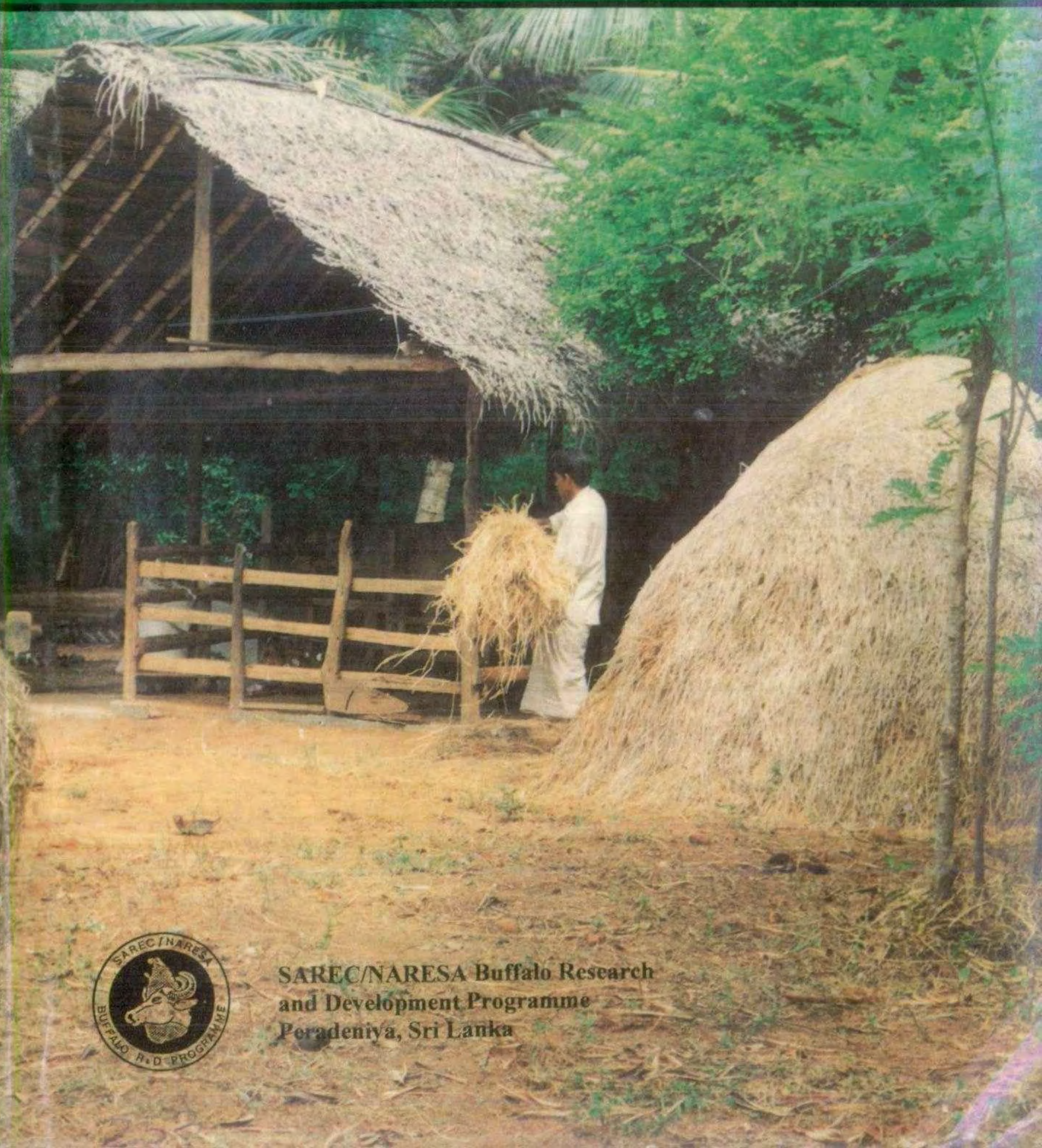
WATER BUFFALO IN ASIA: I

Nutrition of the Buffalo



SAREC/NARESA Buffalo Research
and Development Programme
Peradeniya, Sri Lanka

Water Buffalo in Asia – Nutrition   Ibrahim, Pathirana, Siriwardene   2001

WATER BUFFALO IN ASIA

Publication of the SAREC/NARESA Buffalo Information Dissemination Programme

Volume 1 - Nutrition of the Buffalo

Edited by

M. N. M. Ibrahim
K. K. Pathirana and
J. A. de S. Siriwardene

National Science Foundation
2001

WATER BUFFALO IN ASIA

Publication of the SAREC/NARESA Buffalo
Information Dissemination Programme

Volume 1: Nutrition of the Buffalo
Volume 2: Buffalo Production and Management
Volume 3: Genetics and Reproduction of the Buffalo
Volume 4: Diseases of the Buffalo

ISBN 955-590-034-5

Printed in Sri Lanka

FOREWORD

It is with great pleasure that I write this foreword for the book on the nutrition of the buffalo. I was involved in water buffalo research from the early 1980s and was associated very closely with my senior colleagues who were instrumental in obtaining funds from Swedish Agency for Research Cooperation with Developing Countries (SAREC) for the SAREC/NARESA Water Buffalo Research and Development Programme. This programme commenced in 1984 and continued until the end of 1999. The Phase III of the programme (1994-1999) was primarily directed towards dissemination of information. This book is the 22nd of the series of 24 publications planned at the inception of the Phase III of the Programme. I am pleased to note that the project has fulfilled its obligations and met the donor's expectations.

Feeding of ruminants under limiting conditions is one of the formidable challenges faced by the farmers in tropical Asia. The discipline of ruminant nutrition has been one that has been studied in depth by nutritionists in many parts of the world. However, most of the published work relates to cattle and sheep, while nutrition of the buffalo has received sparse coverage, although the buffalo is uniquely different from cattle in many ways. The information in this book is intended to fill that void.

One of trust areas of the SAREC/NARESA Water Buffalo Research Programme was been the development of feeding systems for buffaloes. Seemingly appropriate technologies for practical feeding of ruminants have been developed. As stated earlier, the aim of the final phase of the Water Buffalo Research Programme was to compile and disseminate the information to the wide spectrum of the users. While many intermediaries will benefit from these text books, it is important to bear in mind that the ultimate end user of the researcher is the farmer. but most often the beneficiaries have been undergraduates and postgraduates students, and veterinarians and extension workers.

In this context, the Text Book on Water Buffalo,in 4 volumes, caters to the needs of undergraduates in veterinary, animal and agricultural sciences, postgraduate students in animal nutrition and researchers in the livestock sector. It is very well known that scarcity of books and non-relevance of the contents and the difficulty in assimilating the required knowledge from some of the voluminous text books available have frustrated the Sri Lankan university undergraduates and graduate students in their quest for knowledge. I find that this book on nutrition has been written with all these constraints in mind. The contributors have taken great care to present the information in very a concise manner with the required clarity and emphasis particularly on the application of the information under local conditions.

I have no doubt that this publication will fulfill the long felt need for a text book which provides an adequate coverage on water buffalo.

Professor H. Abeygunawardena
Dean, Faculty of Veterinary Medicine and Animal Science
University of Peradeniya,
Peradeniya

PREFACE

The renewed interest in the buffalo worldwide is a result of the recognition of the potential of the buffalo to assume the role of a useful multipurpose animal in farming systems in developing countries. The research information that has emerged during the past two to three decades has revealed that the buffalo exhibits many positive features, particularly in relation to its ability to adapt to the tropical environment and thrive under the harsh conditions that prevail in tropical countries. Much of the information used hitherto in feeding and management of the buffalo was drawn from research data relating to dairy cattle. Recent research findings reveal that the buffalo has the ability to utilize coarse fibrous feeds more efficiently than dairy cattle and this combined with the potential of the river type buffalo for milk production, places the buffalo at an advantage over dairy cattle in fitting into the role of a multipurpose farm animal. This is evident from the successes achieved in India and Pakistan where the river buffalo has emerged as the principal milking animal contributing the greater proportion of the milk produced in these countries. There is thus an urgent need to make the current research information relating to the nutrition of the buffalo available to those involved in buffalo production.

This publication presents the current knowledge on the nutrition of the buffalo. The book in made up of seven chapters. Chapter 1 deals with the anatomy of the digestive tract of the buffalo. Chapter 2 deals with digestion and absorption of nutrients. Chapter 3 gives details of metabolic pathways and utilisation of nutrients, Chapter 4 on nutrient requirements, Chapter 5 fibrous feeds and their utilisation, Chapter 6 on feeding systems and ration formulation and Chapter 7 on nutritional management of metabolic disorders. The authors have attempted to highlight the information that has particular relevance to the Sri Lankan situation.

Readers are encouraged to use the information in this book in conjunction with the information presented in previous publications intended for use by extension workers and farmers. These publication present information on the nutrition on the buffalo as a component of a package of technologies that are applicable in extensive crop-livestock integrated farming systems. These management packages were developed with the participation of farmers who participated in the adaptive research effort to test the applicability of technologies developed by the scientists.

The editors wish to thank Ms. Ayesha Herath and Janaka Herath for their assistance in type setting and preparation of the material for publication. They also wish to thank the SAREC/NARESA Buffalo Information Dissemination Programme for providing the financial support and publication of this book. The encouragement and guidance extended by Prof. H. Abeygunawardena is gratefully acknowledged.

KKP
MNMI
JAdeSS

CONTRIBUTORS

M. N. M. Ibrahim, B.Sc. Agric (Sri Lanka), Ph.D (Australia)
Professor of Animal Science, Department of Animal Science, Faculty of Agriculture, University of Peradeniya, Peradeniya.

M.C.N. Jayasuriya. B.Sc. Agric (Ceylon), Ph.D. (Reading, U.K.)
Executive Director, National Science and Technology Commission, Ministry of Science and Technology, Colombo.

H. Peiris: BVSc (Sri Lanka), M.Phil (Sri Lanka), PhD (Queensland)
Head, Department of Biochemistry, University of Sri Jayawardenapura, Colombo.

A.N.F. Perera, B.Sc. (Sri Lanka), Ph.D. (Virginia Tech, U.S.A.)
Professor, Department of Animal Science, Faculty of Agriculture, University of Peradeniya, Peradeniya.

S. Premaratne, B.Sc. (Sri Lanka), Ph.D. (Virginia Tech, U.S.A.)
Senior Lecturer, Depart Department of Animal Science, Faculty of Agriculture, University of Peradeniya, Peradeniya.

J. A. de S. Siriwardene: BVSc (Ceylon), Dip. Agri. Sc. (Wales), PhD (Wales)
Former Director, Department of Animal Production and Health, Peradeniya.

R. Sivakaneshan, BVSc (Ceylon), PhD (Hull)
Associate Professor, Department of Biochemistry, Faculty of Medicine, University of Peradeniya, Peradeniya.

CONTENTS

NA-253-1

Chapter 1

Anatomy of the Digestive Tract

M. C. N. Jayasuriya

Introduction

The digestive tract of animals perform three major functions. It enables the animal to consume feed, digest, absorb the digestible nutrients and excrete undigested and unabsorbed waste products. For this reason, the structure and functions of the digestive tract are largely dependent on the type of feed and the feeding habits of the animal. The digestive tracts of carnivorous and omnivorous animals are relatively simple and digestion takes place in the stomach and intestines, through the mediation of digestive enzymes secreted by various endocrine glands. However, herbivores have developed modifications to their digestive tracts to enable them to utilise cellulose, hemicellulose and other polysaccharides present in cell walls of fibrous plant material. The digestive tracts of the horse and rabbit represent one such modification, where the caecum is well developed and microbial activity enables the animal to digest plant polysaccharides. The ruminant stomach represents another modification which allows the animal to utilise large amounts of cellulosic material through fermentative digestion by micro-organisms in the rumen.

The anatomy of the ruminant stomach has been very well documented and readers looking for details are advised to refer to various specialised texts, such as Sisson and Grossman (1968), Church (1979) and Currie (1988). Since in general, the anatomy and histology of the digestive tract of the buffalo are essentially the same as those of cattle, except for some minor differences, only few attempts have been made to document this information in literature. Sengar and Singh have carried out a comprehensive study in India, on the anatomy and histology of the digestive system of the Indian buffalo and documented their findings in Sengar and Singh (1970a and 1970b). This information will therefore not be repeated here.

For above reasons, the digestive tract of the cow will only be described in brief in this Chapter, providing whatever additional information that is available and is relevant to the buffalo. This will be helpful to the reader in comprehending the following sections on digestion and metabolism of nutrients in the buffalo.

Digestive tract

The digestive tract of the mammal is a long and muscular tube extending from the mouth to anus and lined with mucus membranes. The digestive mechanisms enable the animal to reduce complex dietary materials into forms suitable for absorption and utilisation in the animal body. In mammals, the digestive tract can be divided into the mouth, stomach and the small and large intestines. However in ruminants, it differs from that of other mammals in that the stomach is greatly enlarged and divided into four compartments, the rumen, reticulum, omasum and abomasum (Fig. 1.1) and occupies nearly three-fourths of the volume of the abdominal cavity (Plate 1.1).

The rumen and reticulum together are referred to as the reticulo-rumen. The rumen, which is the largest of the four compartments, acts as a large fermentation vat, where unlike in other types of animals, most of the ingested food is actively fermented by rumen micro-organisms (bacteria, protozoa and fungi) before being exposed to normal

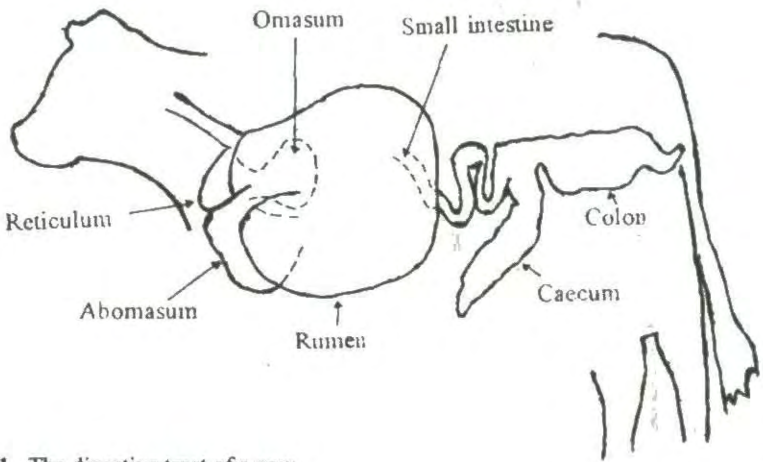


Fig. 1.1 The digestive tract of a cow.

11-JAN-02

Plate 1.1 The digestive tract of the buffalo

digestive enzymes of the stomach and intestines. The ability of rumen micro-organisms to digest cell wall material is essential for ruminants, as this enables the animal to utilise cellulolytic material, which in the absence of cellulose digesting enzymes in the digestive system, would escape digestion.

The mouth

The mouth consists of the oral cavity, lips, palate, cheeks, jaws, teeth, tongue and salivary glands. The upper jaw has no incisor teeth, but the tough dental pads that have replaced the incisors provide a surface against which the lower incisors can work to bite off fibrous feed material while grazing. In general, the adult buffalo has the generalised dental formula of ruminant animals.

The tongue is the main organ that manipulates feed in the mouth and facilitates chewing and formation of the bolus. It is a very muscular organ, sometimes variably pigmented and covered with stratified squamous epithelium that presents a large number of papillae of different kinds on its dorsal side. These papillae are generally known to help in the efficient prehension of feed.

As in cattle and other ruminant animals, chewing occurs in the buffalo at the time of ingestion of feed, merely to mix the food with saliva to form a bolus. Most of the saliva is secreted by the three major salivary glands, the parotid, mandibular and sublingual glands. Mastication takes place during the process of rumination during which most of the grinding of the forage material occurs. Very little forage is broken down at the time of prehension.

It is well documented that both cattle and buffaloes secrete large volumes of saliva during the course of ingestion and rumination. In general, cattle and buffaloes secrete around 120-180 litres of saliva per day, depending on the diet and its composition. Irrespective of age, the electrolyte content is the same in buffaloes and Zebu cattle, except that the chloride content is lower in buffaloes than in Zebu cattle. The rate of secretion of parotid saliva however, may be significantly higher in buffaloes than in Zebu cattle. As in cattle, the amount of saliva secreted in the buffalo is greatly influenced by the amount and quality of the ingested diet. Mechanical stimulation can enhance the secretion of saliva both in cattle and buffaloes.

Saliva is usually alkaline, being highly buffered by the presence of sodium and potassium bicarbonate and phosphate ions. Saliva helps to neutralise the acids formed during fermentation, particularly of carbohydrates in the rumen. Urea, phosphorus, calcium and magnesium are also present in relatively high concentrations in ruminant saliva which probably supplies these nutrients in a readily available form to rumen micro-organisms.

Oesophagus

The feed that is consumed and moistened by saliva when swallowed, enters the reticulum through the oesophagus. The oesophagus is a musculo-membranous tube that continues from the pharynx to the stomach. In the adult buffalo, it is around 100 cm long compared to 90-105 cm in a medium size ox and accounts for 2.5% of the total digestive tract. For more details on the histology of the oesophagus of the buffalo, the reader is referred to Sengar and Singh (1970b).

Complex stomach

In general, the stomach of the ruminant animal is very large and occupies nearly three fourths of the abdominal cavity. Its capacity varies greatly, from 110-270 litres, depending on the age and size of the animal. In a new born calf, the rumen and reticulum together are about half as large as the abomasum. Both are relatively underdeveloped and non-functional, because in a suckling animal digestion takes place primarily in the abomasum and intestine. But as the calf starts to consume solid food, the complex stomach begins to develop rapidly and in 10 to 12 weeks, this ratio is reversed. In an adult animal, the rumen constitutes about 80%, the reticulum 5%, the omasum 7% and the abomasum 8% of the total capacity.

The stomach of the adult buffalo is heavier than that of cattle, as a percentage of the body weight. As in all other ruminants, it is divided into four compartments, the reticulum, rumen, omasum and abomasum. According to Sengar and Singh (1970a), the rumen occupies 88% of the total stomach capacity, contains 5-10% more digesta and weighs about 15% more than that in cattle. The reticulum is a pea-shaped sac, which is incompletely separated from the rumen by the reticulo-ruminal fold, leaving the dorsal extremities of the two compartments in communication (Fig. 1.2). The reticulum and rumen are together called the reticulo-rumen and is that part of the stomach that provides a favourable environment for the growth and functioning of rumen micro-organisms.

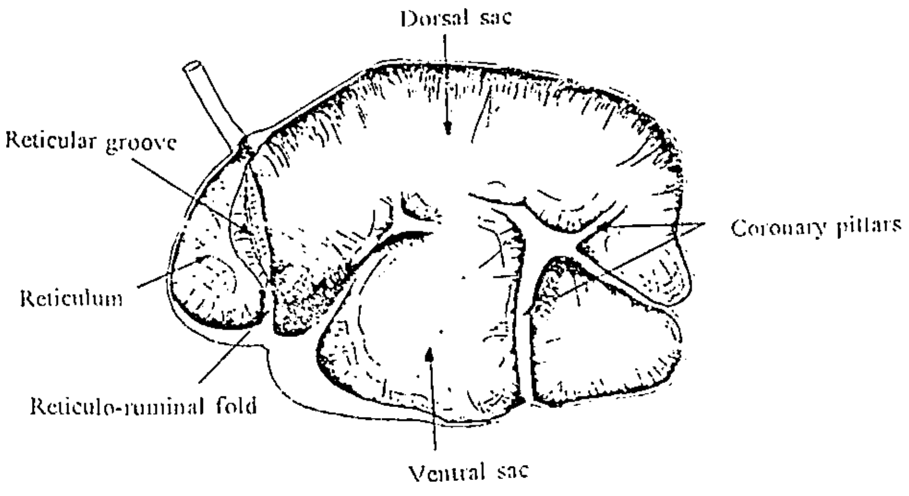


Fig. 1.2 A diagrammatic representation of the inner structure of the reticulo-rumen of the buffalo. (Adapted from Church, 1975)

The development of the reticulo-rumen is complete at about 7 weeks of age in the case of the buffalo. Its ratio to the total volume of the stomach is constant thereafter. At birth, the rumen has a capacity of 1.3 litres. This increases to about 20 litres at the age of 6 weeks. The capacity of the reticulo-rumen and its placement in relation to omasum and abomasum in a swamp buffalo is shown in Plate 1.2.

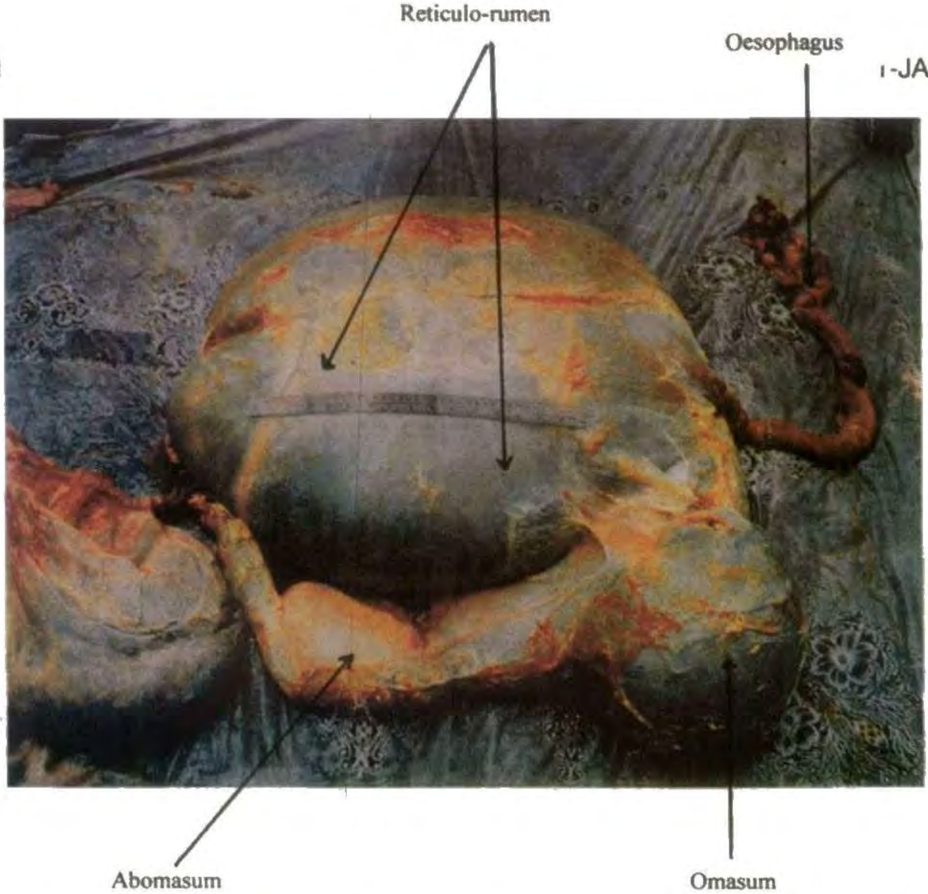


Plate 1.2 The reticulo-rumen in relatin to the omasum and abomasum of the swamp buffalo.

The reticulo-rumen

The reticulum and rumen are incompletely separated by the reticulo-rumen fold with the result that ingesta flows freely from one compartment to the other. The reticulo-rumen communicates with the omasum through the omasal orifice. Running along the wall of the reticulum, between the oesophagus and the omasal orifice is the reticular groove (also called the oesophageal groove). Under certain circumstances, particularly in the pre-ruminant calf, this groove can be closed to provide a tube-like structure, which functions as a bypass, allowing liquid to flow directly from the oesophagus to the omasum, bypassing the rumen.

The inner surface of the reticulum has the appearance of a honeycomb with raised folds and small projections of papillae. The epithelial lining is keratinized, devoid of glands and is thus non-secretory. It is essentially a protective surface with a remarkable absorptive function.

The inner surface of the rumen is also covered with papillae which greatly increases the effective surface area of the rumen. The epithelium of the rumen consists of four layers of cells. It is presented in a simplified form in Fig. 1.3. In general, the structure and functions of the epithelia of the rumen of the buffalo are believed to be very similar to those of cattle. However, the papillae in the rumen are more elaborately developed in the anterior region and are more densely distributed in the posterior region in the buffalo than in cattle. Plates 1.3 and 1.4 show the interior of the reticulo-rumen of a swamp buffalo and the different types of papillae lining its walls.

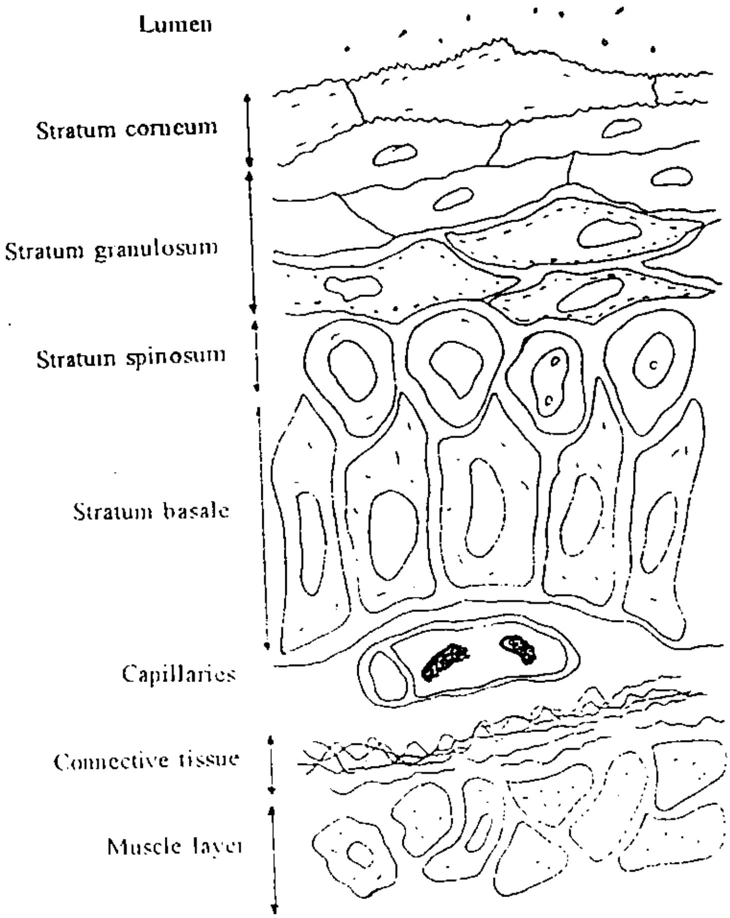
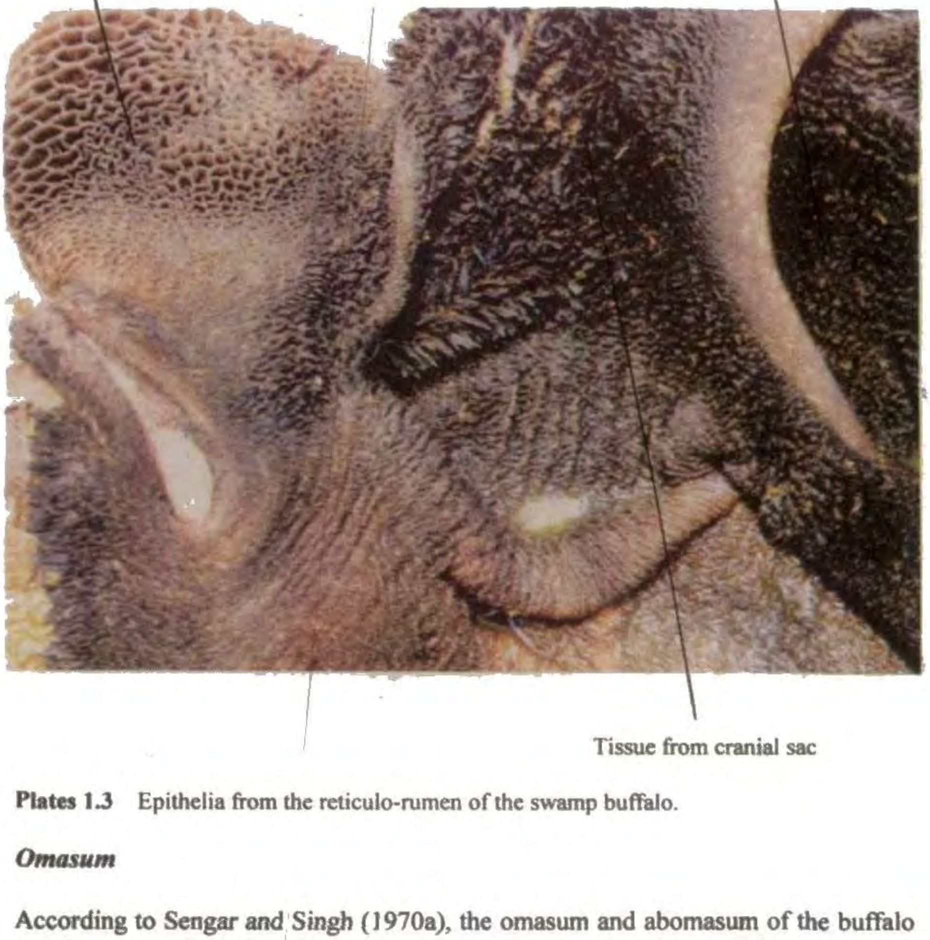


Fig. 1.3 A diagrammatic representation of the inner structure of the epthelium of the reticulo-rumen of the buffalo.

The movements of the ruminant stomach are very complex and involve a series of contractions of the rumen wall, the reticulum and diaphragm. Buffaloes show slower rumen movements than cattle implying a slower rate of outflow of digesta from the rumen. The rate of movement may however vary between the morning and evening hours, being higher in the evening than in the morning, presumably due to increased stimulus caused by the intake of feed (Bhattacharya and Mullick, 1965 - cited by Ranjhan, 1992).



Plates 1.3 Epithelia from the reticulo-rumen of the swamp buffalo.

Omasum

According to Sengar and Singh (1970a), the omasum and abomasum of the buffalo weighs comparatively less than those of cattle. The omasum of the buffalo contains less ingesta than that of cattle but has the same number of thin folds called laminae on the inner surface, which apart from increasing the surface area, also facilitates the absorption of water and volatile fatty acids. For further details on the structure and functions of the rumen epithelium and omasum, the reader is referred to Church (1979) and Steven and Marshall (1970).

Abomasum

The last component of the stomach is the abomasum, the structure and functions of which are similar to those of a monogastric animal. Therefore, the reader is referred to any text book on the anatomy and physiology of the digestive tract of domestic animals, for further details. Although several methods have been employed, it has been difficult to determine the true relative size of various compartments of the ruminant stomach, since the capacity of the stomach can vary with body condition (fat or lean), feed intake and gas fill. Perhaps, it is only an estimate that could be made of the `physiological fill' in a `normally' fed animal. Table 1.1 shows the relative size of the stomach compartments of cattle and sheep on a wet stomach tissue basis, in relation to estimated values for the indigenous swamp buffalo of Sri Lanka

Plate 1.4 The reticulum, reticular groove and the omasum of the swamp buffalo.

Table 1.1 The relative sizes (%) of compartments of the stomachs of cattle, sheep and swamp buffalo on a wet stomach tissue basis

Compartment	Cattle*	Sheep*		Swamp buffalo**
Reticulo-rumen	56-60	69-73		57-64
Omasum	26-30	5-6	)	36-43
Abomasum	13-14	22-23	)	

* Source: Church, 1979;
** Estimated values from a slaughtered animal

Rumen contents

The contents of the reticulo-rumen in the adult buffalo varies from 40-100 kg depending on body size, nature of the diet, the rate of microbial fermentation and the rate of passage of digesta. The dry matter content of rumen ingesta varies from 10-15%. Of all components of the digestive tract, the omasal contents have the highest dry matter content; the lowest being in the small intestine (Ranjhan, 1992).

Rumination

The phenomenon of rumination or re-chewing of the rumen contents (chewing the cud), ingested earlier in time, is one of the special characteristics of ruminant animals. Rumination involves the regurgitation of the ingesta from the reticulo-rumen, swallowing of the regurgitated liquids, re-mastication of the solids with saliva and finally re-swallowing of the bolus. The rumen contents are continually mixed by contractions of the musculature of the walls. Additionally, contractions of the reticulum and the diaphragm, draw back the ingested feed from the rumen into the oesophagus, and the bolus formed is moved to the mouth by the antiperistaltic movements of the oesophagus. During this process, the liquid portion of the ingesta is quickly swallowed and the solid portion is moistened with saliva, chewed and re-swallowed.

The tactile stimulation of the rumen epithelium by coarse feed particles is one way by which the process of rumination is initiated. Therefore, the time spent on rumination would depend, amongst other things, on the intake of cell wall material in the feed. The time spent on rumination is generally divided into many periods, interspersed with intervals of feeding, drinking and resting. The reflex control of the rumination sequence is well documented and the reader is referred to Currie (1988) for more details. Since ruminants spend 60 to70% of their time eating during day light hours, they spend more time ruminating at night than during day light hours. Buffaloes have been found to spend less time ruminating than cattle. Kashiwamura and Jayasuriya (1977a) observed that in a tropical environment, with ambient temperatures ranging from 20-31°C (night to day temperature) and relative humidity ranging from 40-98%, Murrah buffaloes spend 8 hours/day grazing and only 6 hours/day ruminating. Most of the grazing was done at night while wallowing took place during day light hours. The grazing:rumination ratio for pasture was 1.38 indicating the high degree of selectivity exhibited by the animals. Under similar climatic conditions (night to day ambient temperature ranging from 21-28°C and relative humidity ranging from 63-97%), European breeds of cattle spend 9.5 hours grazing and 7 hours ruminating. The grazing to rumination ratio was 1.34 (Kashiwamura and Jayasuriya, 1977b).

Welch and others (cited by Van Soest, 1982) compared rumination rates in goats, sheep and cattle on similar diets where the main variable within each species was the animal size. The results showed that a linear relationship exists between the log of rumination rate and body size, indicating that the rumination rate parallels the relation between the digestive tract or rumen size to body weight.

The intestines

The anatomy and physiology of the intestinal tract of all ruminant livestock, including the buffalo in general, is similar to that of other mammalian species. Therefore, for detailed descriptions, the reader is referred to any specialised text on the subject, in particular to Sisson and Grossman (1968), Church (1979), Currie (1988) and Bondi (1987). However, a brief description of the function of the intestines is provided for completeness in this Chapter .

The intestine of an adult cow measures about twenty times the length of the body. It is slightly smaller in the buffalo, varying between 35 to 40 metres compared to about 50 metres in the case of cattle. In all farm animals, the intestines serve as a major site of digestion and absorption of nutrients. The small intestine is a hollow muscular tube lying between the pyloric and ileocaecal sphincters. The first part of the small intestine, the duodenum, is attached to the liver and the rumen by connective tissue. The bile duct opens into the duodenum, secreting bile from the liver, which is normally stored in the gall bladder until required. The sodium and potassium salts of bile acids play an important role in digestion, by emulsifying fats and activating enzymes.

The pancreas opens further posteriorly into the duodenum through the pancreatic duct and secretes pancreatic juice. This is a bicarbonate-rich secretion containing many enzymes such as proteases and amylase. Two other secretions also enter the small intestine and assist in the digestion of feed. These are the alkaline duodenal juice secreted by Brunner's glands which protects the duodenal wall from hydrochloric acid entering from the stomach. The secretion from the intestinal mucosa, the succuss entericus does not contain enzymes responsible for hydrolysis of disaccharides and peptides, as previously thought, but act on the surface of the intestinal mucosa or intracellularly within the mucosal cells.

The digesta reaching the duodenum is subjected to the action of numerous peristaltic movements, which are caused by contractions of the circular muscles of the intestinal wall. The movements help to transport the digesta along the tract, mixing with digestive juices and bringing the digested nutrients into contact with the intestinal mucous membrane for subsequent absorption. Being the main site of absorption, the small intestine contains a series of microscopic projections called "villi" extending into the intestinal lumen, which greatly increase the available surface area for absorption. The nutrients absorbed through the villi are conveyed either through the portal vein or through the lymphatic system.

The remainder of the small intestine, the jejunum and ileum are arranged in numerous close coils which lie chiefly in the space bounded medially by the right face of the ventral sac of the rumen, dorsally by the large intestine, laterally and ventrally by the abdominal wall and anteriorly by the omasum and the abomasum.

The large intestine consists of the caecum, the colon and the rectum. It is shorter than the small intestine, but considerably larger in diameter. Ruminants in general have relatively small caeca in comparison with other herbivorous animals. Although there is no clear demarcation between the caecum and colon, the site of the ileo-caecal valve is the acknowledged junction.

Most of the absorption of digested nutrients take place in the upper gastro-intestinal tract in all animal species. Feed constituents which escape rumen fermentation and are resistant to digestive enzymes enter the large intestine. The secretions consisting of enzyme-free fluid containing bicarbonate and mucus help to lubricate feed residues. Therefore, any digestion in the large intestine occurs as a result of microbial activity, by a population micro-organisms similar to that in the rumen, but the extent of microbial activity is much less than in the rumen. The epithelium of the large intestine helps to absorb any volatile fatty acids, water and electrolytes.

The undigested food and waste products from the digestive tract accumulate in the rear part of the large intestine in the form of a solid residue, which is expelled as faeces through the anus.

Suggested reading

Bondi, Aron. A. (1987) *Animal Nutrition.* John Wiley & Sons, New York.

Church, D.C. (1979) *Digestive Physiology and Nutrition of Ruminants. Volume 1. Digestive Physiology.* O & B Books, Corvallis, Oregon, USA.

Currie, W.B. (1988) *Structure and Functian of Domestic Animals.* Butterworths, London.

Kashiwamura, F. and Jayasuriya, M.C.N. (1977a) Some observations on grazing behaviour of European cattle in the mid-country of Sri Lanka. *Journal of the National Science Council, Sri Lanka.* **5**, 105.

Kashiwamura, F. and Jayasuriya, M.C.N. (1977b) Some observations on the grazing behaviour of Murrah buffaloes in the dry zone of Sri Lanka. *Journal of the National Agricultural Society.* Sri Lanka. **14**, 27.

Ranjhan, S.K. (1992) Nutrition of river buffaloes in southern Asia. In: Buffalo Production. *World Animal Science.* (Ed.) Tulloh, N.M. and Holmes, J.H.G., Elsevier, New York.

Sisson, S.B.S. and Grossman, J.D. (1968) *The Anatamy of the Domestic Animals.* W.B. Saunders Company, Philadelphia and London.

Sengar, O.P.S. and Singh, S.N. (1970a) Studies on the digestive system of ruminants. Structure of the intestine of the buffalo - Bos bubalis L. *Agra University Journal of Research (Science)*, **19**, 13

Sengar, O.P.S. and Singh, S.N. (1970b) Studies on the digestive system of ruminants. Structure of the foregut in buffalo - Bos bubalis L. *Agra University Journal of Research (Science)*, **19**, 43.

Steven, D.H. and Marshall, A.B. (1970). Organisation of the rumen epithelium. In: Physiology of Digestion and Metabolism in the Ruminant. *Proceedings of the Third International Symposium*, Cambridge, (Ed.) Phillipson, A.T., Oriel Press, UK.

Van Soest, P.J. (1982) *Nutritional ecology of the ruminant.* O & B Books, Corvallis, Oregon, USA

NA - 253 - 2

Chapter 2

Digestion and Absorption

A. N. F. Perera

Introduction

Most of the major processes relating to fibre digestion takes place in the rumen. These require a thorough mixing of feeds through a process referred to as 'propulsion'. The movements of the rumen wall are very complex and involve a series of muscular contractions, which result in changes in pressure within the rumen. These pressure changes facilitate the circulation of ingesta within the reticulo-rumen and eventually their passage into the omasum. Propulsion is a continuous process that facilitates mixing of the feed in the rumen throughout the fermentation period. The presence of large feed particles in the rumen also stimulates the contractions of the reticulum and the diaphragm, which compact the large feed particles in the rumen into boluses, which are moved to the mouth through the oesophagus by rapid anti-peristalsis movements. The bolus is moistened with saliva and masticated again, a process known as 'chewing of the cud' or 'rumination'. Rumination is induced by tactile stimulation of the rumen epithelium by pressure exerted by coarse feed material. Rumination is therefore a very important digestive process in the ruminant.

Rumen environment

The rumen provides a unique environment in which many biochemical reactions take place. This dynamic rumen digestive environment constitutes three distinct phases;

(a) Liquid phase: This is the rumen fluid or rumen liquor comprising a mixed mineral solution containing anions and cations of various types. In addition, a mixture of fermentation by-products and soluble feed components are present. Most of the rumen micro-organisms are free moving, while some are attached to the feed particles in both the liquid and solid phases. Dissolved rumen gases form part of this phase, which provide an excellent medium for rumen microbial activity. The other important function of the liquid phase is the maintenance of the buffering capacity of the rumen.

(b) Gas phase: This phase contains a mixture of many types of gases, which result from the fermentation process, but is nearly devoid of oxygen. This anaerobicity is maintained in the rumen environment to provide optimum conditions for rumen microbial activity and growth.

(c) Solid phase: This phase is made up of insoluble feed particles, 80-90% of which are cellulolytic material originating mainly from the roughage diet. The solid material floats on the surface of the liquid phase and is continually mixed with the liquid phase through propulsion. This action interfaces the solid-liquid phases and facilitates fermentation in the rumen.

Rumen Gases

The rumen gas mixture is composed of 30-40% methane, 20-65% carbon dioxide, 5% hydrogen and small quantities nitrogen, hydrogen sulphate and oxygen. Methane is an important by-product of anaerobic sugar fermentation. It is a high energy product, resulting from carbohydrate fermentation, but unfortunately the methane energy cannot be utilised by the animal and the methane is expelled from the rumen in gaseous form. The estimated energy loss *via* methane is about 8% of the gross energy intake. The major pathway of methane production is through the reduction of carbon dioxide with hydrogen gas, by almost all species of rumen bacteria. Small quantities of methane are also produced by specialised bacteria from formates (H-COO), acetates (CH_3COO) and methanol (CH_3OOH).

Hydrogen is produced during carbohydrate fermentation when sugars are converted to volatile fatty acids. Small quantities are also produced from formates. Hydrogen is rapidly utilised by the methanogenic bacteria in the process of methane production. Therefore in the rumen, hydrogen is maintained at a very low partial pressure to ensure favourable conditions for activity of rumen micro-organisms. Gas production in the rumen is very rapid, immediately after a meal and may exceed 30 l/hr, decreasing to 10 l/hr after 4 hours. The rumen gasses are periodically expelled through the mouth by eructation (belching). A significant amount is also absorbed *via* the rumen wall and exhaled through the lungs.

pH and osmotic pressure

As with other continuous culture systems, the rumen requires a number of homeostatic mechanisms to maintain a pH of 5.5-6.5. However, after ingestion of feed and commencement of fermentation, the rumen pH drops to between 2.5-3.0 due to production of volatile fatty acids. Lowering of pH can bring about many detrimental effects on overall rumen activity, particularly on microbial activity, fibre digestion and may sometimes lead to metabolic disorders. The maintenance of rumen pH within the physiological range is thus important. This is affected by the buffering effect of bicarbonate and phosphate ions originating from saliva. The rapid absorption of volatile fatty acids and rumen ammonia from the rumen also facilitates the maintenance of rumen pH. The osmotic pressure of rumen fluid is close to that of blood and the ionic balance is maintained by the flux of ions between the rumen fluid and blood *via* the rumen wall.

Anaerobicity and temperature

The maintenance of rumen anaerobicity is essential to the rumen system, since many of the microbes present in the rumen are obligatory anaerobes. The anaerobicity is strictly maintained by the continual filling of the void in the rumen by methane and carbon dioxide. Any oxygen entering the rumen during feed ingestion or *via* drinking water is immediately used up to ensure the maintenance of anaerobicity. In order to maintain optimum rumen conditions, it is necessary that the temperature should be maintained close to body temperature (38-42^{0}C).

Rumen microbiology

The major function of the rumen is to retain the ingested feed for as long a time as is necessary for microbial digestion. The digestion process in the rumen is activated largely by a variety of rumen microbes. Microbial fermentation in the reticulo-rumen is achieved mainly by anaerobic bacteria and protozoa, and to a lesser extent by certain fungi.

Of the groups of micro-organisms present in the rumen, the most important group is the rumen bacteria (rumen flora). The total rumen bacterial population in the buffalo is 16.2×10^8/ml, while in cattle it is 13.2×10^8 /ml. The different species of rumen bacteria are grouped according to the substrates they act on. The major groups of bacteria are described below.

Celluloytic bacteria

This is the largest group of bacteria in the rumen and the substrate they act on is cellulose. The main species within this group are; *Bacteriodes succinogen*, *Ruminococcus flavofaciens* and *Ruminococcus albus*. The densities of these bacteria are estimated to be 2.6×1.0^8/ml and 6.9×1.0^8/ml in cattle and buffaloes, respectively. The viable bacterial percentages in cattle and buffaloes are 20% and 42% respectively (Pradhan, 1991).

Amylolytic bacteria

The major substrate that this group acts on is starch or amylose. The main species of bacteria that use amylose are *Bacteroides amylophilus* and *Streptococcus bovis*. The total bacterial counts for each of the species, on straw based diets are 11.0×10^8/ml in buffalo and 8.6×10^8/ml in cattle, and the viability percentages are 68% and 65%, respectively. However, incorporation of soluble carbohydrates in the feed or the provision of less mature grasses, which are rich in starch and sugars can increase the bacterial population.

Proteolytic bacteria

The common species of rumen bacteria generally do not use protein as the major energy source. However, about 30-50% of the bacteria isolated exhibited proteolytic activity towards extracellular proteins. Most species of bacteria exhibit proteolytic activity with the exception of the main cellulolytic bacteria, *B. succinogen*, *R. flavofaciens* and *R. albus*. *Bacteroides amylophilus* is one of the active proteolytic species present in the rumen. These are amlylolytic bacteria which are very important in the fermentation of starch-rich diets. The function of the proteolytic bacteria is the breakdown of dietary proteins into peptides and subsequently to ammonia. The total population of proteolytic bacteria in the buffalo is 0.54×10^8/ml and in cattle 0.41×10^8/ml on straw based diets, while the percentage viability count is 3% in both species.

Table 2.1 Rumen microbial population in cattle and buffalo fed wheat straw - concentrate diet.

Type of microbe	Cattle	Buffalo
Total protozoa	1.15	1.59
Total viable bacteria (x10^8/ml)	13.2	16.2
Cellulolytic bacteria (x10^8/ml)	2.58	6.86
% of viable bacteria	20.0	42.0
Amylolytic bacteria (x10^8/ml)	8.63	11.5
% of viable bacteria	65.0	68.0
Proteolytic bacteria (X10^8/ml)	0.41	0.54
% of viable bacteria	3.0	3.0

Source : Pradhan *et al.* (1990)

Methanogenic bacteria

This group of bacteria is important in the rumen for the removal of excess hydrogen that is produced in the rumen during carbohydrate fermentation and also to keep the rumen environment at a low hydrogen partial pressure. The most important species in this group is *Methanobacterium ruminantium.*

Rumen protozoa

The population of protozoa in the rumen of cattle maintained on fibrous feeds is low (100,000/ml), but when fed on diets rich in starch or sugars, it could be as high as 4,000,000/ml. In the rumen, many species of protozoa are present, but the major species are (a) Entodiniomorphids and (b) Holotrichs. The Entodiniomorphids which are able to take up soluble components, mainly depend on engulfment of particulate matter. They feed on bacteria, starch granules, cellulose and hemicellulose. The Holotrichs are a ciliated type of protozoa widely found in the reticulo-rumen. The three principal holotrich species in the rumen are,

(a) Isotricha intestinalis
(b) Isotricha prostomia
(c) Dasytricha ruminantium

The normal population of holotrichs is 100, 000/ml, but this population increases when the diet is rich in soluble carbohydrates. The protozoa retained in the rumen are subjected to substantial lysis within the rumen. During re-mastication, bacteria and other soluble material are released from the mouth when the feed bolus is squeezed, and immediately passes into the omasum *via* the reticulum, while the protozoa remain in the squeezed bolus. This is due to the large size of cilia which attach them to large particles. Substantial amounts of protozoa are not only retained in rumen but also in the omasum within its more complex structure.

Rumen fungi

Anaerobic fungi that inhabit the rumen have been isolated recently. These fungi belong to the phytomycaetes group. The vegetative stage of fungi carries sporangia developed from rhizoids (similar to the hyphae). These rhizoids grow within plant tissues. When roughage is ingested, sporangia immediately release zoospores which enter the new plant tissues through damaged parts of the plant or stomata of the leaves. Fungi are the first organisms to invade plant structural components starting from the inside. This reduces the tensile strength and facilitates the commencement of bacterial fermentation.

Microbial interactions in the rumen

Types of microbes present in the rumen vary according to the species of livestock, feed and the time after feeding. However, the final products of fermentation are almost the same. Interaction of bacteria with bacteria in the rumen is very common. Most of the microbes in the rumen cannot survive long. They are interdependent as the end-products of one species becomes the substrate for another species. Therefore, in the absence of the first species, the survival of the latter species is uncertain. There is evidence to support the suggestion that end-products obtained from one species when present in a mixed culture is different from those from the same species in a pure culture. This indicates the inter-dependence of species for substrates that are either end-products or intermediate products. Many different species of bacteria are involved in the fermentation of cellulose to VFA. The relationship between hydrogen producing and hydrogen utilising bacteria is well recognised. These associations (syntropic associations) are mutually beneficial to the species and little can be done to alter these associations other than by inhibition of methanogenesis.

Another common interaction in the rumen is that between bacteria and protozoa. Generally, protozoa predate on bacteria by engulfing (ensiling) them. This leads to low bacterial populations and as a result the colonisation around structural feed particles is reduced. This will result in an increase in the retention time of feed in the rumen. Such conditions can be acute when the diet of the animal is low in soluble carbohydrates and rich in structural components. Under these circumstances, it is mandatory for protozoa to predate on bacteria for energy and nitrogen.

Protozoa depend mainly on soluble starch and sugars. Once these are engulfed by the protozoa, they are stored within cells. Thus the competition between protozoa and bacteria for sugars and starch is very severe. Often when high sugar containing diets are fed, protozoa out-number the bacteria. One advantage is that in certain situations, protozoa reduce the severity of acidosis on some diets. Elimination of protozoa from the rumen (defaunation) increases the bacterial numbers in the liquid pool. The apparent dry matter digestibility is increased by 18% under defaunated conditions.

Manipulation of the rumen

Natural rumen conditions can be manipulated to improve productivity of ruminants. This could be done by,

(a) increasing the digestibility of structural carbohydrates in the rumen.
(b) increasing the propionic acid proportion of the total VFA produced (Glycogenic energy to total VFA energy of G/E ratio.)
(c) changing the protein to energy ratio (microbial protein to total VFA energy or P/E ratio)

Methods to improve digestibility

The digestibility of structural carbohydrates can be improved by the following processing and treatment methods.

(i) Physical
(ii) Chemical
(iii) Physico -chemical
(iv) Biological

These processing and treatment methods will be discussed in Chapter 5.

Maintenance of optimum rumen ammonia level

The primary limiting factor affecting microbial growth in the rumen is the inadequacy of soluble nitrogen in the diet to maintain optimum ammonia nitrogen levels in the rumen. The optimum level of ammonia nitrogen in the rumen for high bacterial growth and enhanced fermentation depends on the type of diet. However, the optimum level has been reported to be between 50 - 250 mg of ammonia nitrogen per litre of rumen fluid. Many have suggested that the attachment of bacteria to plant cell walls have a direct relationship with the nitrogen content in the plant material. Diets containing high soluble sugars require high rumen nitrogen levels than diets high in crude protein.

It is important to maintain the optimum ammonia level in the rumen throughout the day to facilitate microbial activity. If the ammonia level falls below the optimum, the microbial population in the rumen will decrease thereby lowering the digestibility of fibrous material. As a result, feed intake too will decrease. Inadequate levels of nitrogen in the rumen will depress both fibre digestion and intake, which will finally lead to low animal performance.

Supply of amino acids and peptides to the rumen

Rumen micro-organisms obtain only 70 % of their nitrogen requirements from the rumen ammonia pool. For increased activity, microbes obtain amino acids and peptides from dietary sources. Therefore, when amino acids and peptides are provided in diets as crude protein, the utilisation of feed is higher. Wheat straw supplemented with a small amount of fish meal or cotton seed meal will improve the utilisation straw than when supplemented with urea alone. Some evidence also exists which indicate that when amino acids and peptides are provided in the diet, there is a reduction in microbial growth and thereby a reduction in digestibility.

Increasing the free pool of cellulolytic bacteria

Cellulolytic bacteria in the rumen are the major and primary fermenters, which directly influence cellulose digestion. They have ready and free access to free cellulose found in immature grasses and other forages. But feeds such as crop residues, which are high in ligno-cellulose complexes are more resistant. Crop residues when present in increased amounts reduces the cellulolytic bacterial population in the rumen. Thus, provision of immature grass increases the cellulolytic bacterial population, thereby improving the utilisation of highly lignified crop residues.

Improving rumen propionic acid production

It is advantageous to attempt to improve the glycogenic acid (propionic acid) production in the rumen. Many chemicals such as feed additives are available which can be used to alter the proportion of volatile fatty acid production, which especially favour propionic acid production. These feed additives reduce hydrogen utilisation by the methanogenic organisms in methane production (methanogenesis) and increase the hydrogen tension to stimulate propionic bacterial growth. In addition, fat synthesis by rumen micro-organisms is also enhanced. Inclusion of a small proportion of poultry litter (10% in the diet) in molasses based diets improves propionic acid production without altering rumen function.

Defaunation in the rumen

The presence of protozoa in the rumen in large numbers may alter the protein to energy ratio in the products of digestion. Protozoa have a high maintenance requirement. They engulf large numbers of rumen bacteria and increase inter-ruminal nitrogen recycling resulting in inefficient utilisation of energy. Defaunation improves the growth rate of young cattle by 43%. Thus, defaunation improves animal production when low protein diets are fed.

Protecting dietary lipids

Lipids are important dietary components of ruminant livestock. Green forage is the major source of lipids for ruminants. These are located in the chloroplast. The important lipids are linolenic acid (53 %), linoleic acid (13 %) and oleic acid (10 %). Cereal based diets provide less long chain fatty acids (LCFA) than forage based diets. Crop residues such as rice, wheat straw and other cereal straws are low in lipids. Supplementation of crop residues with oil cakes and brans will not provide sufficient lipids to meet the animals requirements.

A buffalo weighing 500 kg consuming 12 kg of rice straw (1% lipid), 1 kg of green grass (5 % lipid) and 1 kg of coconut poonac (3 % lipid) consumes about 200 g of lipids, which is far less than the amount a cow could obtain from grass and hay. Dietary fat that is ingested is fermented in the rumen, except LCFA. These LCFA undergo hydrogenation or pass into the small intestine unchanged. Digestion of LCFA by intestinal lipase in the small intestine is very high (> 80 %). Absorption of LCFA from the intestine is directly related to intake. Fatty acids in the intestine are derived not only from dietary sources but also from endogenous and microbial sources.

The addition of fat to the diet will increase the energy density of the diet. But often, this may have detrimental effects on fibre digestion, because dietary fat is said to inhibit cellulolytic bacterial action. Both these actions can lead to poor fermentation of cellulose. In order to maximise the utilisation of dietary fat, they have to be protected from rumen fermentation processes or be introduced in the form of soaps. In dairy cows, dietary fat containing C_6 to C_{14} fatty acids are directly converted into milk fat. This will lead to a low conversion of acetate to milk fat and conserve glucose oxidation for production of NADPH.

Digestion and metabolism of feed

Many nutrients in feed are present in the form of complex macromolecules. Some of these macromolecules are easily soluble, whereas most of them are insoluble. These macromolecules need to be broken down into soluble simpler molecules or compounds before they can be utilised by the animal. This breakdown process is called "digestion" and passage of these digested nutrients through the mucous membrane into blood and lymph is called "absorption". Both digestion and absorption occur in a specialised organ called digestive system, with the assistance of many accessory organs. The digestive processes can be grouped into mechanical, chemical and microbial entities.

In ruminants, prehension of food especially roughage is accomplished with the aid of the tongue. In the mouth, basically the food is subjected to mechanical breakdown through grinding (mastication). Ruminant saliva does not contain amylase or any other digestive enzymes other than a mild lipase of weak activity, which is capable of hydrolysing short chain fatty acids such as butyric and caproic acid. However, the activity of this enzyme becomes low when it reaches the abomasum (pH <3) or the alkaline intestines.

The major site of digestion in ruminants is the reticulo-rumen. Digestion is primarily on microbial-activity and the end products are different from those resulting from enzymatic digestion in the non-ruminant digestive system. Ruminants digest feeds high in structural carbohydrates (crude fibre, cellulose and hemicellulose) with the help of rumen micro-organisms through fermentative digestion.

Digestion and metabolism of carbohydrates in the rumen

Dietary carbohydrates of ruminants are cellulose-based structural carbohydrates, soluble sugars and starch. Lush green forages contain about 30-35% dry matter made up of cellulolytic material, but more mature or fibrous material, such as hay and straw may contain high proportions of structural carbohydrates. The pathway involved in the digestion/conversion of cell wall (fibre) and soluble cell material into pyruvate and VFA are detailed in Chapter 3.

The end products of the fermentation of both soluble and structural carbohydrates are volatile fatty acids (VFA) *viz.* acetic, butyric and propionic acids and certain gases such as CO_2 and CH_4. One of the most important activities in the rumen is fibre digestion, and this in turn depends on many feed factors such as the level and type of cellulolytic material present, the degree of lignification, silicification and crystallinity of cellulose. The enzymes responsible for the degradation of fibre are endoglucanases, exoglucanases, β-glucosidase, β–xylosidase and hemicellulases. The major rumen bacteria that are responsible for the secretion of extra-cellular fibre digestion enzymes are *Vibriobactor succinogens, Ruminococcus flavafacians, R. albus, Clostridium polysaccharolyticum.*

In addition to bacteria, certain rumen fungi are also responsible for the degradation of fibre in the rumen. The rate of extra-cellular enzyme secretion by fungi is much higher when compared to bacteria. Some major rumen fungi, which are involved in fibre digestion in the rumen are *Piromonas* and *Sphacromonas communis*. Rumen ciliate protozoa are not very efficient digesters and their absence may increase feed conversion efficiency and nutrient utilisation.

During fibre digestion, initially the rumen bacteria make attachments to the fibre particles. This facilitates proper contact with the fibre particles and the extracellular enzyme secretion. There is thus a time interval between ingestion of feed and the appearance of fermented products. This time interval is termed the "lag time". The digestion of carbohydrates in the reticulo-rumen is diphasic. The first phase is the period during which the breakdown of complex polysaccharides into simple sugars occurs by extracellular enzymes secreted by rumen microbes. Initially, they are degraded to cellubiose by the action of the cellubiose group of enzymes. Microbial cellulase contain at least two sub-groups namely C-I, which weakens the H-bonds and makes glucose susceptible to further hydrolysis. The next sub-type of cellulase is Cx which hydrolyses cellulase to cellobiose and then to glucose. The degradation of crystalline cellulose is more difficult than amorphous cellulose. Therefore, when the proportion of crystalline cellulose is high in the diet, the population of *B. succinogens* increases.

Sometimes cellulase is also involved in hydrolysing hemicellulose. Hydrolysis of hemicellulose results in pentoses and uronic acid. The two major enzymes responsible for the degradation of pectins are methylesterases and poly-galacturonidase. Degradation of pectins results in galacturonic acid and other sugars such as pentoses. These pentoses are readily phosphorylated to pentose phosphate and then to hexose phosphate and three carbon triose phosphate with the help of transheptolase and transaldolase. Degradation of xylans also results in production of pentose and xylose.

Amylase hydrolyses starch and dextrins to maltose and isomaltose. Thereafter by the action of maltase, maltose phosphorylases and 1,6 glucosidase, they are converted to glucose or glucose - PO_4. Fructose is the result of hydrolysis of sucrose. Therefore, in the first place all polysacharides are converted to simple sugars with the aid of extracellular enzymes.

Once the simple sugars are produced, these soluble manomers are readily metabolised by the rumen microbes. This initiates the second phase of carbohydrate fermentation metabolism in the reticulo-rumen. Simple sugars are readily converted to pyruvate in the microbial cell through different pathways depending on the type of sugar and other rumen conditions. The net synthesis of ATP as energy for microbes depends on the pathway that routes simple sugars to pyruvate (see Chapter 3).

The major glycolytic pathway of glucose to pyruvate (Cmbden-Myer Hoff pathway) provides 2-pyruvate, 3 ATP and 2 (2H) per moleculing glucose. The glycolytic pathway is summarised below.

$$\text{Hexose - PO}_4 + \text{ATP} \rightarrow \text{Fructose - 1 - 6 di PO}_4 + \text{ADP}$$

$$\text{Fructose 1 - 6 di PO}_4 \rightarrow \text{2 Triose PO}_4$$

$$\text{2 Triose PO}_4 + \text{2Pi} + \text{4 ADP} \rightarrow \text{2 Pyruvate} + \text{4ATP} + \text{2(2H)}$$

$$\text{NeH: Hexose - PO}_4 + \text{2 Pi} + \text{3 ADP} \rightarrow \text{2 Pyruvate} + \text{3 ATP} + \text{2(2H)}$$

Pyruvate being the intermediate product of the complete fermentation process, all carbohydrates must eventually be converted to pyruvate. The pyruvates are further metabolised to volatile fatty acids within the microbial cells. The rate and composition of the final product (VFA) depends on the type of carbohydrate, the composition bacterial species present and rumen conditions. The major pathway of acetate is *via* the pyruvate-acetate lyase-pathway. Here, formate acetyl Co enzyme A (CoA) or acetyl $P0_4$ acts as intermediary products.

$$\text{Pyruvate} + H_2O + \text{CoA/or Pi} \rightarrow \text{Acetyl CoA/Acetyl P0}_4 + CO_2 + 2H$$

$$\text{Acetyl CoA} \rightarrow \text{Acetyl PO}_4 \rightarrow \text{Acetate} + \text{ATP} + \text{ADP}$$

$$\text{Pyruvate} + H_20 + \text{CoA/or Pi} \rightarrow \text{Acetate} + \text{ATP} + \text{ADP} + CO_2 + 2H$$

$$\text{Acetyl CoA} \rightarrow \text{Acetyl PO}_4 \rightarrow \text{Acetate} + \text{ATP} + \text{ADP}$$

$$\text{Pyruvate} + H_2O + \text{CoA/or Pi} \rightarrow \text{Acetate} + \text{ATP} + \text{ADP} + CO_2 + 2H$$

An alternate pathway is *via* pyruvate ferredoxin, oxido-reductase which yields ferredoxin (reduced form), CO_2 and acetyl CoA. Hydrogen resulting from acetate formation is used in the formation of propionate by redμction of pyruvate *via* the dicarboxylic acid pathway.

$$\text{Pyruvate} + CO_2 + 2\,(2H) \rightarrow \text{Succinate}$$

$$\text{Succinate} + \text{ATP} + \text{CoA} \rightarrow \text{Succinyl CoA} + \text{ADP} + \text{Pi}$$

$$\text{Succinyl CoA} \rightarrow \text{Methylmalonyl CoA}$$

$$\text{Methylmalonyl CoA} + \text{ADP} + \text{Pi} \rightarrow \text{Propanyl CoA} + \text{ATP} + CO_2$$

$$\text{Propanyl CoA} + \text{ADP} + \text{Pi} \rightarrow \text{Propionate} + \text{CoA} + \text{ATP} + CO_2$$

$$\text{Succinate} + \text{ATP} + \text{CoA} \rightarrow \text{Propionate} + \text{CoA} + \text{ATP} + CO_2$$

Propionate is also produced *via* the acrylate pathway. In this pathway, initially pyruvate is converted to lactate and thereafter to acrylyl - CoA and then to propanyl CoA to produce propionate, ATP and CO_2. This pathway provides 30% of total propionate production in the rumen.

Another pyruvate metabolism pathway that takes place in the rumen is in the production of butyrate. For this pathway, additional energy is required. Both butyrate and higher fatty acids follow two pathways and the major pathway is the reversal of β-oxidation. The other pathway is *via* the malonyl CoA system. The malonyl CoA pathway is usually involved in the synthesis of higher fatty acids. The process of converting acetate to butyrate is not well understood. But it may used to convert oxidised/reduced co-factors in microbial cells for use in further fermentation processes. A summary of the process of conversion of acetate to butyrate is given below.

$$2\ \text{Acetate} + 2\ \text{CoA} + 2\ \text{ATP} \rightarrow 2\ \text{Acetyl CoA} + 2\ \text{ADP}\ 2\ \text{Pi}$$

$$\text{Acetyl CoA} + CO_2 + \text{ATP} \rightarrow \text{Malonyl CoA} + \text{ADP} + \text{Pi}$$

$$\text{Acetyl CoA} + \text{Malonyl CoA} + 2\ (2\text{H}) \rightarrow \text{Butyryl CoA} + CO_2 + \text{CoA}$$

$$\text{Butyryl CoA} + \text{ADP} + \text{Pi} \rightarrow \text{Butyrate} + \text{ATP} + \text{CoA}$$

$$2\ \text{Acetate} + 2\text{ATP} \rightarrow \text{Butyrate} + 2\text{ADP} + 2\text{Pi}$$

In the pyruvate lyase pathway acetyl CoA is responsible for the production energy (ATP) and formate. Formate is further degraded to CH_4 and CO_2 by rumen methanogenic bacteria. About 4.5g of CH_4 is produced from every 100g of carbohydrates digested by the ruminant. Methane production is an energy rich process which removes H from microbial sources. Other minor energy releasing processes in the rumen are to do with the conversion of NO_2 to NO_3, SO_4 to H_2S and the saturation of unsaturated fatty acids. Methane is produced when lush fibre diets are given to ruminants.

The composition of the final products in the rumen is heavily dependent on the nutrient components in the diet. Cellulose rich diets (highly fibrous) result in high acetic acid production. When high concentrate diets are fed both propionic and lactic acid production is increased. However, lactic acid is readily converted to acetic and propionic acids. Diets containing a high proportion of soluble carbohydrates (grains, molasses) favour the activity and growth in the population of *Streptococcus bovis*, which produce large quantities of lactic acid, which in turn could lead to certain metabolic disorders.

Metabolism of protein and nitrogen compounds in the rumen

The digestion and metabolism of protein and nitrogen in the ruminant is unique due to the presence of a compound stomach. The involvement of rumen micro-organisms in protein digestion in the rumen was recognised in the 1930's. Ruminant proteolytic activity begins in the rumen. Micro-organisms which inhabit the rumen, digest dietary proteins through the action of proteolytic enzymes secreted intracellularly in association with the cell wall fraction from which it is liberated. Both rumen bacteria and protozoa are involved in the process of protein digestion.

The protein sources in the diet of the ruminant vary in digestibility, solubility, rumen degradability and quality. The digestion of dietary protein in the rumen and post-rumenally is illustrated in Figure 2.1. The quality and quantity of protein leaving the reticulo-rumen is entirely different from that in the ingested feed. The dietary proteins entering the rumen consist of two major fractions, true protein and non-protein-nitrogen (NPN). True proteins are less soluble in the rumen whereas NPN is highly

DIET	Protein	NPN	Urea
SALIVA	Protein	NPN	Urea
RUMEN	Peptides	Amino acids	Ammonia
LIVER	Ammonia	Amino acids	Urea
ABOMASUM AND INTESTINE	Microbial protein Protein	Endogenous nitrogen Amino acids	
TISSUES	Tissue metabolism		
URINE	Ammonia nitrogen	Urea	
FAECES	Undigested dietary nitrogen	Metabolic faecal nitrogen	

Fig. 2.1 Rumen and post rumen digestion of dietary protein and NPN

soluble. The soluble protein fraction and NPN are subjected to rapid microbial activity and is initially degraded into ammonia. This protein is called "rumen degradable protein (RDP) or rumen degradable nitrogen (RDN)". The portion that is not subjected to degradation in the rumen is called "un-degradable dietary protein" (UDP) or "Protected" or "by-pass" protein. The UDP escapes from the rumen without undergoing any alteration in composition and is digested in the abomasum and small intestine with the aid of proteolytic enzymes secreted by the mucosal layers of the digestive system. NH_3 in the rumen is derived from 2 major sources, through degradation of dietary protein and from urea contributed *via* saliva.

Digestion of carbohydrates in the small intestine

The major site of both soluble and structural carbohydrate digestion is reticulo-rumen. But small amounts of soluble carbohydrates pass into the small intestine and undergo enzymatic hydrolysis. This escape of soluble carbohydrates to the intestine depends on the type of carbohydrate, rate of passage of the digesta, the physical nature of the diet, concentrate to roughage ratio and the rate of fermentation. On an average about 2-30% escape into the intestine.

Starch digestion enables more efficient utilisation of energy since losses as CH_4 and heat is avoided. Microbial polysaccharides also contribute to the carbohydrate pool in the small intestine. However, bacterial polysaccharides are lost from the microbes before the bacteria are killed by the acid conditions and undergo digestion in the intestine. A part of these carbohydrates that are not digested by the rumen ciliate protozoa are retained in the rumen with a high retention time. The carbohydrates that escape to the small intestine, undergo hydrolysis by the action of enzymes secreted from the intestinal epithelia and pancreas. The major hydrolysing enzyme is amylase and the activity of this enzyme from the pancreatic juice is higher than that from the intestinal wall.

Mineral digestion and absorption

Minerals are inorganic elements which are essential for the development and maintenance of the body and for productive purposes. The animal body contains about 3 percent mineral matter. Minerals are generally defined the inorganic residues (ash) retained after burning of animal and plant tissues. The major sources of minerals for animals are; the feed, drinking water and contaminants. During grazing substantial quantities of soil is ingested, which supply certain minerals to the animals.

Accumulation of chemical elements in living organisms (both plant and animals) does not depend only on their biological identity and the geochemistry of the environment, but also on the feed chain by which the organisms are linked to the environment, through soil, micro-organisms, water, air, plants and animals (including man). Animals obtain their mineral elements mainly from food of plant and animal origin. The mineral composition of feed, especially of plant origin, depends on the genetic characteristics of the plant, soil conditions, fertiliser and management, botanical composition, climate, weather and stage of growth.

There are about 45 minerals elements in animal body tissues and feeds. The contents vary in amount and concentration. The minerals that are high in concentration in the body (> 70 mg / Kg live weight) are termed macro-molecules. These are Calcium (Ca), Phosphorous (P), Magnesium (Mg), Sodium (Na), Potassium (K), Chlorine (Cl) and Sulphur (S). The micro minerals are Iron (Fe), Copper (Cu), Cobalt (Co), Manganese (Mn), Zinc (Zn) Iodine (I), Selenium (Se), Molybdenum (Mo), Chromium (Cr), Fluorine (F), Tin (Sn), Vanadium (V), Silicon (Si), Nickel (Ni) and Arsenic (As). Both macro and microelements are essential to sustain life and high productivity.

Minerals play many major functions in animal body and therefore, they are an important and vital portion of the diet. Growth or tissue development is a function of mineral deposition in the tissues. The major tissues where large quantities of minerals are deposited are those in the skeletal system (e.g. calcium and phosphorous). In bones, about 80% comprises inorganic matter. The mechanism of mineral deposition in bone tissue is yet not clear, but certain possible mechanisms have been hypothesised. Minerals are classified broadly into 3 groups;

(a) Minerals localised in the skeletal tissues (osteotropic): These include calcium, phosphorus and in addition magnesium, strontium, beryllium, fluorine, anadium, barium, titanium, radium, silicon and others assist in strengthening and maintaining the rigidity of tissues.

(b) Minerals localised in the reticulo-endothelial system (macrophage system): These include iron, copper, manganese, silver, chromium, nickel, cobalt and certain lanthanides.

(c) Tissue non-specific elements uniformly distributed in the tissues and organs. These are sodium, potassium, sulphur, chlorine, lithium, rubidium and caesium.

An element is considered essential when it is invariably present in animals in similar concentrations in each individual animal and the content of a given element in different tissues follow the same sequence. Any deficiency of an element in the diet will cause severe deficiency symptoms in the animal and definite biochemical changes in the tissues.

The total concentration of minerals in feed is not very important if the bio-availability is low. Optimum level of minerals in a diet relates to its bio-availability to meet the animals nutritional mineral demand to maximise the economically important criteria, such as growth, milk production, pregnancy and health. Minerals in animal feed exist in two forms, either in the soluble form in cytoplasm and cell sap or bound to the cell wall constituents. The minerals in soluble form are released rapidly by the destruction of the cell structure either by physical (mastication) or by chemical (enzymatic) or microbial breakdown. The portion that becomes fixed in the cell wall matrix is difficult to release and make available to the animal, unless the cell wall matrix is completely disintegrated. This is effectively accomplished in the rumen with the aid of the rumen microbes. Therefore, the mineral components in the cell wall are better utilised by ruminants. Bio-availability is thus a function of the concentration of minerals in the feed and the extent of digestion of organic matter. Apparent digestibility as determined by analysis would be higher than the true value as it includes both the unabsorbed and endogenous mineral contents. Major endogenous sources of minerals are saliva and digestive juices. The minerals from these sources are absorbed at similar rate to dietary minerals. However, some minerals that enter the digestive system *via* endogenous sources are not absorbed, but excreted along with the faeces and are defined as endogenous or metabolic minerals. The endogenous minerals are largely macro minerals and particularly the proportion of calcium and phosphorus of endogenous sources are considerably high and often exceeds the amounts in the undigested feed. Therefore, the availability of minerals from dietary sources can be estimated either by total mineral balance experiments or using isotope techniques.

Minerals are generally absorbed in the ionic form, either as cations (Na^+, K^+, Ca^{2+}, Mg) or anions (Cl^-, SO_4^{2-}, NO_3^-, PO_4^{3-}). As with other minerals, they are predominantly absorbed in the small and large intestines. In addition, ruminants have the ability to absorb large quantities of minerals through rumen wall.

The major routes of mineral excretion are by way of urine, faeces and milk. The method of mineral excretion varies with the species of animal and the composition of the diet. Ruminants excrete more calcium and phosphorus in faeces than non-ruminants, where a large proportion is excreted through urine. In both ruminants and non-ruminants, large quantities of calcium and phosphorus are also excreted during lactation, when the requirement of calcium and phosphorus is very high and critical.

Even though the requirements for certain minerals (Cu, Co, Se, Fe) are small, they may not be available in sufficient quantities in the feed. However, a higher level of intake above the upper critical range can bring about toxic symptoms which could result in low growth and productivity or sometimes death.

Certain compounds naturally found in feed, facilitates absorbability. They are amino acids and peptides which produce soluble chelates. These chelating agents, prior to complexing with polyvalent cations are called "ligauds". The liguads are cyclic organic molecules that play a very important role in the absorption of certain minerals.

Chelates may occur naturally in chlorophyll, cytochromes, haemoglobin, vitamin B_{12}, amino acids, hydolysed protein or polysaccharides. Most of the feed grade chelated minerals are complexes of amino acids chelates or proteinates. The mineral elements in the chelated form are released in ionic form at the intestinal wall or may be absorbed into the blood supply as the complex chelated form. Chelated mineral complexes are highly stable. In certain instances, the bondage between the ligaud and the metal ion is so strong, that even after absorption of the metal ion, it will not be available to the animal. Based on their functions, chelates can be divided into 3 major groups.

(a) Chelates that facilitate in transport and storage of metal ions
(b) Chelates essential in metabolism
(c) Chelates that interfere with the utilisation of essential cautions

Suggested reading

Bondi, A.A. (1987) *Animal Nutrition.* John Wiley and Sons, U.K.

Banerjee. G.C. (1982) *A Text Book of Animal Husbandry.* Oxford and IBH Publishing Co. (Pvt.) Ltd., New Delhi., India

Hobson, P.N. (1988) *The Rumen Microbial Ecosystem.* Elsevier Applied Science Publ., NY.

Kamar, D.N. and Pathak, N.N. (1996) *Nutritional Microbiology of Farm Animals.* Vikas Publishing House Pvt. Ltd, New Delhi, India.

McDonald, P., Edwards, R.A. and Greenhalgh, J.F.D. (1988) *Animal Nutrition.* Longmans Press, UK.

Van Soest, P.S.T. (1982) *Nutritional Ecology of the Ruminant.* O & B Books, Corvallis, Oregon, U.S.A.

NA - 253 - 3

Chapter 3

Metabolism and Nutrient Utilisation

H. Peiris

Introduction

Metabolism involves the degradation of complex compounds to simple breakdown products (catabolism) and the synthesis of complex compounds in the animal body from simple products (anabolism). The waste products resulting from degradation of feed materials are eventually excreted. The major function of carbohydrate and lipid metabolism is to provide energy for other metabolic processes. The fermentable carbohydrates are mainly converted to volatile fatty acids in the rumen, which along with glucose are subsequently utilised as energy sources. In protein metabolism, amino acids are catabolized to urea, while the carbon skeletons are utilised as energy sources, as well as in the biosynthesis of other amino acids.

Metabolism of nitrogen

Amino acids derived from exogenous or endogenous protein serve many essential biological functions. They are metabolised in such a manner that the amino nitrogen is ultimately converted to urea and eliminated in urine as a nitrogenous end-product. The term non-protein-nitrogen (NPN) includes nitrogen derived from nitrogen-containing substances other than proteins, such as urea, uric acid, creatinine, creatine and ammonia.

In general, ruminants do not depend totally on exogenous sources for amino acids, as microbes in the rumen degrade both organic and inorganic nitrogenous compounds to resynthesize microbial protein. However, research has revealed that ruminants do respond to amino acid supplementation. Methionine, lysine and threonine have been identified as the first three limiting amino acids in growing steers whereas methionine, valine, isoleucine, tryptophan and lysine are the limiting amino acids in milk production.

Labile protein and protein turnover

The labile protein reserve is generally based on the balance between the rate of urinary nitrogen excretion and the dietary protein intake of the animal. The labile fraction of the protein reserve in the animal body can temporarily meet the energy requirements of the animal and therefore is lost more rapidly during fasting than during feeding of low protein diets.

The term protein turnover refers to the synthesis and degradation of intra-cellular protein where both synthesis and degradation require ATP. It has been estimated that protein synthesis requires 5 moles of ATP per mole peptide bond, where 1 mole of ATP is used for transport of amino acids into the cell and the balance 4 moles of ATP for actual synthesis. This is equivalent to 4.5 KJ per gram of protein synthesised, assuming that 1 mole of ATP is equivalent to 85 KJ of metabolisable energy.

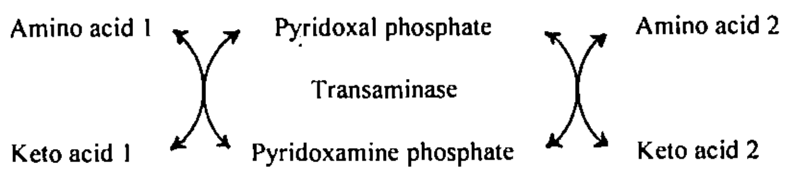
Hormones, like insulin which increase amino acid uptake and prostaglandin $F_{2\alpha}$ and its precursor, arachidonic acid have been implicated in stimulating muscle protein synthesis.

Protein degradation involves two pathways. The dominant system is the lysosomal system where ATP is used in maintaining a high H^+ concentration in lysosome. The second is the ubiquitin system, where ubiquitin (26 amino acid residue polypeptide) conjugates with protein and proteolysis takes place. This is also an ATP dependent process, suggesting that protein turnover contributes to a major drain in energy, particularly in skeletal muscle. Nevertheless, physiological stress caused by lactation, age, endocrine and environmental factors could alter the protein turnover rates.

Degradation of amino acids

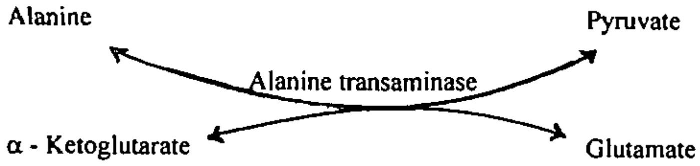
The value of supplementation of ruminant diets with amino acids is limited due to the deaminating activity of rumen microbes. The methionine hydroxy analogue and methionine were reported to increase cellulose fermentation and accelerate the growth of rumen bacteria through accelerated bacterial nitrogen incorporation and the concurrent increase in the substrate digestion rate. However, the initial site of degradation of exogenous amino acids is the rumen, where degradation occurs through the mediation of rumen bacteria. Studies have indicated that arginine and threonine are rapidly degraded (0.5-0.9 mM/hr), while valine and methionine are least rapidly degraded at 0.1-0.14 mM/hr. As far as post-ruminal digestion of dietary and microbial protein is concerned, the amino acids derived from post-ruminal digestion are absorbed into the portal circulation through an active Na^+/K^+ ATPase dependent mechanism. In addition, amino acids that are synthesised in the body and those derived from breakdown of worn-out tissue protein are added to the labile amino acid pool of the body. This pool supplies amino acids for synthesis of body proteins and non-protein-nitrogenous substances.

Amino acids of the animal body are subjected to a process of deamination and transamination. Catabolism of amino acids involves deamination and formation of corresponding keto acids prior to oxidation and subsequent production of energy, while the synthesis of amino acids in tissues involves amination of keto acids derived from carbohydrate, protein and lipid metabolism. The amino acids are removed from the pool for various functions, as in the synthesis of proteins, nitrogenous non-protein substances such as creatine, haem, purine, etc. and in catabolism. Transamination reactions involved are shown below.

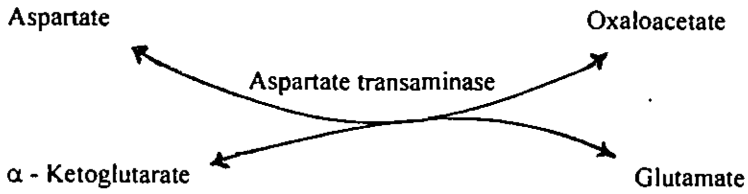


Several transaminases are present and found both in cytosol and in mitochondria. The two important transaminases present in the mammalian tissues are;

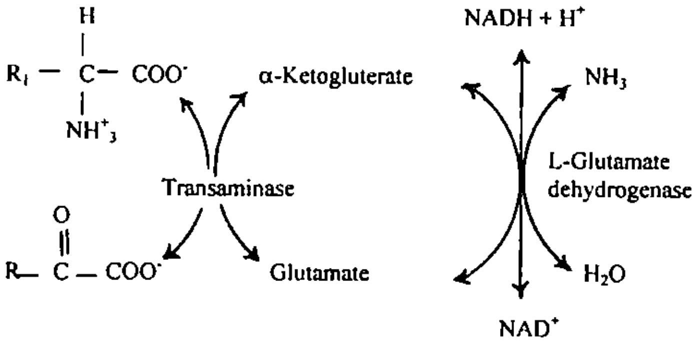
(a) Alanine - pyruvate transaminase (Alanine transaminase)



(b) Glutamate - α ketoglutarate transaminase
(Aspartate transaminase)



L-glutamate dehydrogenase is the main enzyme responsible for the oxidative deamination of amino acids. This is a mitochondrial enzyme active in most tissues, but is most active in liver and kidney. Thus, glutamate dehydrogenase serves as a control point in the metabolism of many amino acids, for the reason that amino nitrogen is funnelled through glutamate.



As the reactions involved in transamination and oxidative deamination are freely reversible, it enables the animal body to synthesise amino acids from carbohydrate intermediates (Fig. 3.1).

Metabolism of non-protein nitrogen compounds

The deamination of amino acids and the catabolism of compounds such as pyrimidines, amines, and haem in animal tissues produce large amounts of ammonia. Amino nitrogen from most of the amino acids is funnelled into glutamate by the action of glutamate dehydrogenase as glutamine accompanied by the release of ammonia. However, some of the amino acids such as serine, threonine, cysteine, homocysteine and histidine liberate ammonia directly through special deamination processes. In addition to the ammonia formed in tissues, a considerable quantity is also produced in the rumen and post-ruminal compartments of the gastro-intestinal tract through the action of bacteria. Bacterial urease and other enzymes act both on dietary proteins and NPN such as urea which is present in fluids secreted into the gastro-intestinal tract.

This ammonia is then absorbed through the epithelial lining of the rumen and intestinal wall and subsequently enters into the portal circulation. Kidneys also produce ammonia in the renal tubular cells from intercellular amino acids, especially glutamine which enters the systemic circulation. Thus ammonia may be excreted in the urine.

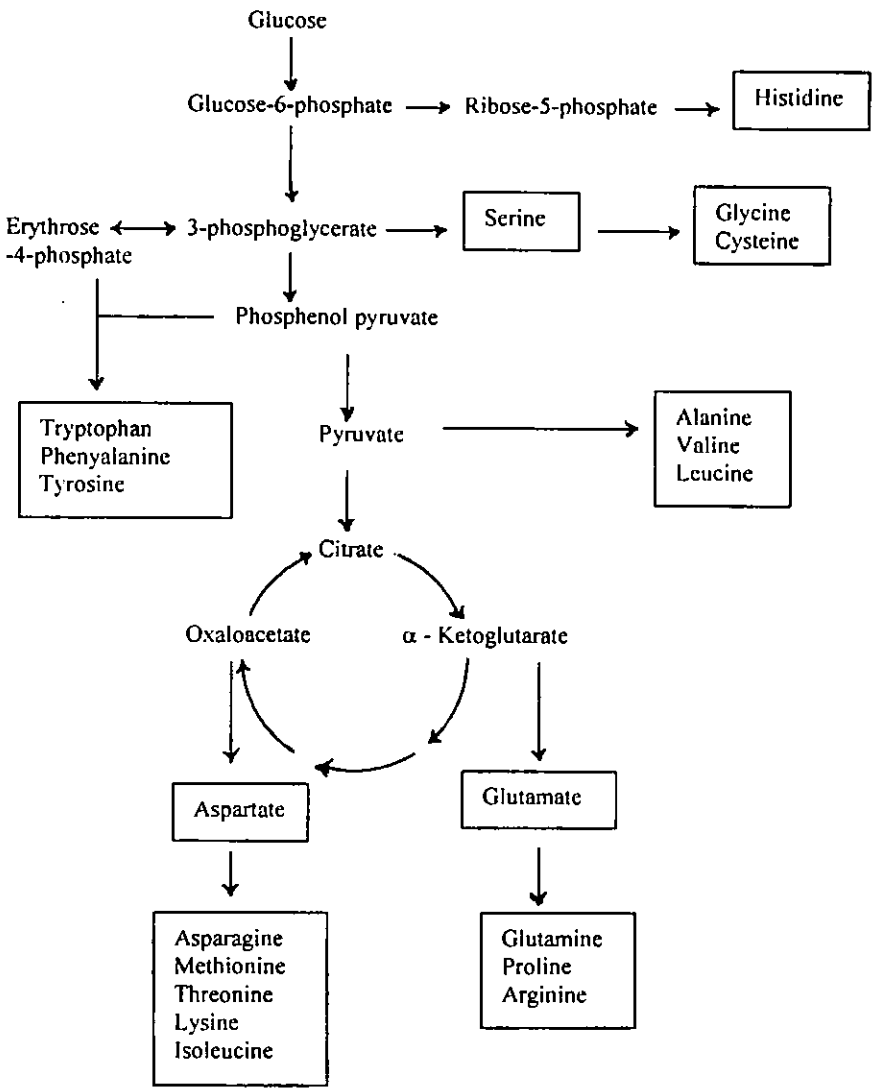


Fig. 3.1 Amino acid biosynthetic families derived from amphibolic intermediates.

$$O=C(NH_2)_2 + H_2O \xrightarrow[\text{urease}]{\text{Bacterial}} CO_2 + 2NH_3$$

Urea

Although ammonia is constantly produced in animal tissues, it is present only in traces in the peripheral blood, because ammonia is toxic to the central nervous system. Therefore rapid removal of ammonia from circulation is necessary. This is achieved in mammals by conversion of ammonia to urea, which is much less toxic. Some of the urea may be returned to the rumen *via* saliva, and also directly through the rumen wall. However, the greater part is excreted in the urine. The concentration of ammonia in rumen liquor may vary widely from 85 to perhaps 300 mg/L, depending on the rate of formation of NH_3 in the rumen. Concentration of <50 mg/L rumen ammonia causes very slow growth of rumen micro-organisms, adversely affecting rumen fermentation, particularly of fibrous feeds.

In summary, the disposal of ammonia in the animal body occurs through:

(a) utilisation of ammonia in the synthesis of new non-essential amino acids by ammoniation of α - keto acids arising from carbohydrate metabolism
(b) biosynthesis of pyrimidine bases
(c) conversion of glutamate to glutamic by glutamine synthetase which is the major mechanism for detoxifying ammonia in the brain, liver and kidneys
(d) elimination in the urine after conversion to urea in the liver
(e) utilisation for synthesis of microbial proteins by the rumen microbes

Biosynthesis of urea: The liver is the principal site of urea formation. The urea that is formed is excreted in the urine. The amount of urea excreted is a direct reflection of the extent of amino acid catabolism and varies considerably with the dietary protein intake.

The overall process of biosynthesis of 1 mole of urea requires 3 moles of ATP and 1 mole each of NH_4^+, CO_2 and amino nitrogen of aspartate. The urea cycle is controlled by the activity of carbamoyl phosphate synthetase and catalytic amounts of N-acetyl glutamate and Mg^{2+}, both of which are necessary for the activity.

Metabolism of purine derivatives: The nucleic acids originating from rumen microbes and epithelial cells undergo extensive digestion in the small intestine. These nucleic acids are degraded to mononucleotides by ribonucleases, deoxyribonucleases and polynucleotidases. The nucleotidases and phosphatases hydrolyse the mononucleotides to nucleosides which are either absorbed or further degraded by intestinal phosphorylase to purine and pyrimidine bases.

The initial degradation and utilisation of these purine nucleosides and free bases take place in the intestinal mucosal cells (Figure 3.2). In cattle (not known in the buffalo, but assumed to be the same) the xanthine oxidase activity is relatively higher in the intestinal mucosa, which convert most of the absorbed purine into uric acid. However, in sheep, the xanthine oxidase activity is very low and as a result the absorbed purine can enter the liver unchanged and is available for incorporation into the tissue nucleic acid (known as the salvage pathway). The absorbed purines, not incorporated into the tissue nucleic acid are completely converted into their metabolic end-products, namely hypoxanthine, xanthine, uric acid and finally allantoin (known as the purine derivatives).

The purine derivatives entering blood are cleared very rapidly *via* different excretory pathways. Urinary excretion is the primary route for disposal of purine and its derivatives. However, there is very little secretion and absorption of these compounds in the nephrotic tubules; thus the urinary excretion of these compounds is a function of the plasma concentration and glomerular filtration rate. In cattle and perhaps in the buffalo, only allantoin and uric acid appear in the urine, while in the case of sheep, all derivatives appear in the urine. Such differences have been attributed to the high activity of xanthine oxidase in the blood and in kidney tissues of cattle which convert xanthine and hypoxanthine to uric acid prior to excretion in the urine.

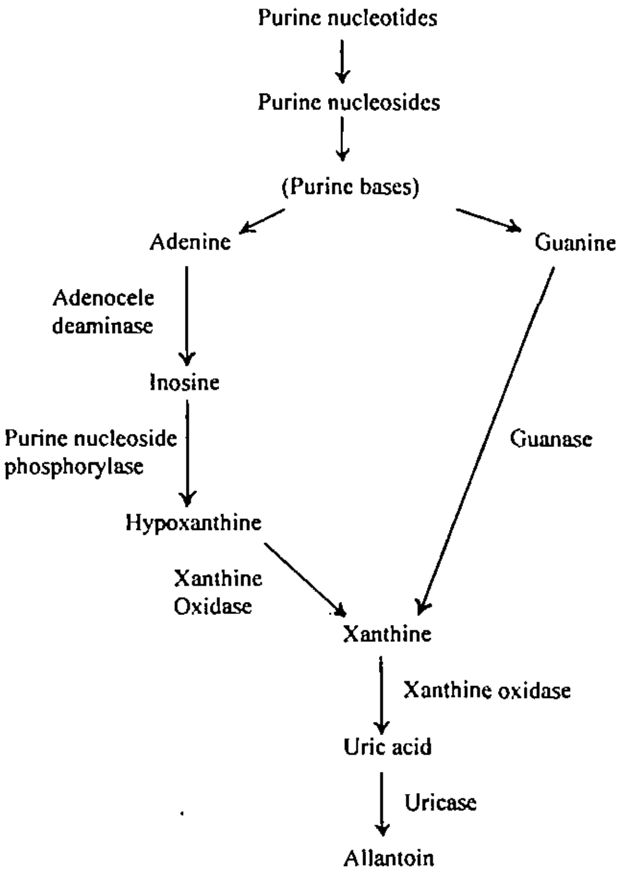


Fig. 3.2 Degradation of purine nucleosides

The principles of degradation of purine nucleotides and formation of purine derivatives have been the basis for the development of a simple laboratory method for estimating the microbial protein supply in sheep and cattle, by the International Feed Resources Unit of the Rowett Research Institute, Aberdeen. Ruminant feed usually contains very low levels of purine, most of these undergo degradation in the rumen and as a result the nucleic acids leaving the rumen are essentially of microbial origin. The research team at the Rowett Research Institute are presently working on purine metabolism in buffalo.

Energy metabolism

Energy metabolism in the animal body may be endergonic (gain of free energy) or exergonic (loss of free energy from the system). Most of the synthetic reactions involved in the animal body are endergonic and require a supply of energy. This energy is usually obtained through exergonic catabolic reactions. The most important energy rich compound in the body is adenosine tri-phosphate (ATP) which may be obtained directly from adenosine monophosphate (AMP) or adenosine di-phosphate (ADP). Alternatively, ATP may be utilised for the performance of essential life processes in maintaining the animal.

Metabolism of volatile fatty acids

Volatile fatty acids (VFA) are derived from ruminal degradation and fermentation of dietary carbohydrates (Fig. 3.3) and most of the acids produced are absorbed directly from the rumen, reticulum and omasum, although some may pass through the abomasum to be absorbed in the small intestine. The rate of VFA production in the rumen is most rapid immediately after a meal.

The VFA (mainly acetic, propionic and butyric acids) are metabolised to a limited extent while passing through the rumen wall. Very little butyric acid reaches the blood at low levels of nutrition. The butyric acid is converted mostly to β-hydroxybutyrate by the rumen epithelium and similar conversion occurs during its passage through the wall of the omasum. To some extent, propionic acid is utilised by the rumen wall as propionyl-CoA (propionyl - Coenzyme A) which is carboxylated to methylmalonyl-CoA. Methylmalonyl-CoA is rearranged to succinyl-CoA, which in turn reacts with propionic acid to regenerate the propionyl-CoA and releases succinic acid which is utilised by the tissues.

Generally, the VFA are dissociated as anions at normal rumen pH in the range of 5.7-6.7. Acetic acid dissociates slightly more to anions than propionic and butyric acids, which may account for its slower absorption. Furthermore, acetic acid may also be less absorbed due to low solubility in the lipoidal substances of the cell membrane. The conversion of butyric and propionic acids in the rumen epithelial tissue makes the diffusion gradient greater for these two acids than for acetic acid, which may account for their greater absorption rates.

Metabolism of lactic acid and other non-volatile organic acids

Many organic acids that are not classified as VFA are present in the rumen in very low concentrations. Among these, lactic acid (L-lactate) is usually present in low concentrations in the rumen. However, when concentrate feedstuffs replace high forage diets, its proportion will increase. In most cases where rapid changes in diet occur from roughages to concentrates, there is a rapid multiplication of *Streptococcus bovis* in the

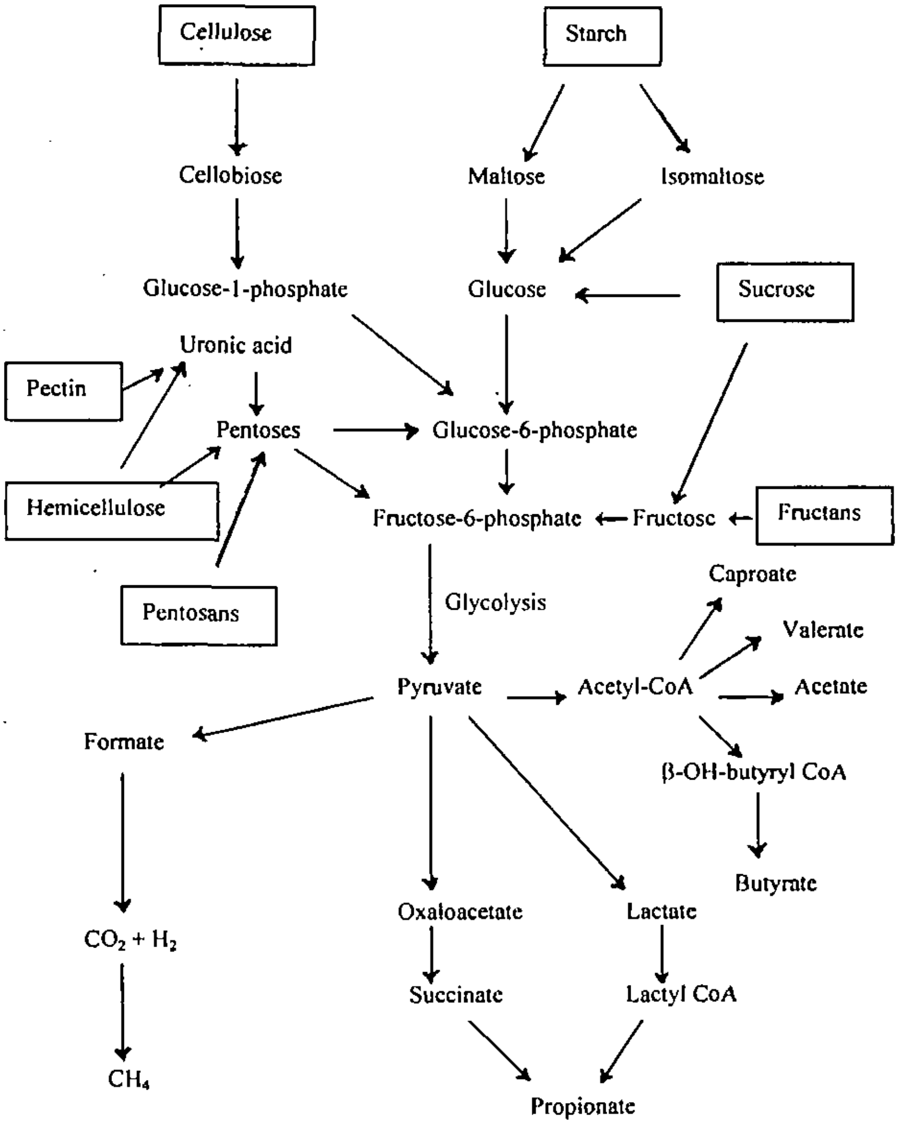


Fig. 3.3 The schematic summary for ruminal degradation and fermentation of carbohydrates

rumen, resulting in an increased production of lactic acid. As a result, the rumen pH may drop to 4.0-4.5 and inhibit the rumen activity which may prove to be fatal in 7-10 days. Adaptation to high concentrate diets from roughage over a long period (30 days) has been found to be the best approach to prevent the development of ulcerative rumen lesions and liver abscesses.

Other organic acids reported to be present in the rumen include oxalic, glyceric, malic, glycolic, malonic, succinic, fumaric and adipic acids. These organic acids are derived mainly from metabolic intermediates and also to a lesser extent as waste products of microbial metabolism.

Fermentation pathways of VFA

Fermentation of Acetate

Hydrogen is used to reduce CO_2 to CH_4. Therefore, one mole of hexose produces 2 each of CH_3COOH, CO_2 and CH_4. In other words, one mole of hexose (672 Kcal) gives two moles of acetic acid (420 kcal). The energy loss in fermentation of one mole of hexose to two moles of acetate is 252 kcal (672-420 kcal).

1 mole of hexose (672 kcal/mole)

↓

2 moles of triose ($CH_2OHCHOH\ CHO$)

↓

$$3\ CH_3COCOOH \xrightarrow{+2H_2O} 2\ \text{Acetic acid} + 2CO_2 + 2H_2$$

Acetic acid is the major product of carbohydrate fermentation in ruminants, including the buffalo. This is the only VFA present in the peripheral blood in significant amounts. Therefore, it is used in many body tissues as a source of energy. In this process, initially the acetic acid is converted to acetyl coenzyme A (acetyl - CoA) in the presence of acetyl - CoA synthetase. The acetyl - CoA is oxidised *via* the tricarboxylic acid cycle (TCA cycle) yielding 10 moles of net ATP per mole oxidised.

Propionic Acid Fermentation

The fermentation of one mole of hexose provides 2 moles of propionic acid gaining 62 kcal (734 - 672 kcal). Depending on the diet, variable amounts of propionate are formed in the rumen and absorbed across the rumen epithelial wall *via* the blood to the liver. However, in the process of diffusion through the rumen wall, a small quantity is converted to lactate. In the liver, propionic acid is converted to glucose through succinyl-CoA (details of reactions are given under gluconeogenesis in Fig. 3.4).

Butyric acid formation

One mole Hexose (672 kcal/mole)

$\downarrow$ $2H_2O$

$2CH_3COOH + CO_2 + 4H_2$

$\downarrow$ Condensation of acetate

$CH_3COCH_2COOH + H_2O$

$\downarrow$ $2H_2$

$CH_3CH_2CH_2COOH + H_2O$ (524 kcal per mole butyrate)
(Butyric acid)

The amount of energy lost in the fermentation of one mole hexose to yield one mole of butyrate, is 148 kcal/mole (i.e. 672-524 kcal). Butyric acid is produced in the rumen in fairly high proportions in animals fed molasses based diets. It is converted to β-hydroxybutyrate during its passage through the rumen and omasum wall. β-hydroxybutyrate is then used as a source of energy by many tissues, including the skeletal muscle. The net gain of ATP per mole of butyric acid oxidised is 25.

In summary, the above fermentation pathways show that the diets giving a high proportion of propionic acid in rumen fermentation, result in a gain of 62 kcal per mole of hexose fermented, compared to energy losses in acetate and butyrate fermentation. It is clear that if the amounts of the moles of acetic, propionic and butyric acid produced are known, the energy losses *via* CO_2 and CH_4 in the rumen can be calculated. In general, relatively high production of propionate is associated with low CH_4 production (yields one mole of H_2 per mole of hexose), while higher in acetate (yield $4H_2$ per mole of hexose fermented) and butyrate (yield $2H_2$ per mole of hexose) production is accompanied by increased methane production (Figure 3.4).

Metabolism of glucose and gluconeogenesis

Metabolism of glucose to pyruvate and lactate takes place in the cytosol of all mammalian cells through what is known as the glycolytic pathway of glucose oxidation (Embden Meyèrhoff Pathway). However, this can function anaerobically by reverting oxidised NAD^+ in the glyceraldehyde-3-phosphate dehydrogenase reaction, by coupling this reaction to the reduction of pyruvate to lactate. Lactate is the end-product of the glycolysis in erythrocytes. Pyruvate formed in glycolysis is further oxidised under aerobic conditions to acetyl-CoA by a multienzyme complex known as pyruvate dehydrogenase. The inability to metabolise pyruvate would frequently lead to lactacidosis.

Acetyl-CoA derived from aerobic glycolysis enters the citric acid cycle where the two carbon unit of acetate is fully oxidised to Co_2 and H_2O. In this process, 11 moles of ATP and one mole of GTP are generated per mole of acetate. Therefore, the overall

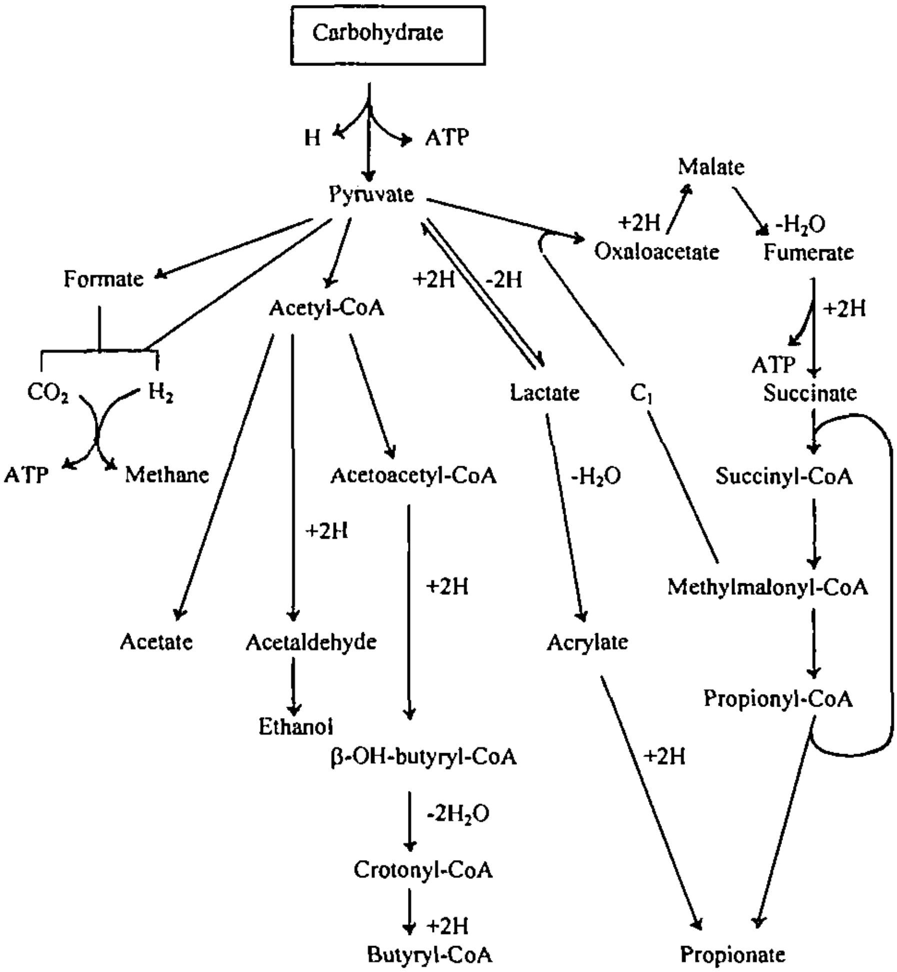


Fig. 3.4 Biochemical pathways of carbohydrate fermentation in the rumen.

generation of high-energy phosphate bonds from oxidation of a mole of glucose under aerobic and anaerobic conditions is calculated as 38 and 2, respectively.

Metabolic and hormonal regulation of glucose: Maintenance of stable levels of glucose in the blood is one of the most finely regulated of all homeostatic mechanisms and one in which the liver, the extra hepatic tissues and several hormones play a part. The liver cells appear to be freely permeable to glucose and apart from the islet cells of the pancreas, the cells of extra hepatic tissues are relatively permeable. Therefore, the passage through the cell membrane is the limiting step in the uptake of glucose in extra hepatic tissues and the glucose is rapidly phosphorylated by hexokinase on entry into the cells. As the hexokinase is inhibited by glucose-6-phosphate, the glucose uptake in extra hepatic tissues is dependent on hexokinase for glucose phosphorylation. The liver in non-ruminants is not subject to this constraint as glucokinase (the predominant enzyme in the liver) is not affected by glucose-6-phosphate. However, such a mechanism is absent from the liver of ruminants including the buffalo, which have little glucose entering the portal circulation from the intestine.

As far as hormonal regulation is concerned, insulin plays a central role in regulation of blood glucose by enhancing the uptake of glucose into both hepatic and peripheral tissues. The islet cells appear to be freely permeable to glucose, which is phosphorylated by glucokinase. Thus, the blood glucose concentration determines the flux through glycolysis, citric acid cycle and generation of ATP which has been identified as the signal for glucose induced synthesis of insulin and its secretion. The insulin antagonistic hormones namely the glycogen thyroid hormone, growth hormone, ephinephrin and adrenocortical (mainly the glucocorticoids) hormones appear to have a glucogenolytic effect.

Gluconeogenesis: Gluconeogenesis is of great importance in ruminant species as almost all dietary carbohydrates are fermented to VFA in the rumen. Propionate which is derived from rumen fermentation is the only major VFA that contributes to gluconeogenesis. As far as non-ruminants are concerned, the rate of gluconeogenesis is lowest after feeding when glucose is being absorbed, and highest during fasting when no exogenous glucose is provided.

Since the dietary carbohydrates are fermented in the rumen, approximately less than 10% of the required glucose is absorbed from the gastro-intestinal tract and hence gluconeogenesis must provide up to 90% of the requirement of glucose. In high producing cows, meeting the glucose demand is a tremendous metabolic challenge as glucose is utilised for lactose. This suggests that even with non-lactating ruminants, the gluconeogenic metabolic pathways need to operate continuously at an efficient rate, and any breakdown could result in serious metabolic disorders (ketosis and pregnancy toxaemia). In addition, a continual supply of glucose is necessary as a source of energy, especially to the nervous system (the CNS), the erythrocytes and the skeletal muscles even under anaerobic conditions. Failure of gluconeogensis could result in brain dysfunction, and death may occur when the blood glucose level falls below the critical glucose concentration.

Gluconeogensis from propionate

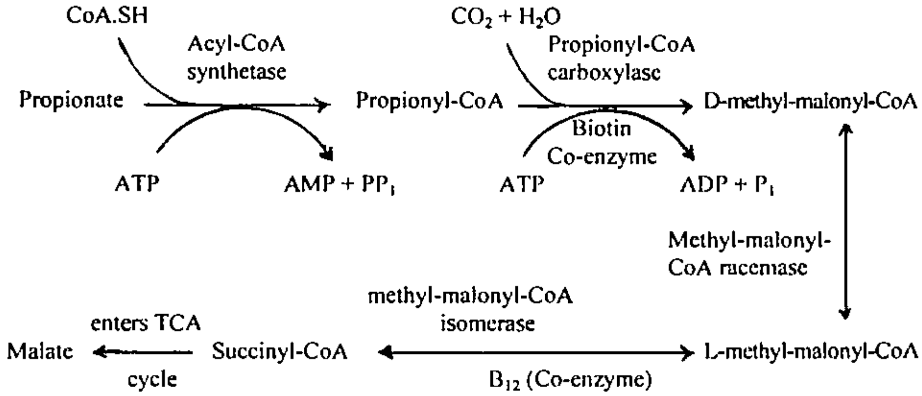


Fig. 3.5 Metabolism of Propionic acid.

Most of the glucose for metabolism in cattle is derived from propionate. The intermediates produced in the conversion of propionate to glucose are shown in Fig.

3.5. Succinyl-CoA entering the TCA cycle is converted to malate, which through oxatoacetate would contribute to the synthesis of glucose.

Gluconeogenesis from amino acids and lactate

The contribution of amino acids to gluconeogenesis varies widely depending on the nutritional and physiological status of the animal. It has been shown that the branched chain amino acids (valine, leucine, isoleucine) play a major role in gluconeogenesis in the liver. Of the amino acids transported from skeletal muscles to the liver during starvation, alanine predominates. This is referred to as the glucose - alanine cycle wheel which has an effect on cycling glucose from the liver to skeletal muscle (Fig. 3.6). The energy required for hepatic synthesis of glucose from pyruvate is derived from the oxidation of fatty acids. On the other hand, the lactate formed by oxidation of glucose in skeletal muscle and erythrocytes is transported to the liver and kidney,

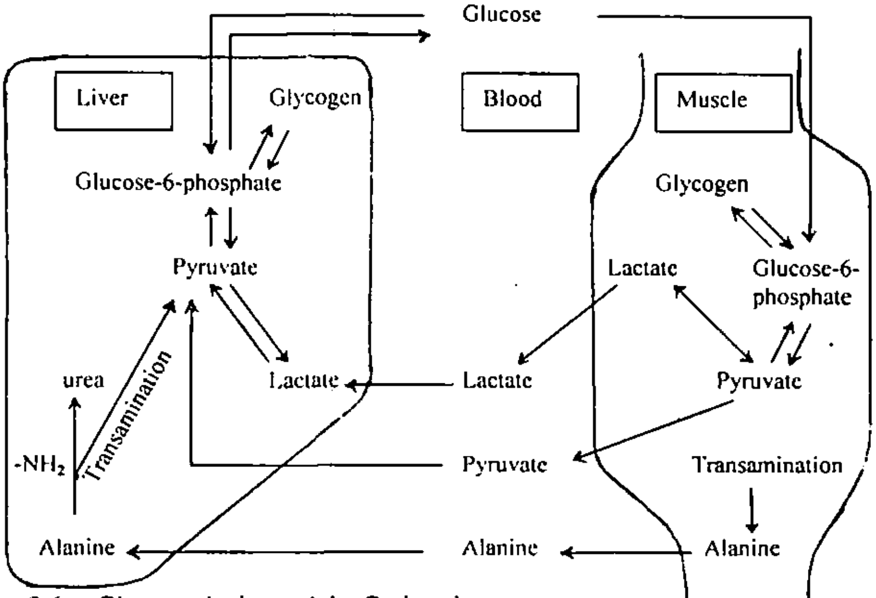
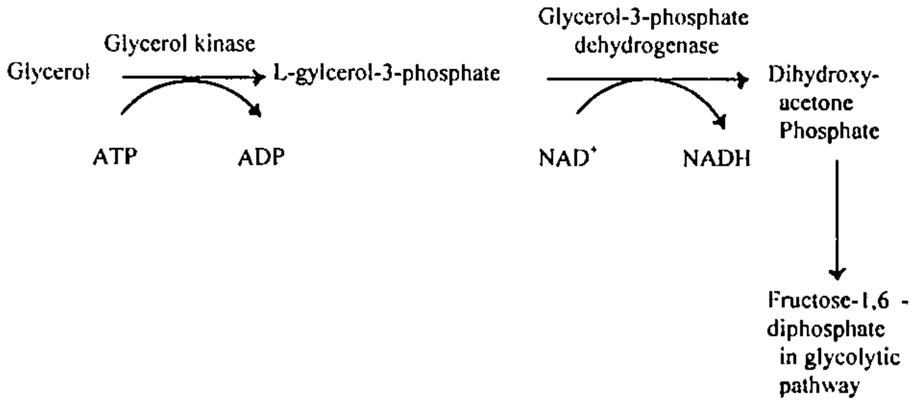


Fig. 3.6 Glucose-alanine and the Cori cycle

where it re-formed to glucose, which again becomes available for oxidation in the tissues. This is known as the Cori or lactic acid cycle (Fig. 3.6).

The stores of triacylglycerides in adipose tissues continuously undergo hydrolysis to form glycerol. This cannot be utilised by adipose tissue and therefore diffuses into the blood and is converted back to glucose by gluconeogenic mechanisms in the glycolytic pathway in the liver and kidney.



Metabolism of lipids and fats

Lipids are stored as depot fat in adipose tissues and these tissue lipids comprise mainly triacylglycerides. These triacylglycerides in the body undergo continuous hydrolysis (lypolysis), and re-esterification. In plasma, the free fatty acids (FFA) or the esterified fatty acids (the long chain fatty acids) are transported, combined with albumin, and in the cell they are attached to a fatty acid binding protein known as Z-protein. However, the short chain fatty acids are more water soluble and thus exist either as an unionized acid or as a fatty acid anion. The major pathway for the catabolism of fatty acids is the β-oxidation pathway. The biosynthesis of fatty acids occurs from acetyl-CoA, catalysed by a multienzyme complex known as fatty acid synthetase.

Oxidation of fatty acids: In this degradation process of fatty acids, two carbon units are sequentially removed, beginning from the carboxy terminal end, where it is involved in oxidation of β-carbon. The enzymes that participate in β-oxidation are present in the mitochondrial matrix. The first stage of β-oxidation is the reaction of the fatty acid with coenzyme A in the presence of ATP and acyl-CoA synthetase to give acyl-CoA. This undergoes a series of reactions to give an acyl-CoA. During the splitting off of the two-carbon acetyl - CoA, the equivalent of five moles of ATP is produced. The remaining acyl-CoA then undergoes the same series of reactions and the process continues until the carbon chain has been completely converted to acetyl-CoA. Acetyl-CoA now enters the TCA cycle and is further oxidised to CO_2 and H_2O. Each mole of acetyl-CoA when metabolised gives 12 moles of ATP. However, the fatty acids with an odd number of carbon atoms are oxidised by the same β - oxidation pathway producing acetyl - CoA until a 3 - carbon (propionyl - CoA) residue remains. This compound is then converted to succinyl - CoA; an intermediate of the TCA cycle. Hence propionyl residues from odd-chain fatty acids are the only part of a fatty acid that is gluconeogenic.

Ketogenesis: Under certain metabolic conditions associated with a high rate of fatty acid oxidation, particularly when the energy demand is high and during starvation, the liver produces considerable quantities of acetoacetate and β-hydroxybutyrate. Acetoacetate continuously undergoes spontaneous decarboxylation to yield acetone. Ketogenesis occurs only in the liver and rumen epithelium. The above three metabolic substances are known as the ketone bodies (Fig. 3.7).

Acetoacetate and β-hydroxybutyrate are interconverted by the β-hydroxybutyrate dehydrogenase, a mitochondrial enzyme. The blood concentration of total ketone bodies in well fed mammals does not normally exceed 0.2 m mol/L, but in ruminants the concentration appears to be higher due to β-hydroxybutyrate formation from butyric acid derived from rumen fermentation. The concentration, particularly of the β-hydroxybutyrate in plasma reflects the balance between fat mobilisation and the capacity of the animal to utilise ketone bodies produced. Therefore, levels of β - hydroxybutyrate in blood which are higher than the reference values of 0.27 and 0.95 (for non-lactating and lactating cows respectively, but not determined for the buffalo) indicate an inadequate energy intake by the animal.

Ketone bodies are oxidised in extra-hepatic tissues in proportion to their concentration in the blood. Most of the evidence suggests that ketonaemia occurs as a consequence of increased production of ketone bodies by the liver and rumen epithelium rather than by a deficiency in their utilisation by extra-hepatic tissues. While acetoacetate and β-hydroxybutyrate are readily oxidised by extra-hepatic tissue, acetone is difficult to oxidise *in vivo* and to a large extent is volatilized in the lungs. Diseases associated with impairment of fatty acid oxidation lead to hypoglycaemia and fatty infiltration of organs.

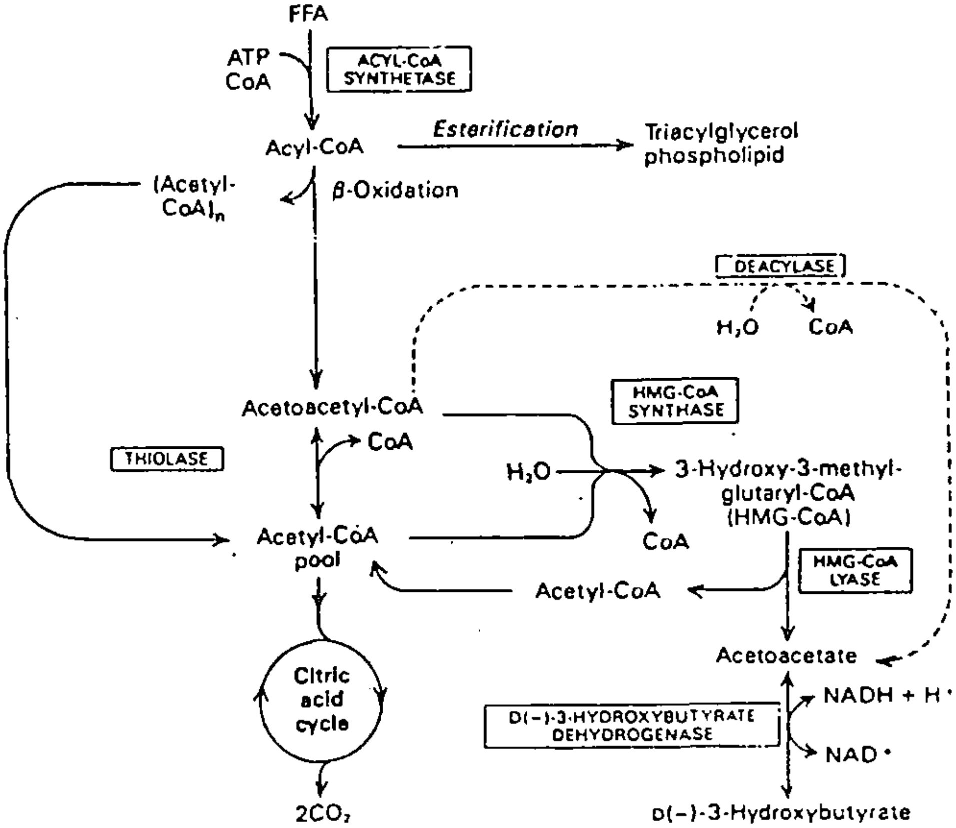


Fig. 3.7 Pathway of ketogenesis in the liver.

Inter-relationship between metabolism of carbohydrates, lipids and proteins

An understanding of the inter-relationship between the metabolic processes is essential to develop a nutritional approach to the diagnosis, prevention and treatment of diseases associated with metabolism. One of the common contributions of catabolism of dietary carbohydrates, proteins and lipids is the release of energy. Energy is generated at various stages of catabolism leading to a complete oxidation of substrates to CO_2 and H_2O. However, during intermediary stages of metabolism of the three dietary components, certain metabolites are formed which are common to various pathways e.g. Acetyl-CoA, oxaloacetate and β-ketoglutarate.

The biochemical reactions of the citric acid cycle (TCA) and their metabolites provide the central core in the inter-relationship between metabolism of carbohydrates, fats and proteins. One of the essential purposes of the TCA cycle is to oxidise the carbon skeleton of acetyl-CoA derived from carbohydrates, fats and certain amino acids to CO_2 and H_2O. In particular is the removal of hydrogen in stepwise fashion, coupling with the electron transport chain and oxidative phosphorylation resulting in the production of high-energy phosphate bounds in ATP. Furthermore, this cycle also provides several intermediary metabolites for the synthesis of endogenous substances and core metabolites involved in the inter-conversions. The following metabolites formed in the course of catabolism of major foodstuffs are responsible for the inter-conversions.

(a) Acetyl-CoA formed from carbohydrate; fat and amino acids.
(b) Oxaloacetate which is formed from pyruvate and aspartate.
(c) β-ketoglutarate, formed from reversible transamination reactions with a number of amino acids.

The importance of these inter-related metabolic pathways is that they help in the maintenance of the blood glucose concentration, regulation of intermediary metabolites and certain protein sparing effects of carbohydrates. In general, when ruminants are fed fermentable carbohydrates, the excretion of nitrogen in urine is greatly decreased, which would indicate that the animals under such conditions are in positive nitrogen balance. The rationale behind such observations is associated with the protein sparing effects of carbohydrates. The excess carbohydrate results in increased fermentation of keto acids of the TCA cycle, which would in turn be aminated to give rise to amino acids and subsequently proteins.

Utilisation of nutrients

Utilisation of protein

As in other ruminants, the protein digestion in the buffalo is dependent on microbial action, the solubility of the dietary protein in the rumen and the rate of passage of proteins to the post-ruminal compartments. The absorbable protein in the gastrointestinal tract of ruminants is known as the metabolizable protein (MP). This appears to be higher when the intake of dietary protein contains sufficient energy for rumen microbes to utilise the NPN sources. In other words, the amount of MP produced per unit of dietary crude protein intake is higher when ruminal ammonia is utilised totally for microbial synthesis than when in excess. When proteins are hydrolysed into the respective metabolites, such as ammonia, CO_2 and indirectly to short-chain fatty acids, the major proportion of ammonia is absorbed through the ruminal wall into the portal blood and is converted to urea in the liver. A significant proportion of this urea is excreted *via* urine, whilst some of it is returned to the rumen *via* saliva or through the ruminal wall by diffusion. The amino acid utilisation in the tissues depends on the following :

(a) whether the amino acid is required for maintenance or for production.
(b) the form of protein storage.
(c) the composition of the available amino acids from a particular protein.
(d) the availability of sufficient energy for utilisation, in other words, the net energy:protein balance of the animal body. Otherwise, the tissue proteins will be utilised inefficiently to generate energy for metabolic activities.

Recent work with buffaloes has shown that the swamp buffaloes and Zebu cattle do not differ in their ability to digest dietary nitrogen. However, buffaloes are more efficient in utilisation of nitrogen for the reason that the buffalo retains more nitrogen by lowering urinary excretion of nitrogen. This is supported by relatively high plasma urea nitrogen in the buffalo, due to greater reabsorption of urea from the kidney tubules than in Zebu cattle. It has also been suggested that the increased efficient of utilisation of nitrogen in buffaloes is probably due to higher microbial nitrogen content, particularly to the high total bacterial and iodophilic organism (Oscillospira type) count in the rumen of the buffalo.

Utilisation of fibre

Information available on the comparative utilisation of dietary fibre is very limited.. However, studies carried out in Philippines, Indonesia and Thailand indicate that buffaloes are able to digest and utilise dietary fibre, (especially in rice-straw based diets) approximately 5 - 7 % more efficiently than cattle. The higher efficiency of fibre digestion and utilisation in the swamp buffalo is invariably associated with the higher production rate of volatile fatty acids and slower outflow rate from the rumen, and also possibly to the longer retention time of fibre compared to Zebu cattle. Therefore, with the exception of a few studies, the bulk of the evidence suggests that the swamp buffalo probably has an inherent capacity to utilise dietary fibre relatively more efficiently than cattle.

Utilisation of minerals

The macro minerals are mainly utilised either for structural purposes (calcium, phosphorus, magnesium and sulphur) or in the maintenance of the acid-base balance (sodium, potassium and chloride) as well as in making a vital contribution to energy transfer, nerve impulse transmission and enzyme activation (potassium, calcium, magnesium). The trace minerals function mainly as enzyme co-factors (manganese and copper) or by contributing structurally or functionally to the activity of enzymes (zinc, molybdenum and selenium), hormones (iodine) or vitamins (cobalt).

The dietary mineral requirements are based on the quantities contained in the tissues or secretions produced in various physiological states, and the inevitable or endogenous losses from the body. The sum of these factors therefore yields the physiological requirement or the net requirement of the animal. The physiological status of the animal has a fundamental influence on the utilisation of dietary minerals. Thus, the requirement for growth, pregnancy and lactation increases the quantity of minerals required at the tissue level which in turn causes an increase in the true absorption of minerals. The depletion of body mineral reserves caused during periods of dietary inadequacy also invokes homeostatic influences which involve increased absorption and/or decreased endogenous excretion.

Interactions involving macro-minerals: It is believed that the ratio of calcium (Ca) to phosphorus (P) in the diet should be maintained between 1:1 or 2:1 as the Ca concentration in plants is invariably higher than that of P. A high level of dietary P associated with a Ca:P ratio of less than 1:1, increases Ca excretion in ruminants. True absorption and retention of Ca can be inhibited by zinc, which shows a similar but less marked effect on P. However, the situation with young, rapidly growing ruminants is very different from adults.

With regard to the buffalo, the research information available on mineral nutrition is very scanty. However, work carried out in Indonesia and Philippines indicates that in general, the serum phosphorus levels in the buffalo is lower than that in Zebu cattle. Apart from the stores of minerals and their concentrations, the rest of the biochemistry of mineral nutrition in the buffalo appear to be very similar to that in cattle with the exception of Ca homeostatic mechanisms in the buffalo which is not clearly resolved. However, in other ruminants, with the onset of lactation, the Ca and P reserves are likely to be mobilised at a greater rate. In general, Ca and P are deposited in the bone in a ratio of 2.2:1, unlike in milk production where the required ratio is 1.3:1. The difficulty of balancing the supply and demand for Ca in early lactation could lead to the incidence of milk fever, which is not a common disease in the buffalo as in cattle. The low incidence of milk fever in the buffalo perhaps may be associated with an efficient Ca homeostasis mechanism in the animal. It has been suggested that a low Ca intake pre-partum, (although hard to attain on natural diets) is an effective experimental technique for controlling milk fever and it is believed to occur by priming the homeostatic mechanisms for Ca.

As far as magnesium (Mg) is concerned, it is closely associated with Ca and P. Magnesium is the most common enzyme activator, particularly important in the activity of phosphorus transferases, decarboxylases and acyl transferases. Magnesium absorption can be decreased by potassium, while it can be increased by sodium.

Interactions involving trace minerals: Copper (Cu), Molybdenum (Mo) and Sulphur (S) appear to be highly interrelated. The availability of dietary Cu is reduced in the presence of increasing Mo concentrations, in the presence of adequate levels of Sulphur. Apart from the above antagonistic effects, xanthine oxidase which occurs in milk contains both Cu and Mo containing iso enzymes, and these levels are directly influenced by the dietary levels of Cu and Mo.

Although copper is not a constituent of haemoglobin, it is present in ceruloplasmin (a x_2 - plasma globulin) which is concerned with the release of iron (Fe) from cells into the plasma. Cu deficiency impairs the absorption of Fe for haemoglobin synthesis. Copper also plays a vital role in cytochrome oxidase which is important in oxidative phosphorylation. Mo is a component of xanthine oxidase enzyme in purine metabolism, in aldehyde oxidase and sulphite oxidase enzymes.

Selenium (Se) plays an important role in maintaining the integrity of cells in the animal body. It is an essential component of glutathione peroxidase, and both glutathione peroxidase and Vitamin E protect cell membranes from damage by peroxide and other active radicals. Some manifestations of Se insufficiency (e.g. white muscle disease) are moderated by vitamin E, while dietary components such as polyunsaturated fatty acids are readily metabolised to peroxide and aggravate the condition if not first hydrogenated in the rumen. Most of the blood Se in ruminants is located in the erythrocytes and the Se concentration and glutathione activities are closely related, particularly when Se concentrations are low. The enzyme has the advantage in being a diagnostic aid, since it exists in the biologically active form of Se. However, the enzyme glutathione peroxidase in plasma is low, unstable and very sensitive to haemolysis. The erythrocyte Se is incorporated at erythropoiesis and like erythrocyte Cu reflects the dietary intake over an extended period. Selenium concentrations in many other tissues (such as the liver, kidney and hair) and fluids also reflect the Se status of animals.

In summary, mineral nutrition of the buffalo is an area that has not been sufficiently investigated. The existing information suggests that the plasma concentrations of P, Mg and Cu in buffaloes are low when compared with those of Zebu cattle.

Suggested reading:

Bondi, A. A. (1987) *Animal Nutrition.* John Wiley and Sons, U. K.

McDonald, P., Edwards, R. A. and Greenhalgh , (1988) *Animal Nutrition.* Longmans House, Burnt Hill, Essex, U. K.

Tulloh, N. M. and Holmes, J. H. G. (1992) *Buffalo Production.* World Animal Science, C6, Production Systems Approach, (Ed. In Chief; A Neimann-Spensen and D. E. Tribe) Elsevier, Amsterdam.

NA-253-4

Chapter 4

Nutrient Requirements of Buffaloes

M.N.M. Ibrahim and S. Premaratne

Introduction

The swamp buffalo is an important source of draught power, and to a limited extent a source of milk and meat. Improvement in productivity of these animals is an urgent need for the Sri Lankan economy. In Sri Lanka, unlike cattle, buffaloes are not widely distributed but are more concentrated in some regions of the country. Productivity of these animals mainly depends on the availability of good quality feed throughout the year. Like in many countries in the region, the rainfall distribution in Sri Lanka is not uniform throughout the year. Pasture production pattern usually follows the rainfall distribution, resulting in a shortage of feed during the dry periods of the year.

Feed shortages during dry periods can be overcome by the use of crop residues, especially rice straw, non-conventional feedstuffs, agro-industrial by-products and tree fodder. Even though the availability of rice straw in Sri Lanka is very high, straw alone can neither provide protein nor energy in sufficient quantities to meet the nutritional needs of these animals, due to the low consumption of poor quality feeds by buffaloes.

The addition of fodder leaves, such as *Gliricidia sepium* (Gliricidia), *Leucaena leucocephala* (Ipil-Ipil) and *Tithonia diversifolia* (wild sun flower) to the diet can improve the utilization of rice straw through improved protein nutrition and the supply of other limiting nutrients to the rumen microbes. Addition of readily available carbohydrate will also help to improve energy nutrition of rumen microbes. However, it is necessary to provide sufficient quantities of energy, protein, essential minerals and particularly vitamin A or its precursors for maintenance, growth, reproduction, production and work.

The general consensus in the literature reviewed, appears to be that poor nutrition accounts for the slow development of buffaloes, higher age at first calving and longer calving intervals in many parts of the world. The provision of adequate nutrition would shorten the age at first calving and the calving interval by several months. Furthermore, it increases the growth rate and milk production in buffaloes.

Energy requirements

Animals require energy for maintenance of body functions, temperature control, growth, reproduction, production and work. A shortage of energy can limit the performance of buffaloes to a greater extent than a shortage of any of the other nutrients. This is associated with either a limited intake of poor quality roughage and high moisture in forages, resulting in a reduction in the intake of energy by buffaloes.

The energy requirements of buffaloes vary, depending mainly on body weight, age, growth, pregnancy, production, work and also on the health and environmental stress.

Stress factors include temperature, water needs, shade, wallowing and wind, whereas health will include diseases and parasites, both external and internal.

Energy requirements are expressed mainly as Metabolizable Energy (ME). Some information on ME and Total Digestible Nutrients (TDN) are included here.

For maintenance

The maintenance requirement of energy is the amount of energy required for maintenance of body functions and temperature without any changes in body weight. For production, dairy animals at peak lactation can consume 3 to 4 times the requirement for maintenance. If animals are fed below the maintenance level, they utilize body reserves to sustain day to day activities. This may not be uneconomical under certain specific situations. However, feeding of diets below the maintenance level for long periods of time will result in starvation and finally death. Furthermore, when animals receive inadequate feed energy to meet the maintenance requirements, protein is utilised to provide the energy deficit, which is an inefficient and costly method.

Requirement data relating to energy for maintenance of buffaloes under Sri Lankan conditions are lacking. According to Kurar and Mudgal (1981), the metabolizable energy intake of dry buffalo cows varies from 100 to 147 Kcal/W $kg^{0.75}$. The variation is associated with the energy:protein ratio in the diet. According to these workers, a higher energy density is associated with a higher metabolizable energy intake. Table 4.1 summarises the data on the maintenance energy requirements of buffaloes under Indian conditions. Detailed information is given in Annex 4.1.

Table 4.1 Energy requirement for maintenance of buffaloes (Kcal ME/Wt $kg^{0.75}$/d).

Type of buffalo	Requirement of Energy	Reference
Dry buffaloes	100 - 147	Kurar and Mudgal (1981)
Dry buffaloes	130.2	Kurar and Mudgal (1977)
Growing buffalo heifer calves	188	Sivaiah and Mudgal (1978)
Young growing buffalo calves	186	Arora *et al.* (1978)
Indian buffaloes	122	Ranjhan and Pathak (1979)
Growing and adult non-producing animals	125	Kearl (1982)

For growth

Energy requirements for growth depend on the composition of tissue growth of buffaloes. Lean tissues contain about 80% water which has no energy value.The energy cost of depositing energy in lean tissue is greater than the energy cost of depositing energy in fat. As a result, the energy required per unit of energy increase in the body varies as the proportion of fat and protein in the body varies. Thus, the energy required for weight gain increases as fat in the body increases. According to literature, the energy density (feed conversion ratio) in a unit of body weight can vary eight-fold. The feed conversion ratio will be lowest in animals, laying down lean tissues (young calves) and greatest in animals laying down fat in the body.

The muscle composition of cattle and buffaloes vary in water, protein, dry matter and fat contents. Buffalo meat contains less dry matter and fat and more water and protein (Matassino *et al.*, 1978). This may influence the energy required per unit of live weight gain. Since the water content of tissues decreases as the fat content increases with age, older animals need more energy per unit body weight gain.

The metabolizable energy (ME) requirement for weight gain has been reported to be 2.21 Kcal ME/g of body weight gain (Sivaiah and Mudgal, 1978). According to Kearl (1982), the ME requirement per gram of gain can vary from about 10 to 15.6 Kcal/g gain for animals weighing from 200-500 kg. As the animal matures, the ME requirement increases for each Kg of live weight gain. This amounts to about 1 Kcal/50 kg increment in body weight gain above the base level of 10 Kcal/g gain. The ME requirement for growth in buffaloes is given in Annex 4.1.

For pregnancy

No information is available on the requirement of energy of buffaloes during pregnancy. In the absence of such information, Kearl (1982) suggested that values established for gain in young animals, be added to the maintenance requirement during the latter stages of gestation. Therefore, ME requirements of buffaloes for the last 3 months of pregnancy have been calculated using the maintenance requirement of 10 Kcal/g of body weight change. Annex 4.1 presents the ME requirement of heifers and mature buffaloes during the last 3 months of gestation.

For lactation

The estimation of the energy requirements for milk production is more complicated than that for growth in buffalo cows. Lactating animals need energy for three functions: namely, for maintenance, growth and milk production. Growth can be positive or negative. A further complication in late lactation is that the animal may need to support a calf in the uterus. Therefore, the energy requirement of each of the additional functions need to be taken into account, in addition to that for milk production.

The nutrient requirements of lactating buffaloes depend on the amount of milk produced and on its nutrient content. Milk production will depend on the breed, individuality of buffaloes and the type of diet fed. The average fat content of buffalo milk is between 6-8%, compared to that in cow milk which is about 4%. In addition, the energy requirement for milk production will depend on other milk constituents such as protein, solids-not-fat, etc. Since the composition of milk varies, particularly the content of fat, the requirement for milk production is usually given as energy per unit of 4% fat corrected milk. Table 4.2 summarises the data on ME requirements for milk production.

Table 4.2 Requirements of Metabolisable Energy for milk production per kg of 4% FCM

Energy requirements, Kcal	References
1603	Mudgal and Kurar (1978)
1171	Srivastava (1970)
1188	Ranjhan and Pathak (1979)
1188	Sen *et al.* (1978)
1003	Sivaiah and Mudgal (1978)
1230	Kearl (1982)

The utilization of energy for the production of milk varies according to the energy density and the energy:protein ratio of the diet. In late lactation, extra feed has to be provided for foetal growth as well as for storage as fat. Annex 4.1 presents the ME requirements for milk production in lactating buffaloes. Energy is expressed here mainly in terms of ME and in addition some information on TDN and FU are also included.

For work

Metabolizable energy requirements for work depends on several factors such as the intensity and duration of the work, the environmental and physical conditions under which the work is performed, the health and the condition of the animal. According to Kearl (1982), energy requirement for work such as ploughing and general cultivation by buffaloes is not very large since the work is performed at a very slow pace.

Energy requirements of a 300 kg buffalo performing normal work and heavy work are 11.4 Mcal ME and 14.4 Mcal ME, respectively (Ranjhan and Pathak, 1979). Kearl (1982) estimated the ME requirement for work using values of 11.9 and 13.9 Mcal ME for normal work and heavy work, respectively. Annex 4.1 presents the energy requirement for work in buffaloes.

Protein requirements

Ruminants like other animals have a need for nitrogenous materials to (a) build new tissues and (b) replace worn-out cells. Rumen microbes are able to synthesise microbial protein from non-protein-nitrogenous compounds and provide the animal with most of its protein needs. So in effect, dietary true protein and essential amino acid requirements are not critical considerations in ruminant nutrition. The amount of protein which microbes produce during growth and multiplication which subsequently becomes available to the animal, is almost completely dependent on the amount of energy fermented. On the other hand, the amount of energy fermented is closely associated with the digestibility of the feed.

Unlike with microbes, the requirements of the animals will vary depending on the amount of protein incorporated in lean meat and milk. Ruminants need protein for maintenance, growth, production, reproduction and work. However, the protein requirement for different functions will vary with breed, age, weight of the animal and the stage of lactation.

For maintenance

If adequate energy is available for maintenance of the animal, the microbial protein produced from rumen degradable protein (RDP) is likely to be sufficient to meet the maintenance requirement for protein. However, if the animal is fed less than its maintenance requirement of energy, the microbial protein production will be limited and the amount produced will not be enough and consequently the animal will lose not only body fat but also protein or lean tissue.

Table 4.3 DP requirement for maintenance of buffaloes (g/W $Kg^{0.75}$/d)

Type of animal	Requirement	Reference
Non - pregnant adult	2.355	Kurar and Mudgal (1981)
	2.089	Singh (1965)
	2.846	Gupta *et al.* (1966)
	2.84	Ranjhan and Pathak (1979)
	2.84	Sen *et al.* (1978)
Growing heifers	3.396	Sivaiah and Mudgal (1978)
Adult buffaloes (355 Kg B.Wt)	1.81	Negi *et al.* (1982)
Average	2.54	Kearl (1982)

The maintenance requirement of protein is related to endogenous urinary nitrogen losses and this is related to the metabolic body weight ($W^{0.75}$), whereas a certain amount of nitrogen which does not originate from feed, will also be lost through faeces. The metabolic faecal nitrogen content is related to the feed intake of the animal. According to several workers, the protein requirement for maintenance of buffaloes is lower than that recommended for cattle by the NRC (1976). Table 4.3 summarises the reported digestible protein (DP) requirements of buffaloes for maintenance. For details see Annex 4.1.

For growth

The digestible protein (DP) requirement for growth depends on the species, breed, age and sex of the animal. Accordingly, different workers have suggested different equations to calculate the digestible protein requirements of buffaloes. Gentsch *et al.* (1975) and Sivaiah and Mudgal (1978) have used the following equation to calculate the DP requirement of growing buffaloes.

$$\text{DP requirement (g/d)} = 2.54 \text{ W Kg}^{0.75} + 0.238 \text{ g LWG} + 0.6631 + 0.6631 \text{ kg LW} - 0.001142 \text{ kg LW}^2$$

where W $kg^{0.75}$ = Metabolic body weight
LWG = Live weight gain
LW = Live weight

However, Baruah *et al.* (1983) used the following equation to calculate the mean DCP requirement of growing buffaloes of about 200 kg body weight.

$$Y = 48.925 + 3.418\ X1 + 0.287\ X2$$

where Y = DCP intake (g)

$X1 = W^{0.75}$ kg

$X2$ = ADG (g)

Annex 4.1 presents the dietary DP requirement for maintenance and growth of growing and pregnant buffaloes during the first 7 months of the gestation period, using the first equation.

For pregnancy

The growth of the foetus during the latter part of pregnancy (last 3 months of gestation) is very rapid. Therefore, the protein requirement increases. Almost double the protein requirement for maintenance has been suggested by NRC (1989) for cows. These values may also be used for buffaloes until specific values for buffaloes become available. However, no additional protein above the maintenance requirement is needed for pregnancy during the early part (first 7 months), since foetal growth is not so rapid during this period.

In addition to the increase in foetal weight, additional membranes are formed during the latter part of pregnancy. According to Kearl (1982), the daily gain attributable to the products of conception during the last 90 days of the gestation period is about 400 g. Assuming that this value is comparable to the digestible protein requirement for growth, 95 g of DP will be required daily for pregnancy during the last 90 days.

For lactation

Lactating animals need digestible protein for maintenance, milk production and often for the development of the foetus. However, it is very difficult to fulfil this requirement during the early part of lactation, especially with high producing animals, since they excrete a considerable amount of protein through milk. Table 4.4 presents some published information on the DP requirement for lactation. For details see Annex 4.1.

Table 4.4 DP requirement for lactation

Item	Amount	DP requirement g/w kg $^{0.75}$/d	Reference
	126.03 g / 100 g of protein secreted in milk	3.2	Kurar and Mudgal (1980)
Mid lactation	166.34 g / 100 g of protein	3.65	Sivaraiah and Mudgal (1978)

DP requirements for lactating animals in Annex 4.1 have been calculated using an average value (3.42 g / W Kg $^{0.75}$) from the two references in Table 4.4.

For work

No information is available on the protein requirement levels for work of buffaloes above that for maintenance. According to PCARR (1978), the following daily requirements can be used for work for male animals weighing more than 272 kg; light work - 90 g DP; medium work - 110 g DP; heavy work - 130 g DP. More details are given in Annex 4.1.

Mineral requirements

Minerals are required in small quantities compared to the nutrients like nitrogen and energy. However, mineral deficiencies can have a marked effect on productivity, particularly on reproductive performance and health. Straw and stover contain certain minerals well below the animals' needs, but on the other hand, they contain an excess of minerals like silica and in some regions lead, selenium and fluorine, leading to either deficiencies or toxicity in animals. Mineral imbalances depend on the type of straw (varieties) and on the type of soil where the crop is grown. Mineral requirements are related to animal output, and therefore, the use of mineral supplements is particularly important for high producing animals.

It is well established that certain mineral elements perform essential functions in the body and they must therefore, be supplied in the feed (Chapter 3). Calcium, phosphorus, magnesium and fluorine are constituents of bone and teeth and give strength to skeletal structures of the body. They are also constituents of soft tissues. Elements such as calcium, phosphorus, magnesium, iron, manganese, copper, zinc and selenium play important roles in enzyme systems. Sodium, potassium and chlorine function as soluble salts to maintain osmotic pressure, acid base balance and pH in the body fluids and also in water metabolism. Iron, copper and cobalt form vitamin B^{12} through rumen microbial activity and which is necessary in the formation of haemoglobin. Iodine is an essential element in a hormone released from the thyroid gland and has many functions in soft tissues. Sulphur occurs in organic compounds, notably in sulphur containing amino acids.

Requirements

While calculating mineral requirements, it is essential to consider the types of feed ingredients that are used in the ration, along with the type of straws and stovers fed. Feeding low quality roughage generally results in increased faecal endogenous losses, for example, Ca and P, leading to an increase in maintenance requirements for these minerals. If the feed ingredients contain anti-metabolites like tannins, phytates, oxalates or silica beyond the acceptable limits, some minerals like P and Ca need to be supplemented to ensure adequate absorption. Also, the need for supplementation may be greater in animals with parasitic infections due to the increased mineral requirement.

Mineral elements are classified as macro, micro and trace elements, depending on their contents in animal tissues and on their biological functions (Table 4.5).

The requirements of calcium and phosphorus in high producing dairy animals are higher than in low yielders because of the high concentration of calcium (0.13%) and phosphorus (0.11%) in milk. The Ca:P ratio is important and a ratio of between 2:1 to 6:1 seems to be optimum. The Ca and P requirement for maintenance of an adult cow weighing 400 kg and yielding 10 kg milk with 4 percent fat will be 46 and 34 g, respectively. Mineral requirements for growth, milk production and work for cattle are given in Tables 4.6a and 4.6b.

Table 4.5 Classification of minerals

Elements	Class
Calcium (Ca), chlorine (Cl), potassium (K), magnesium (Mg), Sodium, (Na), phosphorus (P), sulphur (S)	Macro-elements
Copper (Cu), flourine (Fl), iodine (I), iron (Fe), manganese (Mn), Zinc (Zn),	Micro-elements
Lead (Pb), molybdenum (o), cobalt (Co), chromium (Cr), Nickel (Ni), selenium (Se), vanadium (Va)	Trace elements

The mineral requirements can be expressed in amounts per day or per unit of product, or as a percentage of the dietary dry matter intake. The former is more accurate but the latter is simple and practical as long as there is no variation in feed intake. Since dry matter intake of straws and stovers varies considerably, the expression in absolute amounts may be more appropriate.

Mineral interaction

Minerals interact with each other and with other nutrients. Interactions which mutually enhance absorption in the digestive tract and jointly fulfil some metabolic function are termed synergistic. The interactions which inhibit the absorption of two or more minerals and produce opposite effects on a biochemical function are termed antagonistic. These interactions can take place in the feed itself, in the digestive tract and during tissue and cell metabolism. Because minerals tend to form bonds or complexes, they are more liable to interact than other nutrient substances. Examples of synergistic effects are between Ca and P, Na and Cl, Zn and Mo. Examples of antagonistic effects are the formation of magnesium phosphates in the presence of excess Mg, formation of triple Ca-P-Zn salt in the presence of high Ca and between Cu, Mo and S. The balance between these minerals is therefore an important consideration when determining the requirements of animals.

Toxicity and deficiency symptoms

Some minerals like Ca, P and Zn are stored in body tissues. If a deficiency in the feed occurs, the deficiency symptoms will only appear after a period of time. In the case of calcium and sodium, deficiencies can be observed more quickly, particularly in high producing milch animals and fast growing young stock. When Ca is deficient, or when Ca metabolism is upset after parturition, clinical signs of milk fever may develop in high yielding cows. Ca and P deficiency in young growing animals can cause rickets, unsteady gait, lameness and stunted growth. A moderate deficiency of P in the diet may lead to retardation of growth, impairment of bone mineralization and high mortality in young calves. In adult animals, P deficiency may lead to a decrease in live weight and milk yield due to reduced consumption of feed. Affected animals show depraved appetite and are observed to chew wood and other objects, a condition termed "Pica". Mg deficiency in adult ruminants causes what is known as 'grass staggers' or 'grass tetany', leading to high nervous excitability, shivering and unsteady gait. This condition results from consuming large quantities of grass on pasture land with an imbalance of elements (excess K). Magnesium deficiency may arise in animals fed ammonia treated straw and the high ammonia concentration in the rumen can impair Mg absorption. It is important to remember that feeding of berseem (crude protein content about 20% of dry matter) is likely to produce more ammonia than feeding of urea treated straw with a crude protein content of around 11% or lower.

With working animals, the requirement of minerals like common salt increases due to increased muscular activity. Salt, consisting of Na and Cl, is lost through increased sweating in hot conditions. The addition of salt to the diet is often believed to increase palatability, but this is not yet conclusively proven. A deficiency of most of the micro and trace elements will indirectly affect animal performance by impaired metabolism. Typical symptoms of mineral deficiency are loss of appetite, rough hair coat, listless appearance and decreased body weight. Deficiency symptoms may however not appear for some time in animals deprived of the minerals, as the animal body tries to maintain normal blood levels in spite of a deficiency.

Table 4.6(a) Requirements of Ca and P for maintenance, growth, milk production and work

Description of animal	Calcium	Phosphorus
Pre-ruminant calves (% of diet)	0.8	0.5
Growing calves (% of diet)	0.8	0.5
Adult animals, maintenance (400 kg) (g/day)	18	12
Adult cows (400 kg,) (g/day)	18	14
Pregnant cows* (g/day)	19	19
Milk production (g/day/kg milk)	2.8	2.0
Working bullocks (g/day)	15	15

* In addition to that provided for maintenance

Table 4.6(b) Requirement of other minerals (mg /day/kg bodyweight)

Minerals	Young stock	Mature dairy animals
Cobalt	0.1	0.1
Copper	10	10
Iron	100	50
Magnesium	700	2000
Sulphur	2000	2000
Zinc	30	40
Sodium	2500	4600
Potassium	6000-8000	6000-8000

Source: Prasad *et al. (1995) Handbook of straw feeding systems*

The economic losses due to mineral deficiencies could be high depending on the type of animal. It may range from losses caused by delayed maturity of female calves, to losses in milk production, low performance of working bullocks and reproductive problems.

Sources of minerals

Straws, stovers and other feed ingredients commonly fed to livestock usually contain minerals below the requirements. Therefore, supplementation of each of the deficient minerals is necessary, depending on their availability in a particular area. In the absence of survey information, when dealing with high producing animals, it may be necessary to provide mineral mixtures that contain all elements. Calculated quantities can be incorporated in special feeds, e.g. concentrate or urea-molasses lick blocks. When making mineral premixes or licks, attempts must be made to reduce the cost so as to ensure that the main advantage of feeding low quality roughage is not offset by expensive supplementation.

A list of commonly available straws and their mineral contents is given in Table 4.7. Mineral elements that are required in relatively large quantities are calcium and phosphorus. In order to reduce the cost, it is possible to supplement the feed with feed ingredients that are relatively rich in these minerals, e.g., rice bran, wheat bran, rice polish or leguminous fodders. In a study where treated rice straw at a level of 8 kg DM was provided to a cow weighing 400 kg and producing 7 litres milk, the daily Ca and P balances were found to be -6 and -21g respectively. This was reduced to -5 and -4 g per day respectively, when 1 kg of bran was supplemented. With 5 kg straw, 5 kg greens and 1 kg rice bran both the minerals showed a positive balance.

Table 4.7 Mineral contents of different crop residues

Type of straw	Mineral content (g/kg)				
	Ca	P	Mg	S	Co (ppm)
Rice	21-40	0.05-0.22	0.07-0.25	0.05-0.11	0.081
Wheat	22-42	0.2-1.5	0.08-0.16	0.04-0.10	0.065
Oats	17-36	0.02-0.07	0.11-0.30	0.11-0.30	0.245
Sorghum	8-54	0.10-0.34	*	*	0.205
F. millet	16-30	0.08-0.32	*	0.08-0.11	*

Source : Ranjhan, (1981); Kearl, (1982); Ranawana, (1985); * not known

Most cereals are rich in zinc, iron and sulphur, but poor in calcium. Oil cakes are rich in sulphur, cobalt and are moderate sources of zinc and copper. All roughages tend to contain lower levels of phosphorus. Mineral contents of some of the common feed ingredients are given in Table 4.8. The mineral composition could vary considerably depending upon the fertility status of the soil and/or processing conditions (oil cakes, brans, polish). Animals can be supplemented directly with suitable minerals or with mixtures in boxes or with mineral licks (Table 4.9).

Feeding of formulated mineral mixtures, or pure ingredients, can be a simple way of providing deficient minerals if and when they are available. Selection should be on the basis of biological availability, or release and the absorption coefficient. For example, dicalcium phosphate derived commercially from bone meal is the best Ca and P supplement. On the other hand, rock phosphate though a good source of Ca and P, is rich in Fl, and can cause Fl toxicity.

Biologically, most sulphates and chlorides are more readily available than oxides. The ferrous form of Fe (Fe^{++}) is utilized in tissues and thus is the better form for supplementation than the ferric (Fe^{+++}) form, though the latter can be converted into its Fe^{++} form, in the gastrointestinal tract. Amongst the chemically prepared salts, orthophosphates are readily available, but meta- and pyrophosphates have limited absorption rates. Calcium as calcium silicate is not absorbable.

Table 4.8 Mineral content of common feed ingredients

Feed Ingredient	Mineral content Ca (%)	P (%)	S (%)	Cu (ppm)	Zn (ppm)	Co (ppm)
Oil cakes	0.12	0.48	0.40	16.6	34.6	0.4-0.56
Cereal grains	0.07	0.04	0.56	10.9	74.0	0.40
By-products						
Brans	0.14	0.80	*	11.0	76.1	0.10
Rice polish	0.24	0.49	*	13.9	10.9	0.10
Green fodder						
Legumes	1.5-3.0	0.14-0.40	*	12.0	50.0	0.48-0.63
Non-legumes	0.3	0.12-0.28	*	9.6	*	0.18-0.39
Grasses	0.2-0.3	0.07-0.30	0.06	10.6	*	*

Source: Ranjhan (1981) Underwood (1981); *not known

In conclusion, animals on straw based diets are likely to be deficient in P, Mg, S, Cu, Co and Zn. When straw diets are fed, there is a possibility that the animal will be in negative Ca balance due to the presence of high silica and oxalate (binding). Salt should be provided in the diet of dairy animals and minerals may be provided mixed with concentrate feeds. Supplementation of green fodder with concentrate by-products like brans and oil cakes would be cost effective when these ingredients are available at a cheaper rate than mineral mixtures. The best sources of the various minerals will depend on the type of feed ingredients fed to animals, the availability of leguminous green fodder and the type of animal.

Water requirements

Water is an essential component in animal feed, but it is seldom discussed when nutrient requirements are considered. Water also plays a role in the management of the animals. This section explains the occurrence of water in feeds, its functions in the animal body, and briefly discusses the other uses of water on farm. It also elaborates problems associated with water shortage and water requirements in relation to farmers' perceptions on need and the difficulties encountered to provide adequate water.

The principal nutrients in feedstuffs are water, organic and inorganic matter. As the animal uses water for all its vital needs, it may be appropriate to term water as an essential nutrient, just like protein, energy and minerals. In fact, animals can tolerate lack of food more than a lack of water.

Two-thirds of the animal body is composed of water. The proportion of water is higher in younger animals (8-10 months, 70-75%) and this gradually reduces as the animal grows older (18-20 months, 40-45%). As animals mature, the proportion of protein in the carcass remains almost constant, but the fat content varies. As the fat content of the body increases, the water content decreases. Fat animals may contain less than 50% water, whereas thin animals may contain 60-70% body water. The water requirement of the animals could be met by

- water consumed voluntarily,
- water present in feeds/fodder,
- water formed within the body due to metabolic oxidation (metabolic water)

Table 4.9 Minerals salts used for livestock feeding and their nutrient mineral content (in g/kg)

	Ca	P	Mg	Na	Cl	Cu	Co	I	Zn	Mn
Dicalcium phosphate ($CaHPO_4.2H_2O$)	220	170								
Decalcified bone meal[1]	300	130	10							
Limestone flour ($CaCo_3$)	360									
Sodium phosphate ($NaH_2PO_4.2H_2O$)		190		150						
Disodium phosphate (Na_2HPO_4)		80		120						
Dehydrated sodium phosphate		220		320						
Magnesium sulphate ($MgSO_4.7H_2O$)			90							
Magnesium oxide (MgO)			500							
Iodized salt (NaCl)				390	590			0.04		
Copper sulphate ($CuSO_4.5H_2O$)						240				
Cobalt sulphate ($CoSO_4.7H_2O$)							200			
Stabilised iodine preparation (CuI) (10 g/kg)						3		7		
Zinc sulphate ($ZnSO_4.7H_2O$)									210	
Zinc oxide (ZnO)									750	
Manganese sulphate ($MnSO_4.H_2O$)										220
Manganese oxide (MnO)										580

[1]Bone meal, which is not decalcified, can be also considered as a practical Ca and P supplement.
Source: (Hartmans, 1987).

The water is excreted or lost from the animal body through saliva, urine, faeces, milk and evaporation from the skin or respiration. The loss of water is influenced by the composition of the diet, water intake and the hormones. The latter depends on the environmental temperature and stress on the animal.

Water in the animal serves :

- as a medium for the transport of nutrients and minerals to body tissues
- as a carrier for excreting the waste products
- in maintaining body temperature
- in maintaining the acid-base balance
- as a medium for digestion and metabolism
- as a major component of milk
- as a lubricant to prevent friction in joints
- in diluting the toxic associative factors of feed

The water content in plants/feeds can differ considerably. It can be as high as 90% in feeds like water hyacinth or very succulent grasses, 70-80% in green fodders and between 5-15% in dry feeds like straws and concentrates. Normally, concentrates and other feeds with less than 12% water will not be subject to spoilage through the action of fungi and other microbes. The water content of plants decreases with the stage of maturity. Water in plants serves to transport nutrients to and from leaves to roots, to maintain the rigidity of the plant and as a medium for the various biochemical reactions.

Water needs

As with other nutrients, the requirement for water depends on factors, like:
- animal species,
- the environmental conditions,
- the type of food eaten, i.e. amount of dry matter ingested
- the physiological state of the animals (maintenance, growth, lactation, work).

Young calves receiving milk diets consume greater amounts of water in relation to the dry matter of their diet than older cattle fed on dry feeds such as straws. Lactating animals require the greatest amount of water in proportion to live-weight as water constitutes 85 to 90% of the milk produced. A cow yielding 12 litres of milk per day secretes over 10.5 litres of water in the milk, and for every litre of milk produced about 3 litres of water is said to be required, apart from the quantity that the animal needs for its body functions (Table 4.10). Working bullocks require more water as compared to the non-working bullocks as they loose much water through increased respiration during work.

The extent to which animals can tolerate dehydration and the efficiency of regulating water needs differ widely between species. For example, cattle have a limited ability in this respect, compared to camels. Also the exotic breeds of cattle are rarely able to cope with severe water restrictions when compared to native breeds. Even though buffaloes are widely known to be water-loving animals, they possess as a remarkable ability to thrive under dry conditions. The recent study by Rajaratne and Ranawana (1996) clearly demonstrated the ability of buffaloes to conserve water both by urinary and faecal routes as a response to dehydration.

Table 4.10 Optimum water intake depending on ambient temperature for dairy cows.

Milk yield (kg)		Ambient temperature			
		11 - 20°C		> 20°C	
	Body weight (kg) →	350	600	350	600
0		46	63	56	77
10		58	86	70	105
20		69	98	84	119
30		81	109	98	133
40		98	120	119	147

Water intake = liquid + food moisture (kg/day)
Source: Oliver (1987) cited by Matthewman, (1994)

The type of food also influences water intake. Grazing on low quality tropical pasture results in reduced water intake. As the dry matter intake of large cattle is greater than that of smaller breeds under the same environmental and physiological conditions, the volume of water consumed increases with increasing body size. Straws treated with sodium hydroxide when fed to animals will increase their water intake as they receive more sodium that needs to be excreted in the urine. A similar situation arises if too much salt is offered or mixed in animal feeds. Animals seems to be more tolerant to excess of salt in feed than to excess salt in drinking water. Buffaloes and cattle drink more water on a high-protein than on a low-protein diet, since the nitrogenous end-products need a greater urine volume for excretion. Feeding of diets with high levels of indigestible fibre (straws, matured grass) result in increased loss of water in faeces and animals fed such diets require an increased water intake.

Water intake increases with increase in ambient temperature. An animal kept under cool conditions (below 20°C) usually needs 4-5 litres of water for every kg of dry matter consumed. But when the temperature rises above 30°C, the amount of water needed increases to 10-12 litres per kg of dry food. Cows consume less water under humid than under arid/dry conditions. The water loss varies with the temperature. At 20°C more water is lost through faeces and urine than at temperatures above 30°C. The loss is greater through the body surface and less through urine and the respiratory tract

The frequency of provision of water is also important. Animals that have free access to water, drink more and yield more milk than those offered water only once a day. Normally, lactating cows drink 2-5 times a day and generally provision of water 3 times a day would be adequate. The frequency of watering can also affect milk composition. Animals deprived of water overnight, when offered water in the morning drink copiously, but may seldom drink again during the day. This increased intake of water in the morning causes an increase in the water content of the evening milk. Cattle deprived of water show a marked decrease in feed intake by the fourth day and lose weight equivalent to 16 per cent of the live weight. Water deprivation in lactating cows causes a severe reduction in milk yield after the first 24 hours, probably also due to an associated reduction in feed intake: (non-) lactating cattle and sheep show reduced feed intake when deprived of water. The faeces become dry and deprivation of water can lead to loss of weight in growing calves. Animals receiving drinking water once a day or once in two days in a hot dry climate show depressed feed intake relative to animals receiving water at least twice a day. Animals should be prevented from drinking water from lakes/ponds with a high content of algae, because of the risk of poisoning by drinking such water.

Apart from meeting the water requirement through feed and voluntary consumption, water formed within the body due to metabolic processes is another important source of water. For example, one kilo of carbohydrate when metabolised in the body produces half its quantity (500 ml) of water. Similarly 1 kg of fat gives about 1000 ml of water and 1 kg of protein about 400 ml of water.

Provision of water

There is no doubt that animals should have a free access to clean drinking water, but in areas where water is scarce, water has to be used judiciously and priorities for use have to be set. For example, lactating and pregnant animals should be given priority over young animals and bullocks; crossbred animals should be given priority over local breeds, and sick animals should be given priority over healthy animals.

Water needs other than for drinking

Apart for drinking purposes, water is required for activities like bathing of animals and cleaning of sheds. Many animals are sprinkled with water and their udders washed before milking. This not only helps in cooling the animal body but, also to maintain hygiene. Water/swamp buffaloes often require water ponds/tanks for wallowing, and many farmers are reluctant to maintain buffaloes in areas where tanks or ponds do not exist. The water needs of animals may therefore be much greater than normally estimated. As with many other farm activities, it is mostly the women and children who carry out strenuous work such as fetching water. Before suggesting changes in management, their views should also be taken into account.

In conclusion, the water intake of animals are partly supplied through feed and partly through water consumed voluntarily. The physiological state of the animal influences the water intake. Variations that exist between animals and factors such as the nature of the feed and environmental temperature can affect water needs. There is no clear advantage in restricting water intake (other than in places where water is scarce). As the advantages of providing drinking water are many, animals should be provided with clean drinking water at least twice a day.

Suggested reading

ARC (1980) *The nutrient requirements of ruminant livestock.* Commonwealth Agricultural Bureau (CAB) Farnham Royal, U.K.

Arora, S.P., Chhabra, P.P. Atriga and Sharma, K.N. (1978) Nutrient requirements of calves under *ad libitum* feeding systems. *Indian Journal Dairy Science.* **31**, 9.

Baruah, K.K., Ranjhan, S.K. and Pathak, N.N. (1983) Nutrient requirement for growth of desi male buffalo calves. *Proceedings of 5th World Conference on Animal Production.* National Institute of Animal Industry,.Ibaraki, Japan. P. 305

Gentsch, W., Hoffman, R. Schiemann and Whittenburg, R. (1975) *Tagung sberichte der adl der DDR.* No. **133:** 89.

Georgievskii, V.I., Annenkov, B.N. and Samokhin, N. (1982) Mineral Nutrition of Animals. *Studies in the Agricultural and Food Sciences.* Butterworths, London, UK
Hartmans, J. (1974) Tracing and treating mineral disorders in cattle under field conditions. In: *Troce element metabolism in animals.* pp. 261-273 -2. Park Press, Baltimore, U.S.A./ Butterworth, London, U.K.
Kearl, C. Lenard (1982) *Nutrient requirements of ruminants in developing countries.* International Feedstuffs Institute, Utah Agricultural Experiment Station, Utah State University, Utah, U.SA.
Kurar, C.K. and Mudgal, V.D. (1977) Effect of plane of nutrition on the utilization of faecal nutrients for milk production in buffaloes. *Annual Report National Dairy Research Institute,* Karnal, India. pp. 118-120.
Kurar, C.K. and Mudgal, V.D. (1980) Protein requirements of Murrah buffaloes in the early stage of lactation. *Indian Journal of Dairy Science.* **33**, 443.
Kurar, C.K. and Mudgal, V.D. (1981) Maintenance requirements for protein in buffaloes. *Indian Journal of Animal Science.* **51**, 817.
Matthewman, R.W. (1994) *Dairying.* The Tropical Agriculturist Series (Series editor René Coste, General editor A.J. Smith). CTA/MacMillan.
Maynard, L.A., Loosli, J.K., Hintz, H.F. and Warner, R.G. (1979) *Animal Nutrition.* 7[th] Edition, McGraw-Hill. McGraw-Hill, New York, U.S.A.
McDowell, L.R. (1992) *Minerals in Animal and Human Nutrition.* Academic Press, Inc., U.S.A.
McDowell, R.E. (1975) *Improvement of Livestock Production in Warm Climates* W.H. Freeman & Co. San Fransisco, U.S.A..
Metassino, D., Romita, A., Consentino, E., Girolami,. A. and Colatruglio, P. (1978) *Morphological, chemical and colour characteristics of meat in water buffalo and bovine calves slaughtered at 20, 28 and 36 weeks.* The Hague, Netherlands. pp 187 – 201.
Negi, S.S., Joshi, B.C. and Kehar, N.D. (1968) Minimum digestible crude protein requirement of adult buffalo. *Journal of Research* P.A.U., 5, 92.
NRC (1989) *Nutrient requirements of dairy cattle.* National Research Council, Washington, DC.
Pathak, N.N. and Verma, D.N. (1979) *Nutrient Requirements of Buffalo.* International Book Distributing Co., India
PCARR. (1978) *The Philippines Recommendations for Carabao Production* (1978) The Philippines Council for Agricultural and Resources Research, Los Banos, Laguna, The Philippines.
Rajaratne, A.A.J. and Ranawana, S.S.E. (1996)) Physiological responses of Lankan buffaloes to dehydration. In: *The Role of the Buffalo in Rural Development in Asia* (Eds. B.M.O.A. Perera, J.A de S. Siriwardene, N.U. Horadagoda and M.N.M. Ibrahim) NARESA Press, Colombo, Sri Lanka. pp 195.
Ranjhan, S.K. and Pathak, N.N. (1979) *Management and feeding of buffaloes.* Vikas Publishing House, New Delhi, India.
Sen, K.C., Ray, S.N. and Ranjhan, S.K. (1978) Nutritive value of Indian feeds and feeding of animals. *Indian Council Agriculture Research Bulletin* No. 25.
Sivaiah, K. and Mudgal, V.D. (1978) Effects of feeding different levels of protein and energy on feed utilization for growth and milk production in buffaloes (*Bos bubalis*). *Annual Report of the National Dairy Research Institute.* Karnal, India. pp 145 - 146.
Underwood, E.J. (1974) *Trace elements in human and animal nutrition.* Academic Press, New York, U.S.A.

Annex 4.1 Daily nutrient requirements of buffaloes

Body Wt. (kg)	Gain (or loss) (kg)	DM Intake (kg)	DM Intake % of live wt.	Diet Density (Mcal /kg)	Energy ME (Mcal)	Energy TDN (kg)	Energy FU (kg)	Protein Total[a] (g)	Protein Dig (g)	Minerals Ca (g)	Minerals P (g)	Vit. A (1000 IU)
Maintenance and Growth												
100[b]	.0	2.4	2.4	1.65	3.95	1.09	1.40	163	80	4	4	5
	.25	3.0	3.0	2.15	6.45	1.78	2.29	312	195	9	8	6
	.50	2.8	2.8	3.05	8.95	2.47	3.17	373	254	14	11	6
	.75	2.8	2.8	4.08	11.45	3.16	4.06	439	313	20	14	6
150	.0	3.3	2.2	1.65	5.36	1.48	1.90	223	109	5	5	6
	.25	3.9	2.6	2.00	7.86	2.17	2.79	393	242	10	9	9
	.50	4.1	2.7	2.50	10.36	2.86	3.67	486	319	14	12	9
	.75	3.9	2.6	3.05	12.86	3.55	4.56	548	378	17	15	9
	1.00	3.9	2.6	3.94	15.36	4.24	5.45	609	437	21	17	9
200	.0	4.1	2.0	1.65	6.65	1.84	2.36	288	135	6	6	8
	.25	4.8	2.4	1.95	9.15	2.53	3.24	465	281	10	9	10
	.50	5.1	2.6	2.30	11.65	3.22	4.13	543	341	14	13	12
	.75	5.1	2.6	2.80	14.15	3.91	5.02	610	400	19	17	13
	1.00	4.8	2.4	3.47	16.65	4.60	5.90	682	471	23	20	13
250	.0	4.8	1.9	1.65	7.86	2.17	2.79	327	160	8	8	9
	.25	5.5	2.2	1.90	10.36	2.86	3.67	525	315	12	9	10
	.50	5.9	2.4	2.15	12.86	3.55	4.56	604	374	15	12	12
	.75	6.1	2.4	2.50	15.36	4.24	5.45	677	433	19	17	14
	1.00	5.6	2.2	3.05	17.86	4.93	6.33	732	493	22	19	14
300	.0	5.6	1.9	1.65	9.01	2.49	3.20	377	183	9	9	10
	.25	6.2	2.1	1.90	11.76	3.25	4.17	579	343	13	12	11
	.50	6.8	2.3	2.15	14.51	4.01	5.15	663	402	17	16	13
	.75	7.0	2.3	2.60	18.26	5.04	6.48	736	461	21	19	15
	1.00	6.5	2.2	3.05	20.01	5.52	7.09	790	521	26	23	16
350	.0	6.4	1.8	1.65	10.11	2.79	3.59	426	205	10	10	12
	.25	7.1	2.0	1.90	13.11	3.62	4.65	620	357	13	12	13
	.50	7.6	2.2	2.15	16.11	4.45	5.71	703	416	17	15	15
	.75	7.8	2.2	2.45	19.11	5.28	6.78	776	475	20	18	17
	1.00	7.2	2.1	3.05	22.11	6.11	7.84	826	535	23	21	18

Body Wt. (kg)	Gain (or loss) (kg)	DM Intake (kg)	DM Intake % of live wt.	Diet Density (Mcal /kg)	Energy ME (Mcal)	Energy TDN (kg)	Energy FU (kg)	Protein Total[a] (g)	Protein Dig (g)	Minerals Ca (g)	Minerals P (g)	Vit. A (1000 IU)
400	.0	7.0	1.8	1.65	11.17	3.09	3.96	469	227	11	11	13
	.25	7.7	1.9	1.85	14.42	3.98	5.11	653	369	14	13	14
	.50	8.4	2.1	2.10	17.67	4.88	6.27	740	428	17	16	16
	.75	8.7	2.2	2.40	20.92	5.78	7.42	818	487	20	19	18
	1.00	8.3	2.1	2.90	24.17	6.68	8.57	874	547	23	21	19
450	.0	7.7	1.7	1.65	12.21	3.37	4.33	515	248	12	12	14
	.25	8.6	1.9	1.90	15.71	4.34	5.57	675	365	14	14	15
	.50	9.1	2.0	2.10	19.21	5.31	6.81	758	424	16	16	17
	.75	9.5	2.1	2.40	22.71	6.27	8.05	836	482	18	18	18
	1.00	9.2	2.0	2.85	26.21	7.24	9.29	896	542	20	20	20
	1.10	8.8	2.0	3.05	27.61	7.62	9.79	911	566	21	21	20
500	.0	8.3	1.7	1.65	13.21	3.65	4.68	556	268	13	13	14
	.25	9.1	1.8	1.85	16.96	4.69	6.01	701	374	15	14	16
	.50	9.7	1.9	2.10	20.71	5.72	7.34	786	433	16	16	18
	.75	10.2	2.0	2.40	24.46	6.76	8.67	869	492	18	18	20
	1.00	10.4	2.1	2.80	28.21	7.79	10.00	933	552	20	20	23
	1.10	9.7	1.9	3.05	29.72	8.21	10.54	971	576	21	21	23

Heifers

Last 3 months of gestation[c]

300	.5	6.7	2.2	2.10	14.1	3.9	5.0	538	294	16	14	25
350	.5	7.4	2.1	2.05	15.1	4.2	5.4	592	324	21	16	27
400	.5	8.1	2.0	2.00	16.2	4.5	5.7	647	354	23	18	30
450	.5	8.8	2.0	2.00	17.2	4.8	6.1	726	405	26	20	34
500	.5	9.4	1.9	1.95	18.2	5.0	6.5	779	435	28	22	38

Mature Cows

Last 3 months of gestation

400	.4	8.0	2.0	1.95	15.2	4.2	5.4	644	354	23	18	30
450	.4	8.6	1.9	1.90	16.2	4.5	5.7	720	405	26	20	34
500	.4	9.3	1.9	1.85	17.2	4.8	6.1	776	435	29	22	38
550	.4	9.8	1.8	1.85	18.2	5.0	6.5	832	470	31	24	42
600	.4	10.4	1.7	1.82	19.2	5.3	6.8	889	506	34	26	46
650	.4	11.0	1.7	1.85	20.2	5.6	7.2	944	537	36	28	50
700	.4	11.7	1.7	1.85	21.2	5.9	7.5	992	557	39	30	53
750	.4	12.2	1.6	1.85	22.2	6.1	7.9	1064	607	42	32	57
800	.4	12.7	1.6	1.85	23.2	6.4	8.2	1116	638	44	34	61

Body Wt. (kg)	Gain (or loss) (kg)	DM Intake (kg)	DM Intake % of live wt.	Diet Density (Mcal /kg)	Energy ME (Mcal)	Energy TDN (kg)	Energy FU (kg)	Protein Total[a] (g)	Protein Dig (g)	Minerals Ca (g)	Minerals P (g)	Vit. A (1000 IU)
Lactating Cows												
Producing 4 kg containing 7% fat[d]												
350	.0	8.4	2.4	2.00	16.8	4.6	6.0	865	537	27	21	19
400	.0	9.0	2.3	2.00	18.0	5.0	6.4	908	559	30	23	21
450	.0	9.6	2.1	2.00	19.1	5.3	6.8	950	580	31	24	23
500	.0	10.1	2.0	2.00	20.2	5.6	7.2	988	600	33	25	25
550	.0	10.7	1.9	2.00	21.3	5.9	7.6	1028	620	34	26	27
600	.0	11.2	1.9	2.00	22.4	6.2	7.9	1064	638	35	27	30
650	.0	11.7	1.8	2.00	23.4	6.5	8.3	1098	659	36	28	32
700	.0	12.2	1.7	2.00	24.4	6.7	8.7	1144	678	38	29	34
750	.0	12.6	1.7	2.00	25.3	7.0	9.0	1178	696	39	30	36
800	.0	13.2	1.6	2.00	26.4	7.3	9.4	1214	714	40	31	38
Adult Non-producing Buffalo												
Maintenance												
350	.0	6.3	1.8	1.65	10.1	2.8	3.6	423	205	14	11	15
400	.0	7.0	1.8	1.65	11.2	3.1	4.0	469	227	17	13	17
450	.0	7.6	1.7	1.65	12.2	3.4	4.3	512	248	18	14	19
500	.0	8.2	1.6	1.65	13.2	3.6	4.7	553	268	20	15	21
550	.0	8.9	1.6	1.65	14.2	3.9	5.0	597	288	21	16	23
600	.0	9.5	1.6	1.65	15.2	4.2	5.4	633	305	22	17	26
650	.0	10.3	1.6	1.65	16.1	4.4	5.7	683	327	23	18	28
700	.0	10.6	1.5	1.65	17.0	4.7	6.0	714	346	25	19	30
750	.0	11.0	1.5	1.65	17.9	4.9	6.3	752	364	26	20	32
800	.0	11.5	1.4	1.65	18.8	5.2	6.7	788	382	27	21	34
Working Buffaloes												
Moderate Wwrk (4 h/d)[e,f]												
200	.10	4.8	2.4	2.00	8.57	2.4	3.0	455	272	10	9	10
300	.10	6.5	2.2	2.00	11.89	3.3	4.2	577	335	13	11	13
400	.05	8.0	2.0	2.00	15.02	4.1	5.3	644	354	17	13	17
500	.0	9.3	1.9	1.90	18.02	5.0	6.4	617	295	20	15	21
600	.0	10.7	1.8	1.90	20.91	5.8	7.4	709	339	22	17	26
Heavy work (8 h/d)												
200	.10	4.8	2.4	2.20	10.49	2.9	3.7	486	299	10	9	10
300	.10	6.7	2.2	2.20	14.77	4.1	5.2	623	369	13	11	13
400	.05	9.0	2.2	2.10	18.86	5.2	6.7	715	389	17	13	17
500	.0	10.9	2.2	2.10	22.83	6.3	8.1	699	325	20	15	21
600	.0	12.7	2.1	2.10	26.67	7.4	9.5	815	373	22	17	26

[a] Total protein was calculated from digestible protein.

[b] Small animals will not make gains greater than about 1 to 1.25% of body weight unless diets containing large amounts of fat are provided, i.e. milk or milk replacements.

[c] Energy has been provided for the development of mammary glands, etc. in first calf heifers.

[d] Increase all nutrient requirements except vitamin A 20% during the first lactation and 10% during the second lactation to allow for growth.

[e] Energy has been calculated using a value of 2.40 Kcal ME/h of work/kg of body weight plus the ME requirement for maintenance and growth.

[f] A safety factor of 10% has been added to the DP requirement for growth and maintenance of working buffalo doing moderate work and 20% for heavy work.

Note: Adjustment for milk yield should be made. The nutrient requirements for milk must be added to the maintenance requirement to arrive at the total nutrient requirements for maintenance and production.

Source : Kearl, 1982

NA - 253 - 5

Chapter 5

Fibrous Feeds and their Utilization

A.N.F. Perera and M.N.M. Ibrahim

Introduction

Feed is material which after ingestion undergoes digestion, absorption and is finally utilized in the animal body. The feed that is ingested is present as polymers or large molecular forms (protein, starch, lipids etc.). These subsequently undergo mechanical, chemical (enzymatic) and microbial breakdown into primers or simple molecular forms (amino acids, glucose, fatty acids, glycerol etc.) in the gastro-intestinal tract for easy absorption and utilization at tissue level. Individual components that are important in the animal body (protein, lipids, carbohydrates and minerals) are called nutrients. All nutrients present in feed will not become available in the digestive system for absorption. Certain parts of the feed nutrients are excreted from the digestive system as faeces. The amount excreted depends on the rate and degree of breakdown of nutrients in the digestive system and its capacity to absorb these nutrients.

All animals essentially have to acquire feed either from plant or animal sources or from both. Animals that depend entirely on feed of plant origin are called herbivores, while those that depend solely on feed of animal origin are called carnivores. Some animals that obtain feed from both sources are called omnivores. Buffaloes, cattle, sheep and goat, elephant, horse and rabbit are herbivores. But buffalo, cattle, sheep and goats are further classified as ruminants because of their special adaptability (complex stomach) not only to consume but also to digest high fibre diets (roughages) through their modified digestive system and biology of digestion.

Water is not a nutrient but is an essential component both in plant and animal tissues. Experiments have revealed that an animal may survive more than 100 days without organic feed, but will die in 5-10 days if deprived of water. The water content of the animal body varies with age. In the newborn animal, the body water content is about 75 - 80%. However, this will decline gradually to about 50% in mature fat animals. In addition, the species and dietary conditions also influence the body water content.

Roughage is the major type of feed that is available to ruminants and 80 - 100% of their daily diet includes roughages. Roughages are coarse feedstuff with a nigh cellulolytic material. They could be further classified based on the moisture content into dry (10 - 20 % moisture) and succulents (60 - 90 % moisture) material. Dry roughages include hay, straws, stover, pod husks etc., and succulent roughages include pasture, fodder, silage and many other agricultural wastes. Concentrate feeds are highly digestible and palatable. They are often enriched by inclusion of ingredients high in energy or protein, many of which are by-products of agro-based industries. Such ingredients often have a high nutrient content and consequently are in high demand for human consumption or for other uses. For reasons associated with their low availability, they fetch a high price. Nevertheless there is a high demand these ingredients from the monogastric feed industry.

Roughages

Pasture and fodder grasses

Pasture and fodder grasses belong to the family Graminae. They make a substantial contribution to the production of ruminant livestock. Of the succulent roughages, pasture and fodder are the most convenient and economic feeds available for maintenance of large ruminant species. As in most developing countries, in Sri Lanka pasture and fodder that are found growing naturally on roadsides, waste lands, paddy and tank bunds or forest reserves are either grazed by ruminants or harvested as feed for ruminants. These include *Imperata cylindrica* (iluk), *Panicum repens* (atora), *Cryzopogum* species, *Elusina indica* (balathana), *Agrotis* species, *Echinocloa* species, *Frimbristylis* species (maruk), *Chloris babata*, etc. These grow in abundance during the rainy season and the annual dry matter yields vary from 1000 - 5000 kg per ha. Certain introduced species such *Panicum maximum* "ecotype A" (Guinea A), *Brachiaria brizantha* (signal grass) and *B. mutica* (para grass) are widely distributed and have become naturalized. They often grow in association with other natural grasses. These natural grasses are free-grazed and supply 80% of the pasture requirements of ruminants. In the dry zone of Sri Lanka more than 90% of the ruminant livestock are solely grazed on these natural grasses.

Establishment and maintenance of improved or introduced pasture and fodder require high inputs and improved management skills. Resource-poor smallholder dairy farmers in developing countries cannot meet these requirements. Therefore, these improved grasses are mainly confined to large state farms that can provide high management inputs. Common pasture species that are recommend include Brachiaria *species (B. ruziziensis, B. mutica and B. miliformis)*, Setaria species, Paspalum species, *Pennisetum clandestinum* (Kikuyu) and *Digitaria decumbens* (Pangola). Fodder grasses are more responsive to fertilizer application and soil moisture, therefore they require a higher level of management than pasture grasses. The common fodder species with great feeding potential are napier hybrids such as, Pusa giant napier, Bana, Clone-13, Co-3, Panicum species (Guinea A, Guinea B, Hamil) and *Tripsicum laxum* (Guatemala grass). Fodder grasses need to be cut and fed and therefore their use is confined to intensive feeding management systems where animals are stall fed.

Tender grasses are rich in soluble carbohydrates. These provide easily fermentable organic matter in the rumen yielding energy for use by rumen micro-organisms. This readily fermentable material is important in the utilization of the non-protein nitrogen for microbial protein synthesis. Quality of grass declines with the maturity, therefore, better growth and production responses can be obtained from grass harvested at the correct time.

Legumes and tree fodder

Pasture legumes play an important role in improving the quality of grasses when grown as a mixed sward. To obtain an associative effect of legumes to grasses, compatible combinations must be carefully chosen. However, many mixed swards failed to perform as expected due to inadequate knowledge of farmers to implement proper management practices to ensure the sustenance of both components in the mixture. Of the many criteria required to maintain a successful association, soil fertility and individual nutrient supplies to satisfy the requirements of both crops play a key role. When a mixed sward is heavily fertilized with potassium accompanied by insufficient supply of phosphorus necessary for legume growth, the grass component takes advantage over the legume component and smothers the legume.

Some common legumes found in Sri Lanka are, *Macroptelium atroperpureum* (Siratro), *Centrosema pubescence* (Centro), *Calapogonium muconoides* (Calapo), *Peuraria phasioloides* (Peuro), Stylosanthus species (Stylo), Desmodium species (green leaf and silver leaf), *Dolichos lablab*, *Glycine white* etc.

When legumes are included in the diet, they improve palatability and digestibility due to the high protein content. In tropical regions, when good quality grasses are provided with legumes in equal proportions, milk yields up to 5 liters can be easily obtained. Legumes are also rich in calcium, phosphorus and other mineral elements. They play an important role in ruminant feeding, when poor quality grasses or crop residues are fed. They act as protein supplements to bridge the protein deficiencies in the basal feed, so as to maintain optimum ammonia level in the rumen. Some legumes are also rich in "by-pass" or protected protein, which escape degradation to ammonia in the rumen. Therefore, these by-pass proteins can play an important role in high milk producers to satisfy their true protein requirements.

In addition to legumes associated with pasture, leaves from many shrubs and trees can also be used for feeding ruminant livestock. They are generally classified as 'tree fodder' and the crops are referred to as 'fodder trees'. Fodder trees are dicots and are classified according to their growth habits, family or uses. The two major classes are leguminous and non-leguminous fodder trees. The botanical names and the vernacular names of some important fodder trees are presented in Table 5.1.

Fodder trees are found growing naturally or cultivated in a orgainsed manner. When planted, they are established in a manner that will be suitable for the particular farming system. The most effective way of establishing these in small homesteads is in the form of live fences. However, in many agricultural systems, leguminous shrubs are planted for a specific purpose. In alley cropping, leguminous shrubs are planted in a single row system to provide sufficient green mulch. In sloping lands, leguminous shrubs are grown in double rows, utilising the 'Sloping Agricultural Land Technology' (SALT), for purposes of soil conservation and green mulching. Both alley cropping and SALT generate biomass in excess, and therefore the surplus can be used as valuable fodder. In tea, coffee and cocoa plantations, fodder type trees are grown for shade. In pepper and vanilla cultivation, they are used as supports for the vines. Branches removed during periodical lopping can be used as high quality fodder.

Tree fodder is rich in minerals and protein. Fodder trees provide sufficient biomass especially during the dry season when all other pasture legumes and grasses have completely ceased to grow. They are able to withstand drought conditions because of the deep and extensive root system. The high protein content in tree fodder makes these materials excellent supplements for feeding with low quality roughages.

Table 5.1 Botanical and vernacular names of some fodder trees and shrub species

Botanical Name	Common name	Type of growth	Source
Legumes:			
Leucaena leucocephala	Ipil Ipil	Tree/shrub	I
Calliandra calothysus	Calliandra	Shrub	I
Gliricidia sepium	Gliricidia	Shrub	L
Erythrina variegata	Dadap/Erabadu	Tree/shrub	L
Moringa olecifera	Drumstick/Murunga	Tree/shrub	L
Sesbania ***glandiflora***	Kathurumurunga	Tree/shrub	L
Sesbania sesben	Diyasiyabala	Shrub	I
Desmodium ransonii	Desmodium	Shrub	I
Flammgia macrophylla	Flamingia	Shrub	I
Desmenthus virgatus	Desmanthus	Shrub	I
Stylosanthus scabra	Stylo	Shrub	I
Adananthera pavonia	Mathatiya	Tree	L
Periserianthus fulcateria	Albizzia	Tree	L
Bauhinia recemosa	Maila	Tree	L
Tamarindus indica	Tamarind/Siyambala	Tree	L
Enterolobium saman	Raintree	Tree	L
Pithicelobium dulce	Andara	Tree/shrub	L
Accasia mangium	Accasia	Tree/shrub	I
Accasis auriculiformis	Accasia	Tree/shrub	I
Non leguminous:			
Tithonia diversifolia	Wild sunflower	Shrub	L
Morus alba	Mulberry	Shrub	L
Artocarpus heterophyllus	Jak	Tree	L
Azadirecta indica	Neem	Tree	L
Thespesia papulnae	Gansuriya	Tree	L
Mangifera indica	Mango	Tree	L
Ficus relegiosa	Bo	Tree	L
Ficus bengalensis	Banian tree	Tree	L
Artocarpus atilis	Breadfruit	Tree	L
Airtocarpus nobilis	Waldel	Tree	L
Pterocarpus indica	Wal-ehela	Tree	L
Hibiscus esculanta	Shoe flower	Shrub	L
Manihot esculanta	Cassava	Shrub	L
Musa *spp.*	Banana		L
Ceiba petendara	Kapok	Tree	L

I = recently introduced; L = indigenous or introduced and naturalized

The basal feed of all ruminants is roughage. The major source of roughage is grass and other green forages. However, the availability of natural green forage is seasonal since this depends on rainfall. The problem of forage availability is acute in the dry zone and even in the wet and intermediate zones during the inter-monsoonal dry periods. Overall, the total availability of green forages (grasses and other broad leaves) cannot meet the total year round requirements of the ruminant livestock population. Therefore, in order to sustain the present livestock population and maintain productivity, the evaluation and utilization of other fibrous feeds is essential.

Non-conventional fibrous feeds

Fibrous feeds are of many types and these are derived from many different sources. They can be subdivided into two main groups;

- Fibrous Crop Residues (FCR)
- Agro Industrial By-products (AIBP)

These are alternate feed resources that could be incorporated in common basal feeds (grass and leaves). As these are not considered to be traditional feeds, they are generally called " non-conventional feeds".

Characteristics of fibrous feed: The general characteristics of fibrous feeds are:

- the bulky nature (low bulk density)
- seasonal availability
- location specificity
- high crude fibre content (>18%)
- low crude protein content (<12%)
- high lignin content
- coarse and rough texture leading to low palatability
- low digestibility
- and in some cases, contain Anti-Nutritional Factors (ANF).

The FCR can be grouped into;

Cereal Straws	-	rice, millet
Stover	-	maize and sorghum
Pulse straws	-	green gram, black gram, cowpea, soybean, ground nut.
Other green matter	-	sugarcane tops, banana pseudo-stems, manioc leaves, sweet potato vines.

Some examples of AIBP are sugarcane bagasse, fruits and vegetable cannery waste, palm press fibre, waste/spent tea leaves and poultry litter. The nutritive value of some of the fibrous feeds mentioned above and limitations in their use as ruminant feeds are given in Table 5.2.

Pre-treatment of fibrous feeds

The majority of the agro-industrial residues, of which cereal straw and other crop residues form the bulk, are noted for their low biodegradability and poor voluntary intake by ruminants. In many instances, they are mainly used to satisfy the maintenance requirements of ruminants. However, their nutritive value can be improved by treatment (physical or chemical) or by supplementation. Hence, the objective of pretreatment is to increase the biodegradability and/or the quantity consumed voluntarily. The treatment processes involved range from simple grinding procedures to elaborate chemical pulping operations. Several pretreatment processes are technologically possible but not economically feasible. Animal nutritionists require cheap, safe and effective methods of treatments. Over the years, an enormous amount of research has been carried out on the utilisation and practical application of crop residues, with varying degrees of success. Therefore, it is appropriate to examine the different treatment procedures available and the methods of application.

Table 5.2 Nutritive value and limitations of non-conventional fibrous feeds.

Fibrous feeds	DM %	Crude protein %	Ether extract %	Crude fibre %	Digestibility %	Limitations of use
Rice straw	93	5	1-2	36	30	Low CP, oxalic acid
Pulse straw	89	15	2-3	36	57	High lignin
Cereal straws	85-92	5-9	2-4	36-48	47-62	Low CP, coarseness
Banana pseudo-stems	12-18	5-8	1-2	25	63	High water content, tannin
Manioc leaves	27	15-20	5-8	15-20	57-62	HCN content
Sweet potatoes vines	20	10-14	3-5	35-38	48-58	
Sugarcane tops	35-40	4-8	2-3	30-38	38-48	High silica and low palatability
Bagasse	88-92	2-4	1-2	45-49	25-34	High lignin, low palatability
Spent tea leaves	87	14-17	4-6	22-26	-	High tannin
Poultry litter	90	20-24	1-2	20-40	25-32	High silica, dusty
Palm press fibre	90-94	3-5	1-2	40-60	27-32	High lignin, low digestibility
Cannery waste	10-18	5-8	1-3	18-24	54-62	High perishability, low storage quality

Pretreatment can be classified into physical, chemical, physico-chemical and biological methods

Physical treatment

Grinding and pelleting increases voluntary feed intake, but frequently depresses digestibility. The fact that the digestibility is not improved by normal grinding methods suggests that grinding does not have a significant effect on ligno-cellulose complexes. Increased *in vitro* digestibility and physical separation of cell wall components is possible by extreme reduction in the particle size, for example by grinding with a ball mill. But *in vivo*, the increase in the rate of passage due to low particle size and a higher feed intake may result in a loss of organic matter.

Since 1970, a number of reports have appeared in the literature describing the affect of steam treatment under pressure on fibrous residues. Under laboratory conditions, such treatment has often proved to be very successfull. Although large increases in both *in vitro* and *in vivo* digestibility were observed when sugar cane bagasse was steam processed, poor sheep performances were recorded, when treated bagasse constituted 40 per cent of the ration. Chemical studies indicate that there is extensive degradation of cellulose and hemicellulose accompanied by the production of undesirable polyphenol-like compounds when bagasse was processed. With straw and bagasse, the improvement achieved by steam processing is generally either equal to or less than the effect produced by treatment with sodium hydroxide. Steam treatment of low quality roughages has no application under small-scale farming conditions due to the nature and cost of equipment and the fuel requirements for such treatment.

Chemical treatment

Since 1900, a number of chemicals have been tested for their ability to increase the digestibility of roughages. But most of the studies have been carried with the use of sodium hydroxide (NaOH) because of its effectiveness, ease of application and short reaction time. The other chemicals that have been examined to a lesser extent include ammonia (anhydrous, aqueous, urea-ammonia), calcium hydroxide, sodium chlorite, chlorine gas and sulphur dioxide. These chemicals can be grouped into alkalis and oxidants and they produce their effects in different ways. The objective of chemical treatment is to increase the digestibility by increasing lignin solubility or by weakening the bonds between lignin or phenolic groups and other cell wall constituents, mainly hemicellulose. Hemicelluloses are highly susceptible to extreme pH conditions (below 4 or above 8), increasing their solubility.

Alkali saponifies uronic acid and acetic acid esters, neutralizes free uronic acid groups and thereby weakens the bonds. This increases the swelling capacity of cellulose and also enables greater penetration of microbial enzymes. The action of oxidants (sulphur dioxide, chlorine gas or chlorinated compounds) on lignin leads to sulphonation of lignin or to the formation of chloro-lignins. To prevent depolymerisation of the oxidative end-products of lignin and also to remove the residual chemical used, neutralization with a weak alkali is beneficial. Alkali treatment of crop residues has been extensively reviewed by a number of workers (Ibrahim, 1981).

Ammonia treatment of fibrous feeds

In the last 2 decades, considerably interest has been shown on the use of anhydrous ammonia (NH_3 gas), aqueous ammonia (NH_4OH) and ammonia released during urea degradation, in the treatment of fibrous feeds. Anhydrous ammonia and urea-ammonia can only act as an alkali when dissolved in water through formation of ammonium hydroxide. Gas-tight conditions are necessary for ammonia treatment. Almost identical procedures for treating straw with ammonia gas have been developed independently in Norway (1978) and Canada (1977).

A number of digestibility studies have been carried out to compare untreated straw with ammonia-treated straw and a few comparisons have been made with NaOH-treated straw. Generally, the increases in digestibility obtained through ammonia treatment range from 5 to 17 units. As two-thirds of the ammonia applied remains unutilised, the material needs to be aerated before feeding to improve palatability and voluntary feed consumption.

The advantages of ammonia are that it leaves no residual alkali and it increases the nitrogen content of the treated material. As urea is readily available in developing countries, the recent trend has been to use the ammonia released by urea degradation. Straw is usually highly colonized with microflora spores (bacteria, actinomycetes and fungi) and with storage, the number of bacteria increases. Under adequate moisture and suitable temperature conditions, some microbes that produce urease are capable of degrading urea to ammonia that then permeates through the straw. Basically, urea treatment involves ensiling straw with 4-5 per cent urea solution (w/v) for a period of 4-6 weeks.

Physico-chemical treatment

Chopping, milling or grinding of fibrous material could influence the effectiveness of a chemical by increasing the surface area. Research in Germany has shown that pelleting straw mixed with 2 per cent urea could increase both OMD and organic matter intake (g/kg W 0.75). Milk yields from cows fed straw treated with 2 per cent urea and 2 per cent ammonium carbonate was equal to those fed traditional diets of hay and roots. In grass straw, wood species and rice straw, additive effects were reported when both steam pressure and alkali were used in combination.

Important aspects to remember in feeding of urea treated straw

- Adequate quantities of straw should be collected and properly stored for drought feeding
- Straw should be treated only to meet one days' requirement
- Left over feed should not be retained and fed on the following day
- Treated straw should not be fed immediately after opening polythene covering. Animals may refuse to eat
- It is necessary to provide a readily available source of energy. The amount offered should be at least 10% of the total basal ration (100g per kg of dry straw). For cows producing more than 2-3 l/d, a supplementary feed must be given at the rate of 1kg of concentrate for every 2 litres of milk produced.

Biological treatment

Limited research has been directed towards the use of bacteria, fungi or enzymes in upgrading the nutritive value of fibrous residues. Much of the published work has been done on the possible use of wastes for the production of single-cell proteins to be used as foodstuffs for non-ruminants.

Fungi of the white rot type are known to metabolize lignin, cellulose and other fibrous components in wood species. It may be possible, by screening and careful selection, to isolate white rot fungi species, which selectively degrade lignin. At the same time, care would need to be taken to ensure that toxins are not produced. There may be a need to investigate factors such as temperature, pH, aeration, moisture content, nutrient additives and duration of incubation. Fungi (basidiomycetes) convert ligno-cellulose directly into fungal protein (mushroom) and some are suitable as human and animal food. Certain mushrooms are poisonous, but the edible ones are domestically cultivated on straw and sawdust. Paddy straw mushroom is commonly grown on rice straw and is cultivated by individual families in the grain-growing regions of the tropical world. The possibilities of utilizing the mycelia-rich residues, after mushroom harvesting, as an animal feed need to be investigated.

Urea treatment of crop residues

The treatment procedure is easy to carry out. Chopped straw or stover is spread over a cemented floor on a polythene sheet and sprinkled with 4% urea solution using a watering can or a tin with a perforated bottom. The 4% urea solution is prepared by dissolving 40g of urea in 1 litre of water. The ratio of straw to water should be 1:1. After treatment, the treated straw should be well covered with a polythene sheet to prevent the escape of ammonia. The treated straw is ready for feeding after 7 days of storage. Therefore, once the treatment of straw is started, one day's requirement of straw must be treated on each subsequent day to ensure that a continuous supply treated straw is available thereafter. After 7 days of storage, the treated straw should be allowed to remain in the open for 0.5 - 1 hr prior to feeding, to facilitate the liberation of excess free ammonia.

Supplementation

Supplementation is necessary to bridge the nutrient deficiencies in the basal feed, when compared with the nutrient requirements of the animal. For the purpose of supplementation, urea, concentrates and tree fodder are generally used. Supplementation is a convenient and efficient method that an ordinary farmer is able to practise.

Supplementation increases:

- the digestibility of the basal feed because of a better nutrient balance in the rumen
- the intake resulting from a higher rate of passage influenced by high digestibility

Supplements do not change the micro-structure of the fibrous feed, but only facilitate utilization. The type of supplement to be used will depend on the nutrient that is deficient in the basal feed. The most common types of supplements used are urea, urea - molasses - mineral blocks (UMMB), concentrates and tree fodder.

Concentrate feeds

The feeding of concentrates is the most common and traditional method of supplementation. Concentrates formulated by feed manufacturers are readily available in the market. Farmers also prepare concentrate mixtures on-farm, using commonly available ingredients such as coconut poonac and rice bran. As a general rule, 1kg of concentrate is given for maintenance and thereafter 0.5kg is allowed for every additional litre of milk produced. But if quality green feed is available to satisfy the roughage requirements, the nutrient requirements for maintenance and production of up to 2-3 litres of milk per day can be met without additional feeding of concentrates. Thus, every attempt should be made to minimize feeding of concentrates wherever possible, so as to reduce the cost of production.

Tree fodder

This is the most economical and sustainable system of supplementation. Tree fodder may contain certain limiting factors. Therefore, they should not be used as the sole feed. When proper use is made of tree fodder as feed supplements, they could contribute to a great extent to improve the quality of the feed offered to the animal. Generally tree fodder can be included up to about 30-40% in the diet. In ccrtain situations, 2-3 litres of milk per day can be obtained by feeding a combination of grass and tree fodder alone without recourse to supplementary concentrate feeding.

Urea

Urea is generally used to treat fibrous feeds. Urea supplementation has proved to be effective, but the level of urea must not exceed more than 1-1.5% on dry matter basis. For each kg of straw, a urea solution containing 10 - 15 g of urea per litre must be added to straw at a ratio of 1: 0.75. The method of application of the 1-1.5% solution of urea to straw is similar to that used for urea treatment, the difference being that the straw can be fed 2-3 hours after spraying. As with feeding of urea treated straw, a source of readily available carbohydrate must be given in the feed, and the introduction of urea supplemented straw to animals must be done gradually.

Important: In circumstances where excess urea is fed, signs of ammonia toxicity will be evident, such as purple or blue coloration of the mucosal membranes of the mouth, muzzle and eyes. In such situations, veterinary assistance should be sought immediately and in the meantime 1-1.5 litres of vinegar should be administered as a drench.

Urea-Molasses-Mineral Block (UMMB)

The use of UMMB in the diet provides the complete supplementation of nitrogen, energy and minerals. This is practised in many countries and its use is now becoming popular in Sri Lanka.

Collection and storage of rice straw

Rice straw is a seasonal product in Sri Lanka and it is produced twice a year in certain areas and sometimes only once. Straw must be dried, collected and stored as soon as possible after the rice is threshed. Collected straw must not be allowed to get wet. Well-dried straw that is properly stored can be kept for nearly 2 years without loss of its original nutritive value and acceptance by the animal. Wet straw can become mouldy and becomes unsuitable for livestock feeding. Mouldy straw is unacceptable to ruminants and if consumed, may lead to certain metabolic disorders or toxicity due to the presence of mycotoxin.

Well-dried straw can be made into square bales or loosely stacked in a hay barn or a similar building. Straw must be protected from rain and stored in an appropriate manner that will allow adequate ventilation. Stacking straw on a rock surface or on wooden platform will provide the necessary protection. When stored out in the open, precautions must be taken to prevent damage by termites.

Conclusions

Of the physical treatments, gamma irradiation and steam processing seem to be promising on a variety of crop residues, but they are only of academic importance for economic reasons. Although strong alkali such (sodium hydroxide) improves the nutritive value of a range of crop residues, its use is hindered both in developed and developing world due to the high cost of the chemical and health hazards associated with its corrosive nature. In the seventies and early eighties, urea-ammonia treatment was claimed to be an appropriate method to enhance the nutritive value of crop residues. Even though a considerable amount of research and extension efforts have made towards the propagation of the use of urea treatment among farmers in the Asian region, the overall adoption rate has been marginal.

Suggested reading

Doyle, P.T., Devendra, C. and Pearce, G.R. (1986) *Rice straw as a feed for ruminants.* IDP, Canberra, Australia.

Ibrahim, M.N.M. and Schiere, J.B. (1986) Rice Straw and related feeds in ruminant rations. In: *Proceedings of an International Seminar. Straw Utilization Project Publication No. 2.*, Department of Tropical Animal Production, Wageningen Agricultural University, The Netherlands.

Ibrahim, M.N.M. (1983) Physical, chemical, physico-chemical and biological treatment of crop residues. In: *The utilization of fibrous agricultural residues* (Ed. G.R. Pearce). Australian Development Assistance Bureau, Australian Government Publishing Service, Canberra, Australia. pp. 53-68.

Kiran Singh and Schiere, J.B. (1993) Feeding of ruminants on fibrous crop residues. In: *Proceedings of an International Workshop.* Indian Council of Agricultural Research, New Delhi, India.

Schiere, J.B. and Ibrahim, M.N.M. (1989) *Feeding of urea-ammonia treated rice straw.* Pudoc Publishing Co., Wageningen, The Netherlands.

Sundstol, F. and Owen, E. (1987) *Straw and other fibrous by-products as feed.* Elsevier, Amsterdam, The Netherlands.

Chapter 6

Feeding Systems and Ration Formulation

M.N.M. Ibrahim and J.A. de S. Siriwardene

Introduction

Forage constitutes the cheapest form of feed for ruminants. The traditional feeding systems practised in Sri Lanka are based on the forage resource base within each of the production systems, which in turn is largely influenced by climatic and environmental variations during the different seasons of the year. The major traditional feeding systems fall into five broad groups (Fig. 6.1) and combination of these systems. Year round feed availability is affected by factors such as the rainfall pattern, cropping systems and intensity of production.

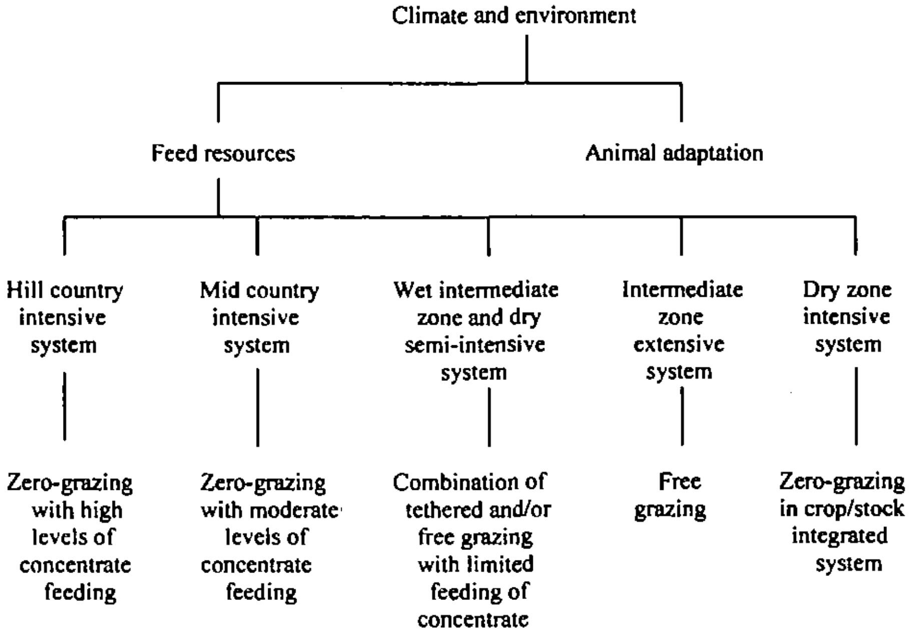


Fig. 6.1 Major feeding management systems

Feed availability, which is dependent on the level of precipitation, is a function of the balance between the rate of evaporation, the rate of precipitation and the length of the dry period. Under extensive management systems, ruminants obtain most of their nutrients from grazing or browsing. During the wet season, when abundant green forage feed is available, animals obtain adequate good quality pasture through selective grazing. However, during the dry periods, the availability and quality of forage declines, limiting intake and selectivity during grazing. Spells of dry weather that occur between periods of rain are experienced in almost all parts of the country, leading to a decline in the quantity and quality of forage. This is evident even in the hill country during January and February when dry weather combined with frost, depletes forage availability in open fields.

Therefore it is important to recognize the need to develop feeding systems for each agro-climatic zone, based on the feed resource base, the quality and year round availability of the feed resources. Under tropical conditions, plant growth slows down and often ceases during harsh dry conditions. During dry periods, pasture and fodder mature rapidly with the consequent decline in quality. Problems associated with the capability of the farmer to provide adequate feed of good quality are generally encountered under these conditions.

Farmers in Sri Lanka are basically crop farmers. It has been estimated that only 30 % of crop farmers rear any type of livestock. The difficulties associated with finding time and labour particularly during the cultivation and harvesting seasons, prevent farmers from giving adequate time to dairy activities in mixed farming systems. This is one of the reasons for the reluctance of dairy farmers to practice forage conservation as a means of overcoming feed shortages during dry periods, a procedure that is widely practised in countries such as India and Pakistan. Sri Lankan scientists have so far not been able to come up with practical and appropriate procedures to help livestock farmers to overcome the recurring problem

Table 6.1 Extent of land under pasture and the estimated yield of pasture

Categories of pasture land	**Extent of land categories (in ha) in relation to the estimated annual pasture production potential (kg/ha/yr)**				**Total DM production (MT/yr)**
	1MT (DM/yr)	**2MT (DM/yr)**	**4MT (DM/yr)**	**7MT (DM/yr)**	
Unirrigated highlands in dry zone	325,000				325,000
Villus in dry zone			50,000		200,000
30% of land area under coconut			140,000		560,000
5% of hill country tea estate land				4,500	31,500
Patana land in hill country	55,000				55,000
Herbage from paddy lands (grazed for 2 m between seasons)	120,000				120,000
Roadsides etc.		5,000			10,000
Grazing land in Wet zone		20,000			40,000
Fallow paddy land		150,000			300,000
Total extent of land (ha)	500,000	175,000	190,000	4,500	869,500
Total pasture production (MT/yr)					1,641,500
Plus the DM yield from improved pasture – 13,000 ha x 10MT/yr					130,000
Total pasture production (MT of DM/yr)					1,716500

Source: Siriwardene (2000)

of feed scarcity during the dry seasons of the year. It would appear that the most compelling task facing planners, researchers and extension workers associated with cattle and buffalo production is to do with development procedures for harnessing and efficient utilisation of the available feed resources.

The forage resources can be broadly grouped into (1) pasture and fodder crops (2) fibrous crop residues and (3) non-conventional feed resources.

Pasture and fodder resources

Ruminant production whether under the traditional extensive and semi-intensive management systems or intensive systems depends to a large extent on forage as the major feed resource. This is true in greater measure in developing countries in the South Asian region. It has been estimated that the total extent of land under forage in Sri Lanka is 869,500 ha and that the total pasture and fodder availability in terms of dry matter is 1,716,500 MT per annum (Table 6.1). The forage that is available in more than 95 percent of this land area is naturalised Guinea grass and indigenous grass varieties, while no more than 5 percent of the balance extent of land is cultivated with improved pasture and forage species (Siriwardene, 2000).

Table 6.2 Availability of fibrous crop residues

Crop residues	Extent of land cultivated (ha)[1]	Total yield of primary crop (MT/yr)	Grain/crop to residue ratio	DM yield of crop residues (MT/yr)
Rice straw	863,439	2,810,000	1:1	2,810,000
Maize stover	35,938	34,800	1:2[2]	71,876
Kurakkan straw	6,339	4,900	1:3[2]	14,700
Meneri straw	340	200	1:3[2]	600
Sorghum stover	241	220	1:3[2]	660
Green gram	18,097	16,100	1:1	16,100
Cowpea residue	18,105	16,100	1:1	16,100
Dhal	30	-	1.1	30
Gingelly	8,560	4,500	1:1	4,500
Ground nut	9,896	-	1:5[2]	7,710
Manioc leaves	32,824	288,700	2:1	144,350
Sweet potato vines	9,125	61,800	2:1	30,900
Sugarcane tops	-	685,000	5:1[3]	137,000
Total				3,254,526

Sources: 1. Statistical Abstracts (1996)
2. Joshi, A.L. *et al.*(1988)
3. Preston, T.R. (1995)

Fibrous crop residues

The estimated of the annual availability of fibrous crop residues is over 3.2 million metric tonnes of dry matter (Table 6.2). These estimates have been calculated by conversion of the annual crop production data utilising grain (or crop) to residue ratios applicable to each of the crops listed.

Non-conventional feed resources

While a variety of non-conventional feed resources are available, the availability of these resources is subject to variation from year to year. At the same time, estimates of the availability of the potential resources are incomplete. An estimate of non-conventional feed resources estimated in 1984 places the figure at 225,341 MT (Table 6.3).

Table 6.3 Availability of non-conventional feed resources

Ingredients	**Potential availability (MT/yr)**
Rubber seed cake	36,000
Tea refuse	5,000
Spent brewers grain	9,000
Pineapple waste	3,720
Mango seed meal	37,825
Tamarind seed meal	30,000
Molasses	48,000
Husk from pulses	7,500
Cocoa pod husk	150
Total	225,341

Source: Ranjhan and Chadhokar (1984)

Concentrate feeds

The two main ingredients that are used in ruminant feeds are coconut poonac and rice bran. Other ingredients that are often incorporated into commercial feeds to a lesser extent are broken rice, maize, bran from pulses, molasses and minerals. The production of paddy is estimated to be 2.8 million MT per year. At an extraction rate of rice bran at 4%, the potential availability of rice bran is estimated to be 112,000 MT per year. The availability of coconut poonac varies between 10,000 to 20,000 MT per year. The potential availability of these two ingredients together could therefore be around 122,000 MT per year.

The challenge for the future is to develop technologies that will make it possible to use the resources available in a form that can be utilised for direct feeding or for incorporation in commercial production of feed mixtures.

Formulation of animal rations involves the selection and combination of a number of feedstuffs in a manner that will meet the animal requirements at the lowest possible cost. The manufacture and use of balanced feeds has steadily increased in recent times with increased domestication, intensification of livestock management practices and the realisation of the importance of nutrition in ruminant production. Ration formulation as a daily farming practice requires a knowledge of the availability, price and composition of feeds. It also requires an insight into the nutrient requirements of animals, based on the objectives for which they are maintained. Ration formulation may not always provide a least cost ration, as will be explained in this chapter. Different approaches are often used by extensionists and farmers to formulate rations, though their conclusions may be similar.

Principles of ration formulation

Ration formulation involves the selection and allocation of feed ingredients in such a way that the cost of the ration is kept low while ensuring that adequate nutrients are supplied to the animal for its maintenance and desired production level. Traditionally, farmers have used some methods of least cost ration formulation (LCRF), which have been based on farmers' experiences. Income maximisation is not always attained by LCRF, since the cheapest ration for an individual animal may lead to a sub-optimal allocation of all available feeds to the herd as a whole. The optimal ration may be found through 'trial and error', but a farmer or extensionist may want to calculate this based on sound principles. A graph or the use of a few equations will provide a number of combinations of ingredients, which will help them to get close to the optimum, but if a computer is available, a simple linear program is most appropriate to find the answer.

When the number of available ingredients is large, linear programming (LP) on a computer is the only way to perform the required calculations. Ration formulation then becomes purely a mathematical process of minimising the feed cost of a ration, without affecting its feeding value. An increase in feed prices and commercialisation of dairy farm activities prompts farmers or feed companies to use LCRF for this purpose. The required information to apply LCRF consists of:

- the type and quantity of feed resources available in an area: agricultural and industrial (by) products
- the concentration of energy (ME/TDN), protein (CP) and other nutrients in each feed resource
- the availability of nutrients in the feedstuff
- the price of each feed resource
- the nutrient requirements for maintenance, production, reproduction and growth functions of the animal
- the maximum intake level of the animal, and
- the desirable production level

The usefulness and desired level of accuracy of feeding standards depend on the context and purpose of their application. Farmers develop standards based on their experience of feed allocation in relation to factors such as palatability, dry matter intake, fat content, production of milk and animal health, while scientists conduct experimental trials under controlled conditions for this purpose. It is desirable that the experience, knowledge and skills developed by farmers and the standards developed by scientists are complementary rather than mutually exclusive. Scientists often fail to understand farmers' values and priorities in low input farming systems.

Relevance of ration formulation in different farming systems

A large variety of farming systems exists in South and South East Asia, due to differences in climate, geography and soil. Differences also exist in family size, off-farm income and market prices. One of the important factors known to determine the relevance of LCRF in a particular system is the degree of external input use.

Low external input farming systems

The basis of most Sri Lankan/Indian farming units is the smallholder enterprise that holds one or a few animals, raised on crop residues and crop by-products with the use of underemployed family labour, which often is a female work force. Although financial returns from the animals are low, the systems are still cost-effective. In India, over 60% of the milk output in the Operation Flood areas come from smallholder farms.

Feed is the major constraint in these farming systems. Generally, feed availability is low and the situation further becomes critical due to regional and seasonal variations in climate and feed quality. Thus, in a low external input farming system, production is achieved mainly through grazing, feeding of cut grass and straw, supplemented with an almost insignificant quantity of concentrate feed.

In a low-input farming system, during periods of feed scarcity animals are allowed to adjust to the prevailing circumstances resulting in a decline in their daily weight gain or even a loss of body weight. The use of purchased feed in such systems is not financially attractive.

High external input farming systems

Farmers in high external input farming systems purchase relatively large quantities of feed from the market. Generally, feed inputs are adjusted to cater to the desired production level. In a high input farming system, sufficient feeds are purchased to maintain the production levels of high yielding crossbred animals. These farming systems generally have good access to markets and therefore receive remunerative prices for their products. Urban dairies in particular, which are specialised dairy farms located near large towns or cities, have excellent market facilities. Milk production on these farms is based entirely on purchased feed inputs.

Feeding values and ration formulation methods

A few methods for obtaining relevant information on optimal rations are now described. Each of them can be adapted for use under local conditions, such as the available resources, weather conditions, individual farming practices, cropping patterns, feeding practices and personal preferences.

Farmers' perceptions about feed value and ration formulation

Farmers have their own perceptions of the nutritive value of feeds, and they allot feeds to the animals strictly according to these. Their practices are often based on traditional experiences which may be quite appropriate. Some farmers in India believe that mustard oil cake (MO cake) is a "hot feed" and must not be fed to lactating cows. Others think that it can be fed during winter months only, and still others that it can be fed in all seasons. A Bengali farmer even mentioned once on grounds: "why should I waste MO cake by feeding it to my animals when I can also use it to fertilise my horticultural crops?". Actually, these farmers use approximately 60-80 kg/ha.

Traditional farmers' notions vary from place to place. In some districts of West-Bengal, most farmers feed mustard oil cake round the year if it is available. In many areas, mustard cake is fed along with another oil cake to 'neutralise' the so-called hot effect of mustard cake. Oil cake as such is considered as a cold feed. Some farmers in villages think that boiled rice-grid should not be fed to cows during the first week of lactation, as this could disturb the initiation of lactation. Many farmers think that feeding of bamboo leaves may help in bringing anoestrus cows into heat.

In general, women manage the livestock enterprise in rural India and some parts of Sri Lanka. They receive occasional help from their male counterparts who are mostly engaged in other agricultural activities and who dedicate less time to the livestock enterprise. It is mostly the women that feed the livestock and know in their own way what to feed, when to feed, how to feed and how much to feed. They try to get the best possible output within the framework of resource constraints at their farms.

Farmers have their own perceptions, partly inherited from local traditions, about the quality of feeds. They try to balance animal rations in such a way as to keep the total costs at a minimum. With local cattle, farmers usually are able to approach the minimum cost with the available resources, since the animal requirements in terms of quantity and quality are relatively low. With crossbred cows, in most situations higher quality feeds have to be purchased. Although in those cases the total costs of the ration will increase, most farmers are able to realise low costs.

The above may be true in some parts of India, but in other countries and in particular in Sri Lanka, the farmers do not seem to appreciate that to obtain more milk they must give more and better feed. Many farmers do not have a clue about actual requirements even in broad terms.

Use of locally available extension material

Extension material or leaflets relating to feeding values of local feeds, ration formulation methods and quantities to be fed to different species and classes of animals are often written in simple language and in an easily understandable form. These are supplied to farmers by the State Extension Departments, Universities and Non-Governmental Organisations. This extension information may not be very specific, but generally caters to the needs of growing, lactating and dry animals. The recommended rations are standards that often need to be modified according to personal insights and the farming system, particularly in relation to seasonal patterns of feed availability. The advantage of such extension material is that it is written in simple form in the local language, with the use of understandable terminology and often devoid of complicated technical terms.

The presentation of recommendations in percentages or fractions is a risky method. For example, if an animal consumes high quality feed, and the required amount of calcium (or other nutrient) is expressed as a percentage, e.g. 0.5%, then this percentage has to be doubled if a low quality feed such as straw is consumed. This is due to the limited intake of the straw. For example, a farmer may be advised to feed a concentrate mixture as part of a straw-based ration to his or her dairy animal(s). This type of recommendation will only be reliable if the available feeds are classified in terms of their composition and dry matter percentage, and if the advise given is for a complete feed rather than for individual ingredients. The farmer does not have to know technical terms, nor how to perform a number of calculations to define the ration. An example of such a recommendation is shown in Table 6.4.

Table 6.4 Recommended diets and daily ration (kg) for two groups of dairy animals

Ingredient	Animal types	
	Zebu cows	Buffaloes Pure bred Indian cattle Crossbred cows
Straw	4 kg	4 –6 kg
Concentrate for maintenance	1 – 1.5 kg	2 kg
Concentrate for milk production	1 kg/ 2L of milk	1 kg/ 2L of milk
for gestation (in addition)	1.25-1.75 kg	1.25-1.75 kg

When green fodder is available, the amount of concentrate mixture may be reduced at the rate of 1 kg concentrate for every 8-10 kg fresh green fodder. This type of information extended through leaflets to farmers may be useful for use under village conditions, but requires clear language, careful interpretation and frequent revision under changing feed resource conditions.

Buffalo production can be increased through application of improved management skills and by meeting the nutritional requirements of the animals with locally available feed resources. The majority of buffaloes are raised in small village farms at a subsistence level of management, where feed availability is dependent on cropping systems. Seasonal climatic patterns greatly influence the availability of feeds and that in turn affects the performance of the animals.

Water, energy, protein and minerals must be provided in adequate and balanced amounts if optimum results are to be achieved in terms of maintenance, growth, production and reproduction. Variations in nutrient requirements are to be expected between individual animals of the same weight and breed, even while performing the same function. Nutrient requirement information should be used as a guide in establishing a feeding regime and not as absolutes. They do not replace the expertise of the farmer in matching the nutrient intakes to the performance of their animals. Nutrient requirements can be used as a starting point when formulating a diet and to estimate the feed requirements for any period of time. The first requirement for balancing a diet is to establish guidelines as to how much of each of the various dietary nutrients is needed, to supply nourishment to an animal in amounts that will meet its requirements for maintenance, growth, production and reproduction.

Nutritive value of feedstuff

The biological value of feedstuff

The biological value is determined in terms of the dry matter content, protein content, energy content, digestibility, amount and kind of minerals and amount and kind of vitamins.

Intake of dry matter

The amount of nutrition that an animal receives depends on two factors: (a) the amount of nutrients in the feed and (b) the quantity of feed the animal consumes.

While it is relatively easy to measure the quality of the feed, it is more difficult to assess how much an animal will eat, particularly if the animal is roaming at will and is grazing or browsing. One of the most important skills in animal husbandry is to persuade livestock to meet their nutritional needs by eating more of cheap, low quality feeds rather than expensive ones. To do this one must have an idea of the consumption of different types of feed, even though it may be impossible to know exactly how much an animal eats. Animals have two sets of competing feelings about feed; (a) the desire to start eating (appetite) and (b) the decision that enough has been eaten (satiety).

In general, how much a cow will eat depends on its body weight, the milk yield and on the type and quality of the feed. Consumption of concentrate will lower the consumption of roughage, if the roughage is of high quality. If the quality of the roughage is average or low, provision of concentrates may slightly increase the intake of the roughage. To prevent disorders in rumen function, it is advisable to provide roughage, at least to a level of one third of the total dry matter in the daily ration.

Protein requirements

The protein requirements of cows and the protein content of feedstuffs are expressed in g crude protein (g CP) or in g digestible crude protein (g DCP). Protein requirements of cows can only be met by the nitrogenous compounds in the feed (true protein and non-protein nitrogen). A shortage of proteinous compounds in the feed cannot be compensated by carbohydrates (CHOs) or other substances and will therefore result in low production

Energy

Energy is supplied by the organic matter in the ration; carbohydrates, protein and fats. The cow only uses protein to supply energy when the level carbohydrate and fat in the ration is inadequate to meet the daily requirement or when protein is fed in excess of the requirement. Protein for energy should be avoided because protein is usually expensive. The amount of energy that a cow needs and the amount of energy a feedstuff supplies can be expressed in several ways. For simplicity, the oldest and the most common system, namely the Total Digestible Nutrient (TDN) system is used here. In the TDN system, 1 kg of CHO is assumed to liberate 4000 kcal, while the same applies to 1 kg of digestible crude protein. As fat is rich in energy, 1 kg of digestible crude fat liberates 9000 kcal.

Nutrient content in feeds

The nutritive value of a feed is usually assessed by the amounts of nutrients it contains. Feeds can be generally classified as roughages and concentrates. Roughages include grasses (natural and improved), creepers (climbers), legumes (e.g. siratro, centrosema), leguminous tree fodder (e.g. glyricidia and ipil ipil) and non-leguminous (e.g. jak and mango) trees and shrubs and agricultural (straws, stover) and agro-industrial byproducts (soya hulls, bagasse). Concentrates include coconut poonac, rice bran/polish and cereal grains etc. Rather elaborate information on the nutritive value of locally available feedstuff have been published (Ibrahim, 1988a and 1988b). The nutritional values of some selected feeds are given in Table 6.5.

Supplementation

The fibrous portion of the diet is more slowly digested and provides bulk to the feed eaten by animals. The poor digestibility of fibrous feeds is reflected by low intakes. Digestion could however be accelerated by ensuring that the rumen microbes are given the nutrients that are deficient, such as good sources of energy and nitrogen to correct any imbalances. The vigour with which microbes break down feed entering the rumen, depends upon the rate at which they grow and reproduce. In order to grow rapidly they must have sufficient energy and nitrogen (protein) to meet their requirements. Situations can arise where the rate of energy and nitrogen release from a poor quality fibrous feed is insufficient to meet the needs of the microbes. Adding a small quantity of material that is readily broken down may stimulate the microbes not only to actively break down the new material entering the rumen, but also to attack the low quality material with renewed vigour. The two critical nutrients which microbes need, so as to perform their functions efficiently are energy and protein. Addition of a relatively small quantity of supplement(s) containing these nutrients to roughage-based diets can lead to appreciable increases in intake. Materials that are good sources of 'instant energy' are grains such as maize and sorghum, or molasses. Leguminous tree leaves (glyricidia, ipil ipil), protein supplements (fish meal, soya bean meal) and non-protein-nitrogen sources, such as urea are good sources of nitrogen. In addition to the above two nutrients, supplementation with minerals is also important.

Table 6.5 Nutritive values of selected feeds (g/kg fresh weight)

Feedstuff			DM	TDN	DCP
Grasses	Guinea	Before flowering	210	116	19
		After flowering	301	105	09
	Napier grass		156	81	20
	Signal grass	Before flowering	195	113	18
		After flowering	228	114	11
	Natural grass	From roadside	250	100	25
		From paddy field	180	88	18
Legumes	Gliricidia		226	142	50
	Ipil ipil		227	154	50
	Erythrina		237	119	64
	Wild sunflower		153	81	30
	Albizia		353	124	56
Tree leaves and shrubs	Jak leaves		314	151	28
	Girapala		250	165	31
	Madu-wal		300	146	25
Straw	Rice straw		900	300	0
	Urea treated rice straw		520	260	39
	Rice stubble		850	315	0
	Groundnut straw		900	531	54
	Maize stover		903	447	29
Concentrates	Coconut poonac		923	683	148
	Coconut residue		952	609	29
	Rice bran		902	343	72
	Rice polish		894	733	72
	Dairy feed mixture		940	620	124
	UMMB		900	764	46

Source: Ibrahim, M.N.M. (1988b)

The farmer and the nutritionist have almost no control (in extensive management systems) over what or how much the individual animal eats. In the process of matching animal production to resources of land and herbage, the farmer has a number of simple choices; (a) he could adjust the number of animals in the farm, so as to obtain production, making maximum use of the natural vegetation available, (b) he could alter the vegetation that covers the land in such a way that it provides more and better feed to his animals and (c) he could bring in feed from other sources, so as to maintain the number of animals he desires to keep, without changing the nature of the land or his herbage resource base. The above choices are not exclusive, as many farmers may adopt a combination of these options.

Meeting the needs for nutrients

The aim of using feeding standards is to optimise nutrition, but generally it does not consider social and economic factors. Economic optimisation has to be effected by selection of cheaper feeds and their judicious incorporation in the ration. Feeding standards for low-input animal production systems in the temperate regions have been developed by the Agricultural Research Council (1980, 1984) in the U.K. and by the National Research Council (1988) in the U.S.A. They have been adapted for survival feeding by Cronjé (1990). Various attempts have been made to develop feeding standards for India. Ray and Ranjhan (1978) based their recommendations on studies on basal metabolic rates, mostly conducted at the IVRI, Izatnagar and feeding trials conducted at other research stations in India. ICAR has also published nutrient requirements for cattle, buffaloes, sheep, goats, camels, poultry and swine (ICAR, 1985). The publication by Kearl (1982) on nutrient requirements for developing countries was partially based on such Indian work. Also, the publication of Ibrahim (1988) on Feeding Tables for ruminants in Sri Lanka is partly based on the work of Kearl (1982). The relevance and general applicability of feeding standards developed for high input systems to tropical environments is doubtful (Ketelaars and Tolkamp, 1991; Schiere and de Wit, 1993).

Animals require a certain amount of nutrients to maintain essential body functions or to survive. Amounts of nutrients (TDN and DCP) required vary with the body size, production level (weight gain or growth rate; amount of milk produced); reproductive status and the amount of work (draught) performed. The demand for nutrients at various stages of development from calf-hood to maturity is shown in Table 6.6.

Table 6.6 Nutrition requirement pattern depending on the physiological state

	Maintenance	**Growth**	**Pregnancy**	**Lactation**
Calf	✓✓	✓✓✓		
Heifer (non pregnant)	✓✓	✓✓		
Heifer (Pregnant)	✓✓	✓✓	✓✓	
Lactating cow	✓✓			✓✓
Pregnant lactating cow	✓✓		✓✓	✓✓
Dry cow (pregnant)	✓✓		✓✓✓	

NB: the ticks indicate the needs and importance

Nutrient requirements of buffaloes for maintenance, production and reproduction could be obtained from nutrient requirement Table 6.7. These tables provide information on requirements for varying body weights and production levels. Such tables are rather complicated and difficult for persons without a basic knowledge of nutrition, to understand and make proper use of the information. A composite and a simplified version of the nutrient requirement information titled "Feeding tables - A practical guide" was produced in 1988. This pocket booklet gives the nutrient requirements for cattle and buffaloes, and also the feeding values of locally available ruminant feedstuffs. The nutrient requirements for a growing, lactating buffalo cow weighing 350 kg is presented in Table 6.6. The information presented could be used to determine the nutrient requirements of cows of different body weights, milk production levels and varying milk fat contents.

Calculation of the composition of a ration

In order to move from the nutrient needs of the animal to formulation of the ration, it is necessary to divide the total requirement for each nutrient of the animal, by the amount of the particular nutrient supplied by a kg of feed. For example, if a cow needs an energy supply of 4900 g TDN/day and fresh grass contains 104 g TDN per kg grass, then the cow will need to consume 47 kg (4900/104) of fresh grass per

Table 6.7 Daily nutrient requirements (g TDN and g DCP) for a growing, lactating buffalo cow weighing 350 kg (maintenance, growth, milk production and gestation)

Milk yield	Milk with 4.0% fat		Milk with 6.0% fat		Milk with 8.0% fat	
(l/d)	TDN	DCP	TDN	DCP	TDN	DCP
1	4710	565	4800	580	4900	600
2	5050	625	5230	655	5430	690
3	5390	685	5660	730	5960	780
4	5730	745	6090	805	6490	780
5	6070	805	6520	880	7020	960
6	6410	865	6950	955	7550	1050
7	6750	925	7380	1030	8080	1140
8	7090	985	7810	1105	8610	1230
9	7430	1045	8240	1180	9140	1320
10	7770	1105	8670	1255	9670	1410

(Source: Ibrahim, 1988b)

Adjustment for different body weights: For every 50 kg difference in body weight, add or subtract 300 g TDN and 25 g DCP.

Adjustment for fat content in milk: For every 1% increase in fat content provide an additional 50 g TDN and 8 g DCP for every litre of milk produced.

Example on the use of Table 6.7

To calculate the TDN and DCP requirements for a buffalo cow weighing 300 kg and producing 4 litres of milk with 7% fat, the requirement for:

	TDN (g)	DCP (g)
- 350 kg cow producing 4 litres milk with 6% fat	6090	805
- For 50 kg less bodyweight	-300	-25
- For 4 litres milk with 7% fat (4x50 TDN & 4x8 DCP)	+200	+32
- The total requirement of nutrients	**5990**	**812**

day. Frequently, there are two or more feeds that need to be combined to make up the diet of the animal. The farmer has to decide on the mixture of feeds that are most appropriate. This decision will depend on the feeds that are available, the nutrient contents and the cost. The process of putting together feed ingredients to ensure that the requirements of the animal are met, is called the *ration formulation.* The methodology involved in ration formulation is illustrated below with the aid of a practical example (Box 6.1). The example, given below gives the farmer a choice of the following two options:

	Option 1	*Option 2*
Guinea grass	50 kg	50 kg
Glyricidia	3 kg	3 kg
Coconut poonac	1.24 kg	-
Urea-molasses-multinutrient mixture (UMM)	-	1.1 kg

The ultimate choice is an economic one which in this case favours the use of UMM in place of coconut poonac. An additional advantage with the use of UMM is that it contains mineral elements such as calcium and phosphorus which are equally important to the animal as TDN and DCP.

BOX 6.1

A farmer has a pregnant buffalo cow weighing 400 kg producing 5 litres of milk per day containing 7% fat. The farmer has access to Guinea grass (1 month regrowth), gliricidia, coconut poonac and urea-molasses-mineral supplements, with which to prepare a suitable ration to meet the daily nutrient requirements of the animal.

Step 1. Use Table 6.7 to determine the TDN and DCP requirements.

	g TDN	g DCP
A 350 kg cow producing 5 litres of milk with 6% fat requires	6520	880
The requirement for the extra 50 kg body weight	300	25
And for the extra 1% fat (50x5 TDN and 8x5 DCP)	250	40
Total requirement	7070	945

Step 2. Obtain the nutritive values (g/kg fresh weight) of the available feeds from Table 6.5.

	TDN	DCP
Guinea grass	116	19
Gliricidia	142	50
Coconut poonac	683	148
Urea-molasses-mineral mixture	764	46

Step 3. Ration formulation

	DM Intake (kg)	TDN (g)	DCP (g)
50 kg Guinea grass, grazed or cut and fed	10.5	5800	950
5 kg Gliricidia	0.7	426	150
Total nutrients from feed	**11.2**	**6226**	**1100**

Note: The maximum dry matter intake of a 400 kg cow is 3% of body weight, which is 12 kg. As the intake of grass and glyricidia by the cow is 11.2 kg, the balance that the cow could consume is 0.8 kg of dry matter. This space limitation in the rumen applies only when roughages are fed. When good quality concentrates or a urea-molasses multinutrient mixture is fed, the cow will consume 2-3 times this amount.
- A third feed resource has now to be included in the ration to overcome the shortfall of 844 g (7070-6226) of TDN. Because of the space limitation in the rumen, one has to feed a concentrate like coconut poonac or urea molasses multinutrient mixture (UMM). The farmer thus has two options.
- The DCP requirement is satisfied by feeding grass and glyricidia

Step 4.

In order to bridge the shortfall of 844 g of TDN one could feed either;
(a) 844/683 = 1.24 kg of coconut poonac at a cost of Rs. 17.36 (@Rs. 14/kg)
or
(b) 844/764 = 1.10 kg of UMM at a cost of Rs. 7.04 (@ Rs. 32.00 for a 5 kg block)

The difference between the choice of including either coconut poonac or UMM is Rs. 10.

Rations for growing and adult buffaloes

The data provided in nutrient requirement tables should be considered as a guide in establishing a feeding regime and not as absolute values. They do not replace the expertise of the farmer in matching the nutrient intakes with the performance of the animals. Nutrient requirements can be used as a starting point when formulating a diet and to estimate the feed requirements for any period of time.

The first requirement in balancing a diet should be to establish guidelines as to how much of each of the various nutrients would be needed to supply nourishment to the animal in amounts that will meet its requirements for maintenance, growth, production and reproduction.

In order to feed the animal according to its requirement one should know:

- The nutrient requirement of the animal
- The nutrient content in feeds
- The capacity of the animal to consume feed

Ration formulation exercises

01. A farmer has a cross-bred buffalo cow weighing 300 kg. He can supply 40 kg of *B. brizantha* (before flowering) and Gliricidia 1 kg daily. What is the expected milk yield with a butter fat content of 4.3%.

02. In order to feed his lactating cow (BW 350 kg; 4L milk with 4.5% fat), Mr. Ali composes the following ration:

- 30 kg of Guinea (1m)
- 5 kg of Ipil-ipil (leaves and twigs)
- 1 kg of rice bran

(a) Will the ration meet the requirements of the cow?
(b) Is the ration in accordance with the intake capacity of TDN/DCP?

03. Mr. Sirisena is an enthusiastic farmer who has 1 ha of paddy land and also owns 2 buffalo cows in milk. As there is nothing to graze on during the dry season, he offers straw in adequate quantities to his animals along with some Jak leaves and 12 kg of gliricidia. The live weight of each animal is 300 kg and the fat content in the milk produced is 4.5%.

(a) What will be the daily milk production?
(b) If he gives treated straw, what will be the milk production?

04. A farmer has a Murrah buffalo cow weighing 300 kg is in its second lactation. He wants to get maximum production from his cow (expected fat 5.5%). He can find the following quantities of feeds daily.

- 15 kg rice straw
- 25 kg guinea grass
- 1 kg of rice polish and 0.25 kg of coconut residue

Prepare a suitable ration for this cow and what will be the expected milk yield?

05. A farmer intends to start a dairy farm with Murrah x indigenous crosses. He has established 2 acres of *B. brizantha* pasture (before flowering) and 0.5 acres of Napier. He also has 1 acre of paddy land. He has planted Gliricidia as a live fence from which he could obtain 2.5 kg of fresh leaves and twigs daily.

(a) How many animals can he rear, if the average body weight of a cow is 350 kg and has the potential to produce 4 liters of milk (5.7% fat) per day. Assume that he produces 2 crops of paddy per year.
(b) If he can provide 1 kg of rice bran for each animal, what will be the expected milk yield?

06. A farmer in the Galaha area wants to start a dairy farm. He has established 2 hectares of *B. brizantha* pasture and he has planted gliricidia for fencing. In addition, he has established *B. milliformis* in his 3.5 acres of coconut land. He can get straw from his paddy field (1 hectare). The straw can be treated with urea and given as treated straw. Paddy is a one season crop in this area. He has about 1 acre of natural grass in his well grown home garden.

(a) What is the yearly yield of grass and straw?
(b) How many animals (cows) can he maintain? (body weight 300 kg, 4L of milk with 5.3% fat)

(c) What is the amount of concentrates should be given if he wants to increase the milk yield by 2L?

Assume that the Gliricidia production in terms of fresh weight is 8000 kg per year.

07. A coconut land has been selected to establish a livestock farm. Out of an area of 16 hectares available for a buffalo unit, 12 hectares is to be cultivated with *B. brizantha* and the remaining 4 hectares with Napier. It has been decided to plant gliricidia on the fences.

The expected annual yields/acre of green forage are:

B. brizantha	-	25,000 kg
Napier	-	40,000 kg
Gliricidia	-	20,000 kg

(a) What are the daily DM yields from these resources?

(b) If 8 kg of DM is sufficient for 1 livestock unit (BW about 300 kg), how many L.U. can they keep? (cow, heifers, etc.)

(c) Assuming that these are cross-bred animals with an average daily milk production of 6 litres, propose a concentrate/feed mixture (ration) as to maintain production of these animals.

08. A milking buffalo cow weighing 300 kg and producing 6 litres of milk with 6% fat is tethered twice a day for 4 hour periods each (08.00 - 12.00h and 13.00 to 17.00h). During tethering she is tied to 2 different coconut trees, around which the 43-56 days old pasture (*B. brizantha*) is completely consumed by her. During the night 4 kg of urea treated rice straw is fed. During milking, 1 kg of commercial concentrate is offered each day.

What will be the length of the rope used to tether if we assume that:

- in both tethering periods an equal amount of grass is consumed
- no pasture is available, around a radius of 1 m at the base of coconut trees
- a 1 m length of rope is used to tie the animal to the tree.
- during the wet season, 1 m^2 pasture = 1 kg fresh material
- during the dry season, 1 m^2 pasture = 0.45 kg fresh material

The yield from 1 m^2 of pasture is 1kg fresh material during the wet season
The yield from 1 m^2 of pasture is 0.45kg fresh material during the dry season

Suggested reading

Abeygunawardena, H. and Siriwardene, J.A. de S. (1999) *Cattle and Buffalo Farming – Handbook for Veterinarians*. National Science Foundation Press, Colombo, Sri Lanka, pp. 1-7.

Agricultural Research Council (1980) *The nutrient requirements of ruminant livestock.* Commonwealth Agricultural Bureau, Slough, U.K.

Agricultural Research Council (1984) *The nutrient requirements of farm livestock.* Supplement No. 1. Commonwealth Agricultural Bureau, Slough, U.K.

Crampton, E.W. and Harris, L.E. (1968) *Applied Animal Nutrition*, 2nd edition. Freeman, San Francisco, CA. 663 p.

Ibrahim, M.N.M. (1988). *Feeding tables for ruminants in Sri Lanka.* Published under the Animal Feeds Act of Sri Lanka.

Ibrahim, M.N.M. (1988). *Feeding tables - A Practical Guide*. Published by the ETI Division of the Department of Animal Production and Health, Peradeniya, Sri Lanka. 71 pp.

Kearl, L.C. (1982) *Nutrient requirements of ruminants in developing countries*. Utah State Institute, Logan, U.S.A., 381 pp.

National Research Council (1987) *Predicting feed intake of food producing animals*. National Academy Press, Washington DC, 85 pp.

Pesti, G.M. and Miller, B.R. (1993) *Animal feed formulation. Economics and computer applications*. Avi Books, Van Nostrand Reinhold, New York, 166 pp.

Schiere, J.B. and de Wit, J. (1993) *Feeding standards and feeding systems*. Animal Feed Science and Technology **43**, 121-134.

Chapter 7

Nutritional Management of Metabolic Disorders

R. Sivakanesan, A.N.F. Perera and J.A. de S. Siriwardene

Metabolic disorders arise as a consequence of several factors such as the peculiar characteristics of rumen digestion, genetic selection of dairy cattle of high production potential and the desire of the farmer to obtain the maximum yield from dairy animals by supplementary feeding of concentrates.

The most critical period in the life cycle of an animal is at and around the time of parturition. It is at this crucial stage that the animal gives birth to its offspring, initiates lactation and takes on the added function of caring and feeding the newborn. The hormonal influence is strongest during this period. Several reproductive hormones like oestrogen, progesterone, prolactin and oxytocin and other hormones like insulin, growth hormone and thyroid hormones regulate the metabolic activities in the animal. The hormonal influence is so strong that it does not limit production. However, the animal is unable to meet the nutrient demand for hormone driven metabolic events because of its fixed anatomical capacity and limited physiological expandability. Hence, nutrients are drawn from the body reserves to maintain production. This creates a state of metabolic instability in the animal, resulting in the emergence of metabolic disorders.

Metabolic disorders can lead to economic losses in high milk producing and fattening livestock. Many factors are responsible for these metabolic disorders which can be prevented by careful management and dietary manipulation. Most of the metabolic conditions arise as a result of interactions between the nutritional status, body condition, level of production, status of the diet and sometimes hereditary factors. They are mainly associated with production stresses such as in advanced stages of pregnancy, high milk production in early lactation and sudden dietary and climate changes.

Kamar and Pathak (1996) listed some of the common factors responsible for the occurrence of metabolic disorders in different classes of livestock, which are:

1. Physiological stress which demands a high nutrient supply to attain optimum body functions, fast growth, high milk production and rapid foetal growth during the advanced stage of pregnancy.
2. Poor body condition at calving due to underfeeding during pregnancy.
3. An inadequate supply of some of the critical nutrients in the diet during pregnancy, lactation and growth.
4. Environmental stress causing metabolic disturbances due to an excessive or sudden rise or fall in ambient temperature and humidity.
5. An insufficient supply of oxygen at the cellular level of metabolism.
6. Nutritional imbalances and deficiencies caused by sudden changes in metabolic functions under conditions of stress.

7. Grazing on natural herbage infested with toxic plants and feeding of mouldy feeds and fodder.
8. Grazing on lands that are heavily contaminated with effluents containing heavy metals or other harmful chemical wastes from industrial plants.
9. Imbalance in the diet, sudden changes in diet and introduction of new feed ingredients (e.g. urea) without providing adequate time for the adaptation.
10. Long-term use of contaminated drinking water.
11. Ingestion of harmful pesticide residues used for crop protection or during feed storage.
12. Hormonal disturbances caused by bio-simulators used for enhancing growth or milk production.
13. Hereditary factors.
14. Other non-specific factors.

Criteria for determining disorders of metabolic origin

Five criteria have been used to decide whether a condition be regarded as metabolic or not.

1. The condition should be non-infective in nature. However, it should be recognised that in most infections there is some disturbance of metabolic homeostasis, partly due to the direct effect of toxins, and partly due to inappetance that accompanies the infection.

2. The condition should not arise as a consequence of a specific genetic disorder. The incidence of metabolic disorders is much too high to be explained based on genetic defects, because in the latter disorders the frequency of occurrence is extremely low.

3. The condition should not be one that arises due to a dietary deficiency. The pattern of the diet, however, can play an important role in the aetiology of some conditions. For example, the inadequate intake of dietary energy has been associated in many cases of pregnancy toxaemia of sheep. On the other hand, the disorder cannot be produced simply by withdrawing food and may even develop in ewes maintained on an adequate diet.

4. Observable changes in the concentration of one or more blood metabolites should be evident. It should be emphasised that in sub-clinical states, alterations in blood metabolite concentrations are evident even in the absence of clinical symptoms. This feature should be recognised as useful in identification of susceptible animals, by performing metabolic profiles at crucial periods in the production cycle of animals.

5. The condition should usually develop at a time when the metabolic demand is at its highest level, as would be evident at peak production or at critical stages in the production cycle; e.g. at parturition, terminal stages of pregnancy, peak lactation etc.

Some common metabolic disorders, which occur in ruminants, are described below.

Milk Fever

Milk fever is the result of a severe metabolic disorder that occurs in adult bovine females, generally at or around the time of calving. It is commonly seen in high producing dairy cattle and buffaloes and is characterised by general muscle weakness, incoordination and depressed consciousness. The condition is also referred to as parturient paresis or parturient hypocalcaemia. In cattle, milk fever is one of the diseases of economic importance, because it occurs widely and often leads to complications, such as the emergence of the Downer cow syndrome.

The incidence of milk fever increases with age. Although this disorder is called milk fever, affected animals maintain normal body temperature or may sometimes elicit sub-normal temperatures. However, there is no elevation of body temperature.

Aetiology

Milk fever arises due to a decreased responsiveness of the endocrine gland, the parathyroid, to maintain the normal blood calcium concentration. The hypocalcaemic state that prevails in affected animals blocks neuromuscular transmission and causes general paralysis (paresis).

Depression in serum calcium levels usually occur in cattle and buffaloes at the time of calving and is more severe in animals prone to milk fever. Usually three factors are responsible for the maintenance of the calcium level in body fluids. A disturbance in the function of one or more factors may initiate the development of milk fever. Serum calcium depression occurs due to either one or a combination of the following factors.

(a) The excessive depletion of calcium in the body, through colostrum. The extent of depletion depends on the volume of colostrum secreted. A decline in the level of serum calcium becomes evident when the extent of the loss of calcium through colostrum exceeds the normal capability of the animal to absorb calcium from the intestine and to mobilise calcium from the long bones.

(b) An impairment in the process of dietary calcium absorption from the intestine. This is apparent in some animals that show a loss of appetite at the time of parturition. This condition is most likely to arise because of the reduction in the amount of calcium absorbed from the intestine.

(c) The inadequacy of mobilisation or the slow release of calcium from the skeletal reserves during the latter stages of gestation.

Clinical signs

The clinical signs and symptoms observed in milk fever can be described in 3 stages.

The initial stage is very short. The animal is excited and shows muscle tremor and hypersensitiveness. There is stiffness in the hind legs and the animal is reluctant to move or eat. As the condition progresses there is loss of appetite, drop in milk yield, constipation and decreased ruminal movements.

During the second stage, the animal looks drowsy and is in sternal recumbency with its head tucked into the flank. The reflexes disappear and there is hypothermia. The eyes are dull with dilated pupils. The pulse is weak and breathing is usually normal, but is accompanied by a forced grunt during expiration.

During the third stage, the animal assumes lateral recumbency. This generally occurs when treatment is delayed. The cow is almost comatose and there is complete flaccidity of the limbs. Body temperature and pulse rate drops further and the cow is unable to rise. Bloat develops due to prolonged recumbency and lack of rumen movements. Immediate attention and treatment at this stage is very important. If treatment is delayed, the condition deteriorates rapidly and the animal will die due mainly to respiratory failure.

In certain cases, damage to hind legs, pelvic bone, leg muscles and radial paralysis may occur. Prolonged recumbency may lead to degenerative myopathy in large thigh muscles.

Clinical pathology

The normal range of the serum calcium level in cows is between 2.2 and 2.6 mmol/L. In moderate to severe milk fever conditions in cows, the serum calcium level drops to 1.5mmol/L and sometimes to a level as low as 0.25 mmol/L. More severely affected animals show low levels of inorganic phosphorus and elevated levels of serum magnesium. The normal range of phosphorus concentration is between 1.40 and 2.48 mmol/L, but in cows with milk fever the concentration may fall to 1.0 mmol/L. The magnesium concentration usually increases to slightly above the upper limit of the normal range (0.85 to 1.25 mmol/L).

Treatment

Cows with milk fever must be treated as early as possible. Animals respond quickly if they are treated at the initial stages, but recovery during latter stages is not very satisfactory due to the occurrence of relapses. The standard treatment is by parenteral administration of calcium as calcium borogluconate (25% or 40%) solution containing between 8 and 12 gm of calcium. A quick response can be obtained if calcium is administered as an intravenous injection over a period of 10 minutes. Intramuscular and subcutaneous administration is also carried out in order to avoid any adverse effects on the heart. The muscles of the recumbent animal may twitch during treatment and the animal may pass faeces and urine and eructate rumen gases.

The incorporation of magnesium and phosphorus is advocated but there is no evidence of an improvement in recovery in uncomplicated cases. When subclinical hypomagnesaemia is observed during the last month of pregnancy, the addition of magnesium to the solution of calcium borogluconate is advisable. Similarly, when there is evidence either of hypophosphataemia among cows in late pregnancy or of persistent low phosphorus among cows in relapse, the inclusion of phosphorus is advisable.

Animals subjected to continued excessive drainage of calcium in milk, may be treated with calcium borogluconate administered 2 or 3 times at intervals of 12 hours. In milder cases, calcium salts such as calcium lactate may be fed at the rate of 60-100 g daily for 3-4 days following the initial parenteral administration. Milking/suckling must be partial and cows must not be stripped during first 24 - 48 hours. Milking should be gradually increased. Recumbent animals should be turned from side to side 3 to 4 times daily and propped up in the sternal position. Legs and bone prominence should be massaged. Comfortable bedding such as straw, hay or sawdust should be provided. Oral administration of liquids should be avoided as far as possible to prevent the development of "drenchy pneumonia".

Nutritional management

Dietary calcium restriction by careful selection of low Ca roughage and withdrawal of any Ca supplements (<20g/d) reduces the incidence of milk fever. When parturition is imminent, calcium intake should be increased as rapidly as possible. Vitamin D administered orally in large doses, 20-30 x 10^6 IU/d for 7 days starting 3 to 4 days prepartum is known to prepare the intestinal tract for proper absorption of dietary calcium. The absorption of calcium from the diet can be raised by alteration in the ionic balance of the diet by the addition of $Cacl_2$ and $MgSO_4$ ('acid diet'). It is essential that the cow's appetite remains high at and around the time of parturition. Maintaining a low Ca:P ratio in the diet increases the percentage of the calcium absorbed.

The Downer Cow Syndrome

Animals affected by the Downer Cow Syndrome are high producers, usually at the stage of peak lactation. Many of these animals have a history of parturient paresis. The condition is also known as " alert downer " or " creeper". During the development of the Downer syndrome, the cow lies in recumbency for a long period with traumatic injuries to limb muscles and nerves. One cause for the recumbency may be mechanical damage to muscles or nerves during calving due to difficult labour. In some instances where prolonged recumbency results from fracture of the bones of the pelvis and limbs, luxation of hip joints, or rupture of major muscles, the prognosis is hopeless in regard to the chances of recovery.

Aetiology

The aetiology of this disorder is not yet clear; but pathogenesis suggests that the condition is a complication of milk fever. It would appear that metabolic disorders, physical injuries caused during parturition and traumatic muscular injuries associated with attempts to rise from prolonged recumbency contribute to the Downer condition. During the prolonged recumbancy period, the muscle tissues lose their permeability and potassium leaks out of muscle cells causing myotonia.

Clinical signs

The affected cows are unable to stand, but other functions, such as eating, drinking, urination and defecation, heart rate and rectal temperature are normal. Although the animals are unable to rise, they try to crawl on the ground with partially flexed hind legs, that give the appearance of frog legs. The recovery rate is very low and death occurs due to complications.

Clinical pathology

Most cows that succumb to Downer cow syndrome, will initially have hypocalcaemia (< 2mmol/L) and hypophosphataemia (<0.9 mmol/L), as do cows with uncomplicated parturient paresis. Considerable increases in serum aspartate aminotransferase (AST) and creatinine phosphokinase is observed and is indicative of traumatic muscle injury. Proteinuria occurs due to excessive muscle damage.

Treatment

The basic aim of treatment is to get the cow on to its feet. The treatment varies with the condition of the cow. Hoisting a cow with hip clamps is only of value if the cow will stand. Cows that show relapses after treatment with calcium alone are given solutions containing calcium, phosphorus, magnesium, glucose and potassium. Central nervous system stimulants given in conjunction with minerals can be administered parenterally. Cows that may survive in a recumbent state over a prolonged period must receive adequate care to minimise further complications such as the development of sores and ulceration.

Hypomagnesaemic tetanies

The term hypomagnesaemic tetanies is applied collectively to conditions that produce depression of serum magnesium in cattle and buffaloes, especially in calves and lactating animals, leading to tetany.

Hypomagnesaemic tetany of calves

This syndrome is associated with a deficiency of magnesium, due to feeding of whole milk over an extended period of time. It develops at 2 to 4 months of age. The absence of a homeostatic mechanism, the low content of magnesium in milk, together with the decreased intestinal absorption of magnesium as the age of growing calves advances, leads to hypomagnesaemia. This results in a decrease in the bone magnesium content with advancing age. This problem is mostly seen in calves fed and raised solely on milk. The condition is also referred to as whole milk tetany.

Clinical findings

Initial clinical signs are restlessness, twitching of ears and muscles around the face and hyperaesthesia. Hypomagnesaemic calves show erection and backward carriage of ears, agitation, excitement, hypersensitivity, anorexia, sunken eyeballs and staggering gait. Heart and respiration rates are increased, whereas rumen movements and body temperature are reduced. Animals are hypersensitive to external stimuli and show opisthotonus, ears folded backwards, retraction of eyelids, muscle twitching, tremor, tonic and clonic spasms, clonic convulsions and tetanic contractions. The tetanic symptoms include retraction of the head, kicking at the belly, champing of the jaws and tonic and clonic convulsions.

The disease may resolve without treatment or may progress to tetanic convulsions with tonic convulsions of the jaws and clonic convulsions of the limbs. Involuntary passage of urine and faeces is observed. Respiratory movements cease during convulsions and death is often rapid. On post-mortem examination, pale mucous membranes are seen. There may be ascites. Various degrees of impaction with straw balls may be observed in the stomach. Pericardial and thoracic effusions and degeneration of adipose tissue are more common. There may be pulmonary lesions, enteritis, emaciation and dehydration.

Clinical pathology

A severe fall in serum magnesium occurs in most clinical cases. During tetany, clinical pathology will reveal a low level of serum magnesium, often with a low level of serum calcium, a moderately elevated level of serum aspartate aminotransferase and a markedly elevated level of creatinine phosphokinase.

Treatment

Magnesium sulphate (10g) dissolved in sterile distilled water should be administered subcutaneously and followed by daily oral administration of 10-15g magnesium oxide. Response to magnesium treatment is only transitory. Sedation with tranquilizers relieves muscular tremors in affected animals.

Hypomagnesaemic tetany of dairy cattle and buffaloes

Hypomagnesaemic tetany of dairy cattle and buffaloes occurs in lactating as well as non-lactating pregnant animals fed a large quantity of young tender herbage. This condition which is also referred to as grass tetany, lactation tetany, hypomagnesaemia, hypomagnesaemic tetany and grass staggers is associated with tetany, observed most commonly in lactating animals.

Aetiology

The condition can occur when the magnesium content in young fresh grass is lower than the requirement of cows for milk. In pregnant and lactating animals, the requirements of magnesium for foetus development and for synthesis of milk is higher. Consequently, the demand for mineral magnesium in the feed is higher. A low level of magnesium in the feed and the lack of mineral supplementation in the diet make these animals vulnerable to the condition.

In the absence of an effective homeostatic mechanism for magnesium, a constant dietary intake and absorption of magnesium becomes essential. The magnesium content in plants is related to the levels of exchangeable magnesium in the soil, although the levels of other exchangeable cations such as calcium, potassium etc. may modify uptake. Application of potassic fertilisers may therefore markedly alter the magnesium content of grasses.

There are many dietary factors that are involved in the development of hypomagnesaemia. These include a high sodium/potassium ratio, feeding of lush grass high in nitrogen, calcium, organic acids such as citric and trans aconitate. The disorder can occur due to either competitive inhibition of magnesium absorption, or chelation of magnesium ions by organic acids, ammonia, or the removal of excess quantities of minerals due to diarrhoea and high intake of dietary potassium.

Clinical findings

Clinical signs of hypomagnesaemia or grass tetany can be divided into those that appear in the acute, subacute, and chronic states.

In the acute condition, the animal stops feeding abruptly, stands alert and exhibits uneasiness due to twitching of muscles and ears. The animal appears frightened or mad and bellows while galloping. Animals fall to the ground and find it difficult to rise. The other signs are convulsion, champing of the jaws, froth-like salivation, retraction of the eyelids and rolling of the eyeballs. The gait is staggered; later the sick animal falls and moves its limbs in spasms. Death may occur in less than 4 hours after the appearance of the clinical symptoms. There may be a sudden rise in body temperature after the tetanic attack. The pulse and respiration rates are increased.

In sub-acute cases, a gradual loss of appetite results in an unthrifty condition. Urination and defaecation becomes more frequent and both milk production and rumen motility decrease. A loss of 22-55 kg in body weight in pregnant animals and a 27% drop in milk yield in lactating animals have been recorded. Retraction of the head with muscle tremor in hind legs is very common. Often recovery is rapid.

The chronic form of the disease is associated with a vague change of temperature and a loss of appetite and body condition.

Treatment

Ruminants in late pregnancy and immediately after calving are susceptible to underfeeding. Care should be taken to prevent a lowering of serum magnesium, which can be brought about by a sudden change in the quality and quantity of the feed, a sudden increase in the quality of the daily ration and calving accompanied by a reduced feed intake.

Magnesium sulphate or magnesium borogluconate (25g) dissloved in about 400-500 ml of distilled water should be administered subcutaneously at a very slow rate. The treatment should be followed by daily oral administration of about 50-60 g magnesium oxide for a period of 7-10 days. If the response is poor, additionally calcium borogluconate administration is advocated.

Ketosis

Ketosis is a condition characterised by an increase in ketone bodies in the body fluids, namely acetoacetate, β-hydroxy-butyrate and acetone. This may be influenced by a number of conditions that relate to carbohydrate metabolism. In cattle and buffaloes early lactation, the requirement for energy yielding nutrients and glucose is at its highest level. The inability of the animal to meet the increased demand for glucose is a precipitating cause of the emergence of ketosis. The animal is thus in a negative glucose balance in early lactation. The increased demand for energy is met by increased gluconeogenesis, resulting in a drain on oxaloacetate.

Dairy cattle and buffaloes, in the early stage and at peak lactation are highly susceptible to ketosis. The condition is characterised by nervous signs, loss of body weight, reduced milk yield and the appearance of ketones in the urine. The biochemical changes include hypoglycaemia, ketonaemia and ketonuria and the condition is associated with a low level of liver glycogen.

Aetiology

In the ruminant, the balance in the efficiency of utilisation of carbohydrate plays an important role in the development of ketosis. Generally about 85% of the total glucose production is used for the synthesis of lactose. The increased demand of glucose for lactose production, particularly in early lactation is met by gluconeogenesis using the TCA cycle intermediate oxaloacetate. This result in a diminution in the activity of the TCA cycle and hence a decrease in the oxidation of acetate favouring the accumulation of acetate. The energy deficit also results in increased breakdown of fat in adipose tissue. The oxidation of fatty acids increases acetyl CoA production and therefore acetate, consequently leading to ketone body production. The ketonaemia and ketonuria due to excretion of ketone bodies in urine, together is referred to as ketosis. The composition and the quantity of feed consumed by the animal may be responsible for the development of ketosis.

The major cause is the heavy drain on energy *via* milk during early lactation, which brings about a negative energy balance. This can be due to a deficient intake of energy, failing to satisfy the nutritional demand or a disturbance in the utilisation of dietary carbohydrates for glucose. Another reason is the feeding of ketogenic fodder or silage, which contains butyric acid or the feeding of large quantities of proteins that favours butyric acid production. Many diseases that reduce the feed intake can cause "secondary ketosis".

Clinical findings

In cattle and buffaloes two forms of the disease, namely the wasting and nervous forms are seen. The wasting type of ketosis is characterised by a gradual loss of appetite and drop in milk yield. Such animals prefer non-ketogenic feed such as highly fibrous feeds (hay, dry fodder and straw) and reject grains and silage. Body temperature, pulse or respiration rates remain normal, but the animal is reluctant to move due to weakness resulting from considerable and rapid loss of body weight. The smell of acetone is evident in the breath and in milk. In the nervous form of ketosis, abnormal behaviour such as encircling movements, pressing of head against objects, staggering gait, excessive salivation and depraved appetite can be observed. Fits can occur once or twice daily. The syndrome is some times confused with rabies.

Subclinical ketosis is generally common in many herds. This condition is characterised by a reduced milk yield and low fertility due to ovarian dysfunction. This results in long calving intervals. Ketosis may be confused with other diseases with similar symptoms such as traumatic reticulitis, abomasal displacement, etc. A decrease in blood glucose and a rise in β-hydroxy butyrate in blood indicate a negative energy balance.

Nutritional management of ketosis

The management of ketosis is not easy. The recommended practise is to provide a dry period of 45 to 60 days for the build-up of body reserves, which will subsequently increase milk yield. However, the restriction of the total energy intake towards the end of the pregnancy period is recommended to limit the build-up of adipose tissue. The reason for this is that the excessive release of fat from body reserves soon after calving could contribute to the build-up of ketone bodies. Towards the end of the pregnancy period, an increase in the amount of concentrate in the diet will help to increase propionate-producing microorganisms so as to meet the increased demand for glucose in early lactation.

Attention to feeding and management should ensure that the cows have an adequate energy. The ration to be used should be introduced at least 2 weeks before parturition to permit the rumen microflora to adapt to the change in the diet. The ration fed during early lactation should provide maximum glucose precursors with the minimum of ketogenic materials, such as hay crop or silage high in butyric acid. The ration should provide maximum energy without reducing food intake. A good practice is to include good quality alfalfa (lucerne) hay in the diet. If concentrates are used, the carbohydrate should be readily digestible (such as ground maize). The diet of susceptible cows should be supplemented with propylene glycol. Cows should not be in poor condition or excessively fat at calving. Cobalt supplementation required for rumen microbial synthesis of vitamin B_{12}, which is required for proper utilization of propionic acid, is beneficial.

Treatment of ketosis should be directed towards the immediate restoration and maintenance of the blood glucose concentration until such time as the animal recovers from the condition. Proper feeding management can control this condition. All high producing cows must be fed with high energy diet during late pregnancy and early lactation period to satisfy their energy demands without much depletion of body fat.

Post parturient haemoglobinuria

The condition occurs following long dry periods, in old farms where soil fertility is low. It mainly affects high producing cattle and buffaloes and is characterised by intravascular haemolysis, haemoglobinuria and anaemia. Over-feeding of feed material, such as sugar cane tops, sugar beet, kale, mustard, cabbage and lucerne that are known to contain inhibitory factors such as metallic ions, interfere with the absorption and assimilation of phosphorous. A deficiency of copper, sodium and potassium increases the sensitivity of erythrocytes to haemolysis.

Aetiology

The most susceptible group are the high producing animals at postpartum stage generally yielding between 8 – 22 litres of milk per day. Buffaloes are more susceptible to ketosis than cattle, particularly when sugar cane tops are fed as part of the diet. A consistent finding in herds with postparturient haemoglobinuria is a deficiency of phosphorus. The feeding of low phosphorus diets for long periods has been incriminated as a cause. Phosphorus deficiency haemoglobinuria occurs only in adult animals in advanced pregnancy and during the perpueral period. It is more frequent after the third pregnancy. Extremely low phosphorus levels have been observed where anaemia and haemoglobinuria were not evident. The condition has been produced in dairy cattle fed fresh or ensiled sugar beet leaves and alfalfa hay. It is suggested that two factors, namely, hypophosphataemia and the haemolytic effect of saponins present in sugar beet leaves and alfalfa hay are associated with the development of postpartum haemoglobinuria.

Clinical findings

Post-parturient haemoglobinuria appears suddenly as a haemolytic syndrome and is followed by other symptoms within the next 24 to 48 hours. It is a condition associated with severe hypophosphataemia. The symptoms include anaemia, rapid loss of appetite, loss of body condition, listlessness, slight icterus, increased heart rate and shallow and rapid respiration. The passing of coffee-coloured urine is the first conspicuous sign of the disease.

In most cases, appetite appears to be normal but the milk yield is significantly reduced. Constipation and the passage of hard and black tinged faeces is common. The body temperature is either normal or marginally subnormal. The heart beat is slightly elevated. The mucous membranes of the conjunctiva and vulva are discoloured or pale in appearance. Laboured breathing and jugular pulsation can be observed during the terminal stages of the disease. Clinical symptoms generally appear after four months of pregnancy. The disease is most commonly observed during summer when animals are fed wheat or paddy straw and stover of maize, sorghum and pearl millet, which are very poor sources of phosphorous.

Treatment

The supplementation of the diet with phosphorus and limiting the feeding of plant material containing inhibitory factors in late pregnancy will be useful. The intravenous injection, accompanied by oral administration of phosphorus in the form of monobasic sodium phosphate has often been found to be effective. In severe cases, blood transfusions may be useful as a supportive therapy.

Lactic acidosis

It is also called acute indigestion, grain engorgement or founders. This condition is caused by disturbances in the digestion and metabolism in the reticulo-rumen caused by high acidic conditions.

Acidosis develops when large quantities of fermentable carbohydrates such as grain, molasses. sugars, tubers and yams, lush pasture and sugar cane are consumed. The degree of acidity is dependant on the rate of fermentability of carbohydrates. Acidosis in bovines is of two types. Acute rumen acidosis, is mostly fatal while the subacute or chronic acidosis causes loss of appetite and reduces productivity.

Generally the lactic acid concentration in the rumen is < 1 mmol/l. However, change in rumen pH changes the microflora and induce lactic acid production. As a result, the lactic acid concentration in the rumen may reach upto 200-300 mmol/l and rumen pH drops to 4.5 or even lower. Lactic acid is absorbed from the rumen wall and acidiosis becomes systemic. High levels of lactic acid in the rumen elevate the osmotic pressure and cause haemo concentration and dehydration. The presence of large quantities of D - lactic acid aggravates the condition, because D - lactic acid cannot be metabolized as efficiently as L - lactic acid.

The affected animals suffer from distended rumen, impaction and occasional abdominal pain. Affected cows tend to lick the belly during abdominal pain. Complete loss of appetite and refraining from drinking water are the other common symptoms. Profuse diarrhoea is observed in many cases and faeces emits a sweet sour smell. Biochemical analysis can confirm the condition; such as low pH in the rumen, low protozoa count, high lactate in blood and acidic urea.

Urea/ammonia toxicity

Urea and ammonia are used in ruminant diets to improve the nutritional value and enhance the utilization of fibrous feed. Over-feeding or the accidental intake of urea or ammonia can cause toxicity. The severity of the condition depends on body size, the extent of rumen fill, composition of microbes in the rumen etc.

Toxicity occurs when the concentration of ammonia in the circulatory blood is high. Ammonia that is absorbed from the rumen is generally detoxified in the liver and other organs. When the supply of ammonia surpasses the rate of detoxification, the excess ammonia enters the peripheral circulation. Urea that enters the rumen is hydrolysed to ammonia by microbial urease. The initial high rate of ammonia production elevates rumen pH and causes " alkalosis". At very high levels of pH of around 11, the free ammonia concentration is increased and subsequently rapid absorption takes place *via* rumen wall into the blood system.

Clinical signs of ammonia toxicity include abdominal pain exhibited by kicking the belly, muscle tremor, incordination, weakness, stiffness of legs, dyspnoea, bloat, bellowing, lachrymation and death. Death is due to respiratory failure.

The expelled air may smell of ammonia. In severe cases, treatment is less effective. However, oral administration of acidifying agents such as 5% acetic acid or vinegar may be helpful. Immediate removal of rumen contents by ruminotomy is more effective than any other treatment. It is best to prevent the development of toxicity by proper feeding, management of diets containing of large quantities of urea and other as non-protein nitrogen sources.

Bloat/ruminal tympany

Accumulation of gases in the rumen produced by rumen microbes during fermentation is called bloat or ruminal tympany Gas is generally trapped in the rumen contents. This condition arises mainly due to the formation of stable foam (froth) in the rumen which blocks the cardia and prevents the release of rumen gas by eructation.

The rate of gas production and its composition depends on the type of feed. Bloat can be divided into 2 types. Primary ruminal tympany is caused by an intake of high protein diet such as legumes, immature pasture grasses, etc. In animals that have not been adapted to feed with high levels of crushed grains also can cause primary tympany. In secondary bloat, the gas that is trapped in the dorsal sac due to physical or any other interference impairs eructation.

Clinical signs include the distension of the left flank due to accumulation of gases in the rumen causing bloat. The animals are restless, rise frequently, kick at the belly and sometimes roll on the ground. During later stages, salivation, dyspnoea, protrusion of the tongue and forward stretching of head are evident. Finally, the animal will collapse and die if unattended.

The treatment depends on the type of tympany. In extreme cases, the dorsal sac has to be punctured with a trocar and canula or with a narrow sharp knife at the paralumber fossa region to release the gas. Legume bloat may be prevented by spraying the pasture with anti-foaming agents such as detergents or silicones. Feedlot bloat may be prevented by addition of fibre into the diet.

Rumen parakeratosis

This condition is common in animals fed with high grain diets, especially under feed-lot conditions. The clinical symptoms are keratinization of the ruminal mucosa with inflammation and ulceration. Bacteria will penetrate the rumen and enter the circulation and cause liver abscesses.

Displaced abomasum.

The actual cause for this condition is not known, but one reason is the excessive production of volatile fatty acids in the rumen and their passage to the abomasum. The presence of volatile fatty acids in the abomasum triggers the displacement of the abomasum. The displacement is caused by atony (lack of motility). This leads to displacement and torsion leading to rupture of the attachment of the abomasum to greater omentum. Treatment is by surgery and suturing the abomasum in its proper position.

Further reading

Banerjee, C.C. (1988) *A text book of animals Husbandry*. (5^{th} Edition), Oxford and IBH Publishing Company, New Delhi, India..

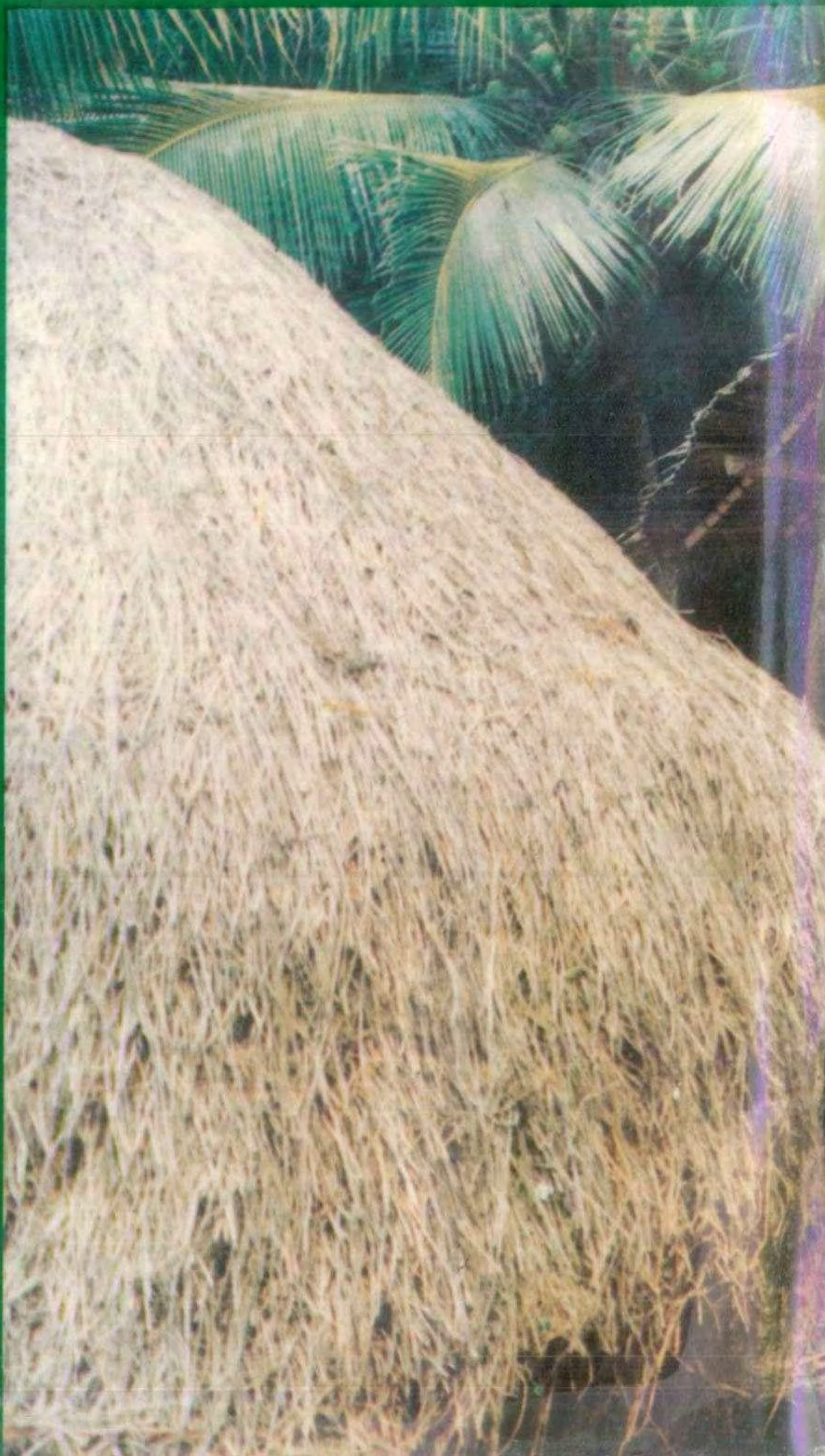
Bondi, A A. (1987) *Animal nutrition*. John Wiley and Sons, New York, USA.

Kumara, D.N. and Pathak. N.N. (1996) Nutritional microbiology of farm animals. Vikas Publishing House Pvt. Ltd., India.

Ranjhan, S.K. and Pathak, N.N. (1992) *Nutritional and metabolic disorders of buffaloes*. In: Buffalo Production (Ed.) Tulloh, N.M and Holmes, J.H.G. World Animal Science C6, Production System Approach:, pp.355-375. Elsevier Science Publishers; Amsterdam; The Netherlands.

Subject index

ISBN 955-590-034-5



Printed by [illegible] Printing Unit