming method.

1. Pearson's square this is a simple hand procedure that allows us to mix two feedstuffs with different nutrient concentration. For this method to work, the desired diet nutrient concentration must be between the nutrient concentrations of the two feedstuffs.
Example I: Suppose we have a protein source such as cotton seed cake (CSC) with 40.9% crude protein (CP) and maize with 8.8% CP, and we need a mixture of the two that will have 18% CP. As shown in the illustration below, we compare the CP percentage of each feed on the left with the desired percentage in the middle of the square. The lesser value is subtracted from the greater value, and the answer, in parts of a mixture rather than percentage, is recorded diagonally, but read horizontally.

CP% of CSC, 40.9 — 9.2 parts of CSC



CP% of maize, 8.8 — 22.9 parts of corn

32.1 parts total

9.2 parts of CSC and 22.9 parts of corn, or
% of CSC in mix = (9.2/32.1) x 100 = 28.66
% of corn in mix = (22.9/32.1) x 100 = 71.34

Check for CP:
28.66% CSC x 40.9% CP = 11.72%
71.34% corn x 8.8% CP = 6.28%
18.00% total CP in mix.

Example 2: When three or more feed ingredients are involved. A mixture of equal parts of rice bran (RB) and copra meal (CM) is available. How much of the RB-CM mixture and fish meal (FM) should be mixed to produce 10kg of feed containing 35% CP? Given: RB 12% CP, CM 20%, FM 58%.
First, solve for the CP content of the RB-CM mixture. A 100g mixture contains 50g RB and 50g CM.

So, (12/100 x 50g RB) + (20/100 x 50g CM)
6 + 10
= 16g CP per 100g mixture or 16% CP in the mixture

RB-CM, 16 — 23
35
FM, 58 — 19
42

RB-CM, 23/42 x 100 = 54.76%
FM, 19/42 x 100 = 45.24%
Total = 100.00%
Therefore,
RB, 12/32 x 54.76 = 20.535
CM, 20/32 x 54.76 = 34.225
FM, = 45.240
Total = 100.00
One kg of feed contains 547.6g of RB-CM mixture and 452.4g of FM. To make a 10kg feed, 5.48 kg of RB-CM mixture and 4.52 kg of FM is needed.

2. **Trial and error method** this is an example of a hand calculation method. The steps include:

(i) First list all the ingredients available for use in the diet to be formulated.

(ii) Estimate the amounts of each ingredient to be used in the ration so that they total 100%. It is expected at this point to determine the levels of **fixed ingredients** and the amount of nutrients they supply. For example we could have the following fixed ingredients: limestone 6.5%, bone meal 2.75%, salt 0.3%, premix 0.25%, lysine 0.15% and methionine 0.1% totally 10.05%. This means the remaining 89.95kg (100-10.05) will come from other ingredients.

(iii) Enter the level of each remaining ingredient and calculate the amount of nutrients each is contributing to the diet. The contribution of each ingredient to the diet for every nutrient is calculated by multiplying the level of all ingredients by the level of nutrient in the ingredient. For example if corn has a level of 54% in the diet and has an energy value of 3430 kilocalories per kilogram, this gives 1852.2Kcal (54/100 x 3430) contributed to the diet by corn. This process is repeated for each ingredient and nutrient until a matrix is complete.

(**iv**) Make a summary of the total of each nutrient calculated for from all ingredients.

(**v**) Compare the summaries to the requirements intended to be calculated for. If the requirements are not satisfied, the level in the diet of two or more ingredients must be changed and new calculations must be made so that the requirements are met.

3. **Algebraic/Simultaneous Equation method** Also you can is convenient to use this method when information other than the nutrient levels of the ingredients are available. Here the amount or parts of the ingredients form the unknown in the equation. For example, if there are two unknowns (amount of maize and amount of soybean meal) that should add up to 100kg to contain 26% CP.

Let X represent the amount of maize
Let Y represent the amount of soybean meal
X + Y = 100 kg ration…….Equation 1
0.10x + 0.44y = 26% protein……..Equation 2
With the two equations (1) and (2) above we can now solve for the two unknowns.
Eliminate X and solve for Y by multiplying equation (1) by .10
.10x + .10 = 10……equation 3
Subtract equation 3 from equation 2

i.e .10x + 0.44y = 26
- .10x + .10y = 10
0.34y = 16, Y = 16/0.34 = 47.06
Substitute the value of y in equation 1 to solve for x
X + 47.06 = 100
Therefore, X = 100 – 47.06 = 52.94y
Total composition: Y (soyabean meal) = 47.06
X (maize) = 52.94
100.00kg

4. Linear programming (computer) the computer formulation is most efficient and accurate as it produces least-cost rations. A feed formulation software is developed having different but linked tables. A list of all feed ingredients are included, their corresponding prices per kg as well as their nutrient value. Cost of additives are also included as well as other cost of production incurred in the production of either a bag or tonne of feed e.g. cost of machinery wear and tear, cost of bag, labour costs etc. The operator feeds in all the nutrient requirements of a particular diet he/she wants to produce as well as the choice of ingredients and the computer brings out the least cost formulation that meets the specified feed requirement. There are available feed formulation software for download on the net. You can do so and try it at home.

SELF-ASSESSMENT EXERCISE

i. List and discuss six basic requirement for formulating a ration.
ii. Distinguish between the manual and computerised method of ration formulation.
iii. Suppose we have a protein source such as cotton seed cake (CSC) with 40.9% crude protein (CP) and maize with 8.8% CP, and we need a mixture of the two that will have 18% CP. Formulate a diet using Person square method.

4.0 CONCLUSION

In this unit you learnt the factors to consider when formulation a feed and the different methods employed to formulate feed which are categorised into manual and computerised methods.

5.0 SUMMARY

In this unit, you have learnt that to meet the nutrient requirement of an animal for proper growth and reproduction, it is important to give it a balanced diet. Hence this is achieved by a proper knowledge of the different methods of feed formulation and this also is dependent on factors such as Characteristics of the animal Nutrient requirement of the

animal, Availability of raw materials (feed ingredients), Nutrient composition of the ingredients, Cost of feed ingredients/feedstuffs and Restrictions on the diet or ingredients.

6.0 TUTOR-MARKED ASSIGNMENT

1. List five requirements for ration formulation.
2. Describe the trail method of ration formulation.

7.0 REFERENCES/FURTHER READING

National Research Council. (2001). Nutrient Requirements of Dairy Cattle. Vol. (7th rev. ed.). Natl. Acad. Sci., Washington, DC.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D. & Morgan,C.A. (1998). *Animal Nutrition*. (5thed.). Published by Longman, Malaysia.

Basic Animal Nutrition and Feeding. (5thed.). Published by John Wiley & Sons, Inc., USA.

MODULE 3

UNIT 1 WATER IN RELATION TO NUTRITION AND WATER METABOLISM, REQUIREMENTS AND THEIR INTERRELATIONSHIP IN NUTRITION

1.0 INTRODUCTION

In your previous class you have learnt the various nutrients that are required by animals. Water is often overlooked and not considered as a nutrient when formulating rations for livestock, but water is extremely important to animals and composes 71% to 73% of the fat-free animal's body weight. Water plays an essential role in a number of functions vital to an animal, such as digestion, nutrient transport, waste excretion, and temperature regulation. Even though water requirements for livestock are not listed, it is assumed that animals have free access to a good-quality water supply; if they do not, their performance and well-being will be impaired.

2.0 OBJECTIVES

At the end of this unit, you will be able:

- list the function of water in the ruminant digestive system
- explain the water requirement of ruminants.

3.0 MAIN CONTENT

Functions and metabolism of water

1. Water is involved in numerous vital functions. It acts as a solvent for many different biological systems. It serves as a medium for dispersion or suspension of colloids and ions within the body, hence necessary for maintain osmotic balance.
2. Food that is consumed is mixed with water, and this allows the digestive secretions that are water soluble to transform the food into end products that can be absorbed and utilised by the animal.
3. Water is used as the medium to transport materials e.g hormones, nutrients, metabolites and gases in the body via the blood and other body fluids to the sites where they will be metabolised.
4. Water is also involved in the transport of waste products eliminated by the animal's body via the urine or digestive tract.
5. It absorbs a large amount of heat when it evaporates, which allows an animal to use it to cool its body.
6. It is a lubricant and support for various organ systems and the fetus.

Water intake requirements

Water requirements of dairy cattle are met from three sources; that ingested as drinking water, that contained on or in feed consumed and that resulting from metabolic oxidation of body tissues The amount of water required depends on the temperature, breed, type of feed, whether the stock are in-milk, dry or fattening, age, physiological state (disease condition, gestation), stage of growth, etc. Indigenous bulls drink approximately half as much as exotics in the same condition. Dry feed increases the water demand. In-milk cattle need more water than steers- each litre of milk calls for an additional 3litres of water. The younger the age the greater percentage of the body made up of water, this composition has to be maintained and so infants require more water in relation to body weight. Salt increases water intake. A high protein diet is associated with increased water requirements to get rid of toxic wastes.

SELF-ASSESSMENT EXERCISE

i. List the function of water in the ruminant digestive system.
ii. Explain the water requirement of ruminants.

4.0 CONCLUSION

In this unit you learnt that water plays an essential role in a number of functions vital to an animal, such as digestion, nutrient transport, waste excretion, and temperature regulation. Also, for this functions to be properly carried out certain water require has to be met which is dependent on several factors.

5.0 SUMMARY

In this unit, you have learnt that water is indispensable for life and is the most important dietary essential nutrient for ruminant nutrition. Water intake and requirements are influenced by physiological state, rate of milk yield and dry matter intake, body weight, composition of diet and environmental factors. Diet moisture content, cow behavior, physical characteristics of water receptacle and ambient temperature also affect water intake.

6.0 TUTOR-MARKED ASSIGNMENT

1. List five functions of water.
2. Name 10 factors that affect water intake and requirement.

7.0 REFERENCES/FURTHER READING

National Research Council. (2001). *Nutrient Requirements of Dairy Cattle. Vol.* (7th Rev. ed.). Natl. Acad. Sci., Washington, DC.

Chew, R.M. (1965). *Water Metabolism of Mammals. In: Chap. 2. Physiological Mammalogy.* Vol. II, W.V. Mayer and R.G. Van Gelder (Eds.), New York, Academic Press.

McDowell, R.E. (1972). *Improvement of Livestock Production in Warm Climates.* W. H. Freeman and Co., San Francisco, CA

UNIT 2 FEED ADDITIVES

1.0 INTRODUCTION

In our course of feed and feeding (ANP 508) we have learnt about different feed ingredient and the nutrients they supply. These are feed ingredients of non-nutritive value that stimulates growth or other types of performance such as egg production, improve the efficiency of feed utilization or may be beneficial to the health or metabolism of the animals. An additive can also be defined as an ingredient or combination of ingredients added in small quantities to a basic feed mix for the purpose of fortifying the basic with trace nutrients, medicines, or drugs to enhance its flavor, texture, or appearance or to retard spoilage or augment its nutritional value.

2.0 OBJECTIVES

At the end of this unit, you will be able to:

- define feed additives
- explain basic characteristics of an ideal feed additive
- list common feed additives and their mode of action.

3.0 MAIN CONTENT

3.1 Characteristics of Ideal Feed Additives

Feed additives are typically non-nutritive compounds or additives added to diets to improve dietary nutrient utilisation, enhance performance, minimise the risk of metabolic diseases, and curtail adverse impacts of diets on the environment. Hence an ideal feed additive should possess the following attributes:

1. Modulate ruminal pH and reduce lactate accumulation.

2. Reduce the risk of development of metabolic diseases like diarrhea in neonates and ruminal acidosis or bloat in older livestock.
3. Enhance rumen development in neonatal ruminants.
4. Improve the efficiency of ruminal energy utilisation by reducing ruminal methanogenesis and decreasing the acetate to propionate ratio without reducing milk fat synthesis.
5. Improve the efficiency of ruminal nitrogen utilisation by (i) reducing proteolysis, peptidolysis, and amino acid deamination, thus minimising production and losses of NH3 to the environment; (ii) inhibiting the activity of ruminal protozoa that phagocytise desirable bacteria, contribute to proteolysis and deamination, and serve as hosts for methanogens; (iii) enhancing the synthesis of microbial protein by facilitating coupling (synchrony) of ruminal energy and protein supply or by other means.
6. Increase ruminal organic matter & fiber digestibility.
7. Increase the level and efficiency of animal performance.
8. It should be cost effective and approved by legislative authorities.

3.2 Common Feed Additives Include

- Feed binders/firming agents: substances added to precipitate residual pectin, thus strengthening the supporting tissues and preventing its collapse during processing. This is particularly important in feed pellets production.
- Antioxidants: used for preservation by retarding deterioration, rancidity, or discoloration due to oxidation. E.g. butylated hydroxytoluene (BHT)
- Carotenoids/xanthophylls pigments: substances used to impart, preserve, or enhance the colour of the feed and/or the end product. Colour pigments are added in poultry diets to improve yolk colour.
- Growth hormones: for improve rate of grain and feed conversion, e.g. Diethylstylbesterol (DES), melengesterol acetate (MGA), rumesin (monensin sodium)
- Antibiotics: added to prevent appearance of microbial infection, promotes/improves digestibility. E.g. oxytetracyclines, bacitracin, coccidiostats
- Enzymes: added to improve digestion of ingredients with high fibre contents and/or breakdown of nonstarch polysaccharides (NSPs). E.g. Amylase, xylanase, phytase (releases trapped phosphorus), beta glucanase, etc

- Amino acids: limiting amino acids like lysine and methionine are added in monogastric feed to make up for this deficiency
- Antitoxins/Toxin neutralisers: added to inhibit the growth of toxin-producing microbes e.g. moulds and fungus. E.g. HSCAS carriers
- Probiotics: they provide colonies of gut friendly bacteria which competitively exclude enteropathogens such as salmonella and E. coli, clostridium from the intestinal mucosa.
- Prebiotics: added in feeds to act against enteropathogens and provide nutrients for the proliferation of the gut friendly bacteria, thus reducing the incidence of enteric infections.
- Choline chloride: added to reduce unwanted fat deposition in body in layer birds and pigs.

SELF-ASSESSMENT EXERCISE

1. What is a feed additive?
2. List five attributes/characteristics of an ideal feed additive.
3. Name and describe the mode of action of six feed additives.

4.0 CONCLUSION

In this unit you learnt that a feed additive is an ingredient or combination of ingredients added in small quantities to a basic feed mix for the purpose of fortifying the basic with trace nutrients, medicines, or drugs to enhance its flavor, texture, or appearance or to retard spoilage or augment its nutritional value example of which are prebiotics, probiotics, antibiotics, enzymes etc. also certain attributes are to be looked out for in selecting an ideal feed additive.

5.0 SUMMARY

In this unit, you have learnt that feed additives can be used to manipulate rumen function, increase the level and efficiency of animal performance, and minimise adverse effects of diets on animal health and the environment. Many of the compounds listed as feed additives would be classed as drugs. There is a trend towards reduced utilisation because of pressure of various groups that believe usage of antibiotics in particular in animal feeds may be dangerous to humans.

6.0 TUTOR-MARKED ASSIGNMENT

1. List five attributes/characteristics of an ideal feed additive.
2. Name and describe the mode of action of six feed additives.
3. What are feed additives?

7.0 REFERENCES/FURTHER READING

National Research Council. (2001). *Nutrient Requirements of Dairy Cattle.* Vol. (7th Rev. ed.). Natl. Acad. Sci., Washington, DC.

McDonald, P., Edwards, R.A., Greenhalgh, J.F.D. & Morgan, C.A. (1998). *Animal Nutrition*. (5thed.). Malaysia:Published by Longman.

Basic Animal Nutrition and Feeding. (5thed.). USA: Published by John Wiley & Sons, Inc.

UNIT 3 NUTRITIONAL DISORDERS

1.0 INTRODUCTION

Ruminant animal is subjected to a number of disorders due to the nature of its GIT and partly due to complication factors introduced by management or nutritional practices in modern day agriculture. These problems primarily involve the rumen.

2.0 OBJECTIVES

By the end of this unit, you will be able to:

- name and explain the nutritional disorders of ruminants.

3.0 MAIN CONTENT

1. Pasture bloat

The feeding of and/or grazing on lush green legumes such as alfalfa or red clover leads to bloat (or hoven) which is a digestive disorder of ruminants caused by the accumulation of gas in the rumen and reticulum when the animal is unable to eructate/belch. If untreated, bloat often leads to death within a matter of minutes from the first signs of distress. Factors that increase the incidence of pasture bloat include a predisposition to bloat (genetic-there is some evidence that bloat occurs more often in certain cattle families) and the amount and rate of feed intake. The most effective method to relieve bloat is to insert a stomach tube (a rubber hose case, ¾ to 1 inch in diametre) or in extreme cases to puncture the rumen with a trocar (insert a trocar and canula at the apex of the blown area, on the left side of the animal, clear of all bones; withdraw the trocar and hold the canula until the bulk of the gas has escaped; then, if necessary, fasten the canula in place with strings tied round the belly) to relieve the pressure. At least 1 pint of defoaming material, such as vegetable oil, should be administered into the rumen immediately.

The provision of hay to ruminants before they have access to pastures likely to produce bloat is the soundest precaution. Alternatively, stock may be placed in a field of mature grass in the early morning from 6 a.m. to 9 a.m.; this ensures that the dry fibre is present in the rumen before the animals begin grazing a lush pasture, and the dew will have dried. Other ways by which the incidence of bloat can be reduced includes: maintaining pastures that do not exceed 50% legumes, feeding straw or dry hay in the legume pasture while animals are grazing, feeding poloxalene once or twice daily following heaviest legume consumption (early morning or late evening), have at least two stockman within sight of the herd, make handy appropriate drenches of 1 part paraffin (kerosene) in 3 parts water and dose 420ml or 15 oz. These precautions may not be sufficient where frothy bloat (formation of gas in the form of bubbles which offer too much resistance to pass up the canula) occurs. If animal is on the point of collapse, make a bold incision through the rumen wall large enough to release the froth. Propriety antibloat remedies to rub on the flank of the animal are now available. It should be borne in mind that several cases may occur simultaneously. Prevention is far better than cure. Bloat is a ‘disease’ of improved nutrition and is part of the penalty paid for more productive pasture and feeding.

2. Grass Tetany

Grass tetany (hypomagnesemia) is usually most pronounced in the spring and is caused by low blood Magnesium levels. Levels of 0.2% Mg or greater in forages reduce the risk of grass tetany. Tetany occurs most frequently in cows that are nursing calves under two months of age. High levels of Nitrogen fertilisation or high levels of potassium in the soil, along with cool, rainy weather, increase the incidence of grass tetany. Clinical signs are not often observed until death. Affected animals may become excitable and appear to be blind. If tetany is suspected, a blood sample should be obtained. Normal blood Mg levels 2.25 mg/100 of serum. Affected animals may have below 1.0 mg Mg/100 ml of serum. Cows that develop tetany once are more likely to develop symptoms the following year. Death losses can be 100% if the condition is not treated rapidly.

To prevent grass tetany, free-choice mineral supplement containing Mg should be made available during the early grazing season. Adequate Mg can be supplied by consumption of 2 oz/day of magnesium oxide. However, MgO is unpalatable, and a mixture of 30% trace mineralized salt, and 8% grain products will increase consumption.

3. Nitrate Toxicity

When nitrate levels are consumed in excess of the rumen's ability to convert them to ammonia, nitrites accumulate in the rumen and are absorbed into the blood stream. High blood nitrate causes hemoglobin to be converted to methemoglobin, which cannot transport oxygen, and death can result from asphyxiation. Symptoms of acute nitrate poisoning include staggered gait, tremors, rapid pulse, and dark mucous membranes due to lack of oxygen. Oat, barley, wheat, sorghum, corn, pigweed, kochia, sunflower, sugar beets, potatoes, and carrots are forage plants that can commonly accumulate nitrates. Other conditions that increase the potential for nitrate accumulation in plants include stresses such as drought, frost, low temperatures, hail damage and cloudy weather. Nitrate levels are highest in the lower portions of the plant, so harvesting at a higher level or leaving a 12-inch stubble reduces the level of nitrate in the forage.

Water can also be a source of nitrates and can contribute to the total nitrate load that the cow is receiving. A level <1,000 (<0.1%) ppm is considered safe for all cattle. Total nitrate loads of from 15 to 45 g/100 lb body weight are considered toxic. A veterinarian should be consulted immediately if nitrate poisoning is suspected. Methylene blue injection intravenously (2 g/500 lb body weight) will convert methemoglobin to hemoglobin.

4. Fescue Toxicosis

Cattle grazing or consuming harvested hay from tall fescue pastures, a common grass species in the Midwest and southern parts of the United States, can exhibit toxic symptoms or reduced performance. Symptoms include decreased intake, reduced growth rate, rough hair coat, excessive salivation and urination, increased body temperature and perspiration. Affected animals may exhibit soreness in one or both hind limbs (fescue foot), and hooves and tails may be sloughed off. The toxicity symptoms have been linked to the presence of an endophytic fungus growing between the cells of tall fescue plants. Fescue toxicosis can be reduced by planting endophyte-free fescue cultivars, cutting fescue hay early, incorporating legumes into tall fescue pastures and keeping fescue in a vegetative state as long as possible by grazing or clipping pastures.

5. Acute Pulmonary Emphysema

This disease, commonly called asthma, occurs when cattle are moved from dry rangelands to lush meadow pastures in late summer or early fall. Abrupt dietary changes from dry to lush forage may trigger the onset of this condition. The first indication is labored breathing. Afflicted animals extend their necks, breathe with an open mouth, and grunt on expiration. It is believed that the amino acid tryptophan in lush forages is converted to a compound that is highly toxic to lung tissues.
Prevention of death from this condition appears to be a combination of grazing management and ionophore. Prevention is critical, because there is no effective treatment. Cattle should be introduced to lush green pastures gradually over a period of several days and not when they are exceptionally hungry. A daily dose of 200 mg monensin has been shown to prevent this condition.

6. Displaced Abomasum

The Abomasum is the fourth or true stomach of ruminants. Normally it lies on the floor of the abdomen. When it becomes filled with gas, it rises to the top of the abdomen, then it is said to be displaced. The abomasum is more likely to be displaced to the left (LDA) than to the right (RDA). Two main risk factor has been implicated.

Calving; the majority of cases occur after calving. During pregnancy the uterus displaces the abomasum so that after calving the abomasum has to move back to its normal position, thus increasing the risk of displacement.

Atony of the Abomasum; if the abomasum stops contracting and turn over its contents, accumulation of gas will occur and the abomasum will tend to move up the abdomen.
Clinical signs; drop in milk yield, reduced rumination, mild colic and distended abdomen, normally very little acetonaemia with ketones in breath and urea.

Diagnosis: blood sampling to identify ketosis and other metabolic changes.
Treatment; this involves casting and rolling the cow and manipulating the abomasum so that it returns to its normal position. This can be effective if done early giving about 50% relapse. Surgery is also an option.
Prevention:

- Ensure cattle are not too fat at calving

- Feed high quality feed with good quality forage
- Feeding a total mixed ration as opposed to concentrate
- Ensure plenty of space at feeding site for exercise
- Minimise change between late dry and early lactation
- Prevent and promptly treat diseases such as milk fever, mastitis and retained placenta which reduce feed intake.
- Maximise cow comfort and minimise stress

1. Urea (ammonia) toxicity

So called urea toxicity is characterised by neurological symptoms. In practice, it occurs following rapid intake of urea that could be due to:

- Insufficient mixing of urea in compounded diets
- Sifting of urea to the bottom of a loose feed mixture
- Leaching of urea in troughs, permitting animals to drink solutions containing high concentrations of urea
- Excessive consumption of urea from blocks that have been softened by rain water collecting in holes licked in the blocks or by over-consumption of liquid mixtures.

The likelihood of toxicity is greater in animals that have not been adapted to urea supplements. Animals that have been fasted for a day or more, and in those with liver dysfunction (e.g fluke infestation or damage from toxic plants) that prevent them from converting ammonia to urea, are also at risk. Urea itself is not toxic; it is the ammonia produced from urea in the rumen that is toxic. When large amounts of urea are consumed, the pH and the concentration of ammonia in the rumen increase, and more ammonia is absorbed that is normally converted to urea in the liver and excreted in the urine. The usual explanation of urea toxicity is that the liver cannot cope with the increased absorption of ammonia; that the level of ammonia in peripheral blood rises; ammonia is carried to the brain in the blood and brings on the clinical symptoms.

SELF-ASSESSMENT EXERCISE

Discuss the following Nutritional disorders i) Urea Toxicity ii) Grass Tetany iii) Acute Pulmonary Emphysema iv) Displaced Abomasum v) Nitrate Toxicity.

4.0 CONCLUSION

In this unit you, learnt the nutritional disorders of ruminants.

5.0 SUMMARY

In this unit, you have learnt that due to the complexity of the ruminant's digestive system, it is proned to several nutritional disorders some of which are pasture bloat, grass tetany, nitrate toxicity, urea toxicity etc.

6.0 TUTOR-MARKED ASSIGNMENT

Explain five (5) nutritional disorders.

7.0 REFERENCES/FURTHER READING

Dawson, K. A. & M. J. Allison (1988). *Digestive Disorders and nutritional Toxicity.* In: P. N. HOBSON (ed.): The Rumen Microbial Ecosystem Elsevier Science, Barking, Pp. 445–459.

Garry, F. B. (2002). Indigestion in Ruminants. In: B. P. SMITH (ed.). *Large Animal Internal Medicine* (2nd ed.). Mosby, St. Louis and Baltimore.