Feeding Systems and Feed Evaluation Models

EDITED BY
M.K. THEODOROU AND J. FRANCE

CABI *Publishing*

FEEDING SYSTEMS AND FEED EVALUATION MODELS

Edited by

M.K. Theodorou

Department of Animal Science and Microbiology
Institute of Grassland and Environmental Research
Aberystwyth
UK

and

J. France

Department of Agriculture
University of Reading
UK

CABI *Publishing*

CABI *Publishing* is a division of CAB *International*

CABI Publishing
CAB International
Wallingford
Oxon OX10 8DE
UK

Tel: +44 (0)1491 832111
Fax: +44 (0)1491 833508
Email: cabi@cabi.org

CABI Publishing
10 E 40th Street
Suite 3203
New York, NY 10016
USA

Tel: +1 212 481 7018
Fax: +1 212 686 7993
Email: cabi-nao@cabi.org

A catalogue record for this book is available from the British Library, London, UK.

Library of Congress Cataloging-in-Publication Data
Feeding systems and feed evaluation models / edited by M.K. Theodorou and J. France.
p. cm.
Includes bibliographical references.
ISBN 0-85199-346-X (alk. paper)
1. Feeds—Evaluation. I. Theodorou, M.K. (Michael K.) II. France, J. (Jim).
SF97.F38 1999
636.08'4—dc21 99-35147
CIP

ISBN 0 85199 346 X

Typeset by AMA DataSet Ltd, UK
Printed and bound in the UK by Biddles Ltd., Guildford and King's Lynn

FEEDING SYSTEMS AND FEED EVALUATION MODELS

Contributors

G. Alderman, *The University of Reading, Department of Agriculture, Earley Gate, Reading, Berkshire RG6 6AT, UK*

R.L. Baldwin, *Department of Animal Science, University of California, Davis, CA 95616-8521, USA*

A. Bannink, *DLO-Institute for Animal Science and Health (DL-DLO), Department of Ruminant Nutrition, PO Box 65, 8200 AB Lelystad, The Netherlands*

D.E. Beever, *The University of Reading, Department of Agriculture, Earley Gate, Reading, Berkshire RG6 6AT, UK*

J.L. Black, *John L. Black Consulting, Locked Bag 21, Warrimoo, NSW 2774, Australia*

G.A. Broderick, *US Dairy Forage Research Center, Agricultural Research Service, USDA, Madison, WI 53706, USA*

J.G. Buchanan-Smith, *Department of Animal and Poultry Science, University of Guelph, Guelph, Ontario, Canada, N1G 2W1*

I.H. Burger, *Waltham Centre for Pet Nutrition, Waltham-on-the-Wolds, Melton Mowbray, Leicestershire LE14 4RT, UK*

A. Chesson, *Rowett Research Institute, Bucksburn, Aberdeen AB21 9SB, UK*

L.I. Chiba, *Department of Animal and Dairy Sciences, Animal Science Building, Auburn University, AL 36849-5415, USA*

R.C. Cochran, *Department of Animal Sciences and Industry, Kansas State University, Manhattan, KA 66506, USA*

D. Cuddeford, *Department of Veterinary Clinical Studies, Royal (Dick) School of Veterinary Studies, The University of Edinburgh, Veterinary Field Station, Easter Bush, Roslin, Midlothian EH25 9RG, UK*

Y. Cui, *Institute of Hydrobiology, The Chinese Academy of Sciences, Wuhan, Hubei 430072, China*

J. Dijkstra, *Animal Nutrition Group, Wageningen Institute of Animal Sciences (WIAS), Wageningen Agricultural University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands*

K.C. Donovan, *Department of Animal Science, University of California, Davis, CA 95616-8521, USA*

D.G. Fox, *Department of Animal Science, Cornell University, Ithaca, NY 14853, USA*

J. France, *The University of Reading, Department of Agriculture, Earley Gate, Reading, Berkshire RG6 6AT, UK*

W.J.J. Gerrits, *Animal Nutrition Group, Wageningen Institute of Animal Sciences (WIAS), Wageningen Agricultural University, PO Box 338, 6700 AH Wageningen, The Netherlands*

G. Hof, *Animal Nutrition Group, Wageningen Institute of Animal Sciences, Wageningen Agricultural University, ZODIAC, Marijkeweg 40, Wageningen, The Netherlands*

S. Leeson, *Department of Animal and Poultry Science, University of Guelph, Guelph, Ontario, Canada, N1G 2W1*

A.C. Longland, *Institute of Grassland and Environmental Research, Plas Gogerddan, Aberystwyth, Ceredigion SY23 3EB, UK*

R.S. Lowman, *Brackenhurst College, Southwell, Nottinghamshire N25 0QF, UK*

M.G. MacLeod, *Roslin Institute (Edinburgh), Roslin, Midlothian EH25 9PS, UK*

S.R. McLennan, *Queensland Beef Industry Institute, Animal Research Institute, Yeerongilly 4105, Brisbane, Australia*

D.P. Poppi, *School of Land and Food, University of Queensland 4072, Brisbane, Australia*

C.K. Reynolds, *Department of Agriculture, The University of Reading, Earley Gate, PO Box 236, Reading, Berkshire RG6 6AT, UK*

L.A. Sinclair, *Harper Adams University College, Edgmond, Newport, Shropshire TF10 8NB, UK*

J.D. Summers, *Department of Animal and Poultry Science, University of Guelph, Guelph, Ontario, Canada, N1G 2W1*

S. Tamminga, *Animal Nutrition Group, Wageningen Institute of Animal Sciences, Wageningen Agricultural University, ZODIAC, Marijkeweg 40, Wageningen, The Netherlands*

M.K. Theodorou, *Institute of Grassland and Environmental Research, Plas Gogerddan, Aberystwyth, Ceredigion SY23 3EB, UK*

R.G. Wilkinson, *Harper Adams University College, Edgmond, Newport, Shropshire TF10 8NB, UK*

S. Xie, *Institute of Hydrobiology, The Chinese Academy of Sciences, Wuhan, Hubei 430072, China*

Preface

As we look back over the millennium, it is difficult to imagine man's evolution in the absence of domesticated livestock. Likewise, domesticated animals are so dependent upon man that in his absence their very existence would be jeopardized to the point where they would not thrive and some would fail to survive. Livestock husbandry developed because it was possible to demonstrate a clear and beneficial relationship between man's intervention and productivity. Thus, it was recognized that an animal's performance could be manipulated and that certain animal feeds or combinations of feeds were nutritious and enhanced performance, whereas others were of less benefit, some being detrimental or even toxic.

As the nutritional sciences developed in modern times, and in an attempt to formalize traditional knowledge, methodologies were elaborated to characterize feedstuffs in order to predict the performance of livestock. Today, we can describe the biological, chemical and physical properties of feedstuffs with an array of sophisticated instrumentation and to an ever-increasing degree of accuracy. However, such exacting science is pointless unless these feedstuff measurements have practical value. By the middle of the 19th century, tables of feeds ranked by nitrogen content were available. The turn of the 20th century saw the beginning of research culminating in feed formulation strategies for ruminants based upon, for example, total digestible nutrients, and starch or corn equivalents. Although these systems of feed evaluation underpin the present-day concepts of digestible and metabolizable energy, their value was lost by the latter part of the 20th century because of the introduction of more intensive livestock production systems. In modern times, the practical goal of any feeding system is to optimize the efficiency of feed utilization, animal output and ultimately financial return to the producer. Broadly speaking, the science underpinning this goal can be broken down into three components and these are melded together in the current net energy

and net protein feeding systems. At a scientific level, the components of our modern-day feeding systems are therefore concerned with (i) methods to describe the animal feedstuffs, (ii) evaluation of the effect on animal response of the ingested nutrients and (iii) the development of suitable predictive routines (normally based upon empirical equations, but as we look to the future, augmented or replaced altogether by mechanistic models) to determine how a desired level of performance can be achieved using various diets or dietary constituents.

As they move into the new millennium, livestock farmers are faced with new challenges. Animals of higher genetic potential have been produced, although in many parts of the world punitive legislation has been introduced to limit the pollution of land and water courses caused by their intensive production. Public concern over animal welfare and the use of genetically modified crops has meant that intensive livestock farming is now less acceptable in certain parts of the world and we are uncertain if this trend is set to continue. Fish and crustacean agriculture has increased more than threefold over the past decade, to a point where farmed fish consume 3 to 4% of total world feed production, bringing with it many problems of resource allocation and pollution control. Ownership of horses and companion animals has also seen unprecedented growth, largely due to the increasing affluence and leisure time of people in the more developed regions of the world.

Although our current feeding systems were developed on the back of a profusion of measurements, they are in fact based upon relatively few nutritional concepts. In the future it will be necessary to define feeds and feed ingredients more tightly to allow predictions to be made with much smaller margins of error whilst taking account of the environmental conflict of production and the quality of the resultant produce. Future rationing systems will therefore benefit from a greater insight into the effects of nutrition on the utilization of energy and protein within the body. Perhaps more importantly, the ability to predict responses and the partitioning of absorbed nutrients will only be achieved by a discriminating view of the biological processes which determine the animal's productive response to its feed. By assembling the feed evaluation methods, feeding systems and feeding models available for livestock production today, we believe that we will be assisting in the development of the new feeding systems of tomorrow.

The scope of the book is best seen in the Contents, but for ease of exposition it is arranged in three sections: methods, systems and models. The chapters stand fairly well alone and can be read out of sequence. While we have tried to cover the areas we judged most relevant to the agricultural scientist, inevitably our own experience and competence and those of our contributors have greatly influenced the choice of topics and their depth of treatment. None the less, all concerned with researching and teaching animal agriculture should find this book of value, including those involved in extension work. The book should also be essential reading for graduate students, and undergraduates of the nutritional sciences could derive much benefit from its study.

ACKNOWLEDGEMENTS

We would like to acknowledge the proof reading contributions made by Geoff Alderman and Lori Jones, and the significant organizational and word processing skills of Christine March.

M.K. Theodorou and J. France

Contents

1 Feed Evaluation for Animal Production

J. France[1], M.K. Theodorou[2], R.S. Lowman[3] and D.E. Beever

[1]*The University of Reading, Department of Agriculture, Reading, Berkshire;*
[2]*Institute of Grassland and Environmental Research, Aberystwyth, Ceredigion;*
[3]*Brackenhurst College, Southwell, Nottinghamshire, UK*

INTRODUCTION

This chapter outlines the role of feed evaluation in animal production, providing an overview of feed evaluation methods, current feeding systems and empirical and mechanistic modelling, and attempts to link these methods, systems and models.

THE NEED FOR FEED EVALUATION

Animal production is concerned with providing food (and clothing) of animal origin for man. Animal production science, which underpins this goal, provides the rational basis for livestock management practices. Feed evaluation concerns the use of methods to describe animal feedstuffs with respect to their ability to sustain different types and levels of animal performance. In feed evaluation, emphasis is placed on determining specific chemical entities, although the physical characteristics of the feed are also important. Subsequently, the acquired data are used, with appropriate animal indices, in feeding systems comprising suitable predictive routines (normally based on empirical equations) to determine whether a desired level of animal performance can be achieved from various diets.

The practical goal of feed evaluation is to optimize the efficiency of feed utilization, animal output and, ultimately, financial return to the producer. In this context, it is important to establish the potential of major feedstuffs and the need for appropriate supplements in order to overcome nutritional deficiencies and raise the level of performance. With respect to the animal, the level of performance will be dictated by the amount of feed voluntarily consumed and the efficiency of utilization of the major nutrients, namely energy and protein. Furthermore, the composition of the animal products (e.g. fat and protein in

 Feeding Systems and Feed Evaluation Models (eds M.K. Theodorou and J. France)

meat and milk) is important, as energy retention *per se* is no longer an adequate index of the performance of the animal or of the nutritive value of the feed.

To meet the requirements, recourse to the feedstuff and characterization of the appropriate indices that are thought likely to influence the level and type of animal performance is necessary. In this chapter, consideration is given to identifying the most important indices, and how these can be used to improve the prediction of animal performance. This is done with reference to the ruminant, as ruminant species have a central role in animal production; other chapters in this volume are concerned with the performance of the monogastric animal.

DIGESTION AND METABOLISM

The first stage in the identification of the most important indices is a consideration of the biology and chemistry of the feed and the links between feed composition on the one hand and output of animal products on the other. It is therefore essential to understand how feed is digested and the main metabolic pathways occurring within the animal.

For most diets, extensive degradation and fermentation of the digestible nutrients occurs within the rumen. Plant cell walls contribute the bulk of the available carbon and energy in the rumen, although soluble sugars, including fructans in grasses, can make a significant contribution, particularly during the initial fermentation period, due to their rapid degradation. Degraded carbohydrates are either used directly by the microbial population in the synthesis of microbial biomass or are fermented with the concomitant production of ATP, which is essential to meet the energy requirements of the population. The fermentation process is associated with the production of volatile fatty acids (VFAs), the extent of VFA production (i.e. moles produced per gram of carbohydrate fermented) being related to the maintenance requirements and growth rates of the microorganisms. The molar proportions of individual VFAs reflect the metabolic activities of the dominant microbial species, whose presence is in part regulated by the type of feed consumed.

Unless significant quantities of undegradable protein are included in the diet, a large proportion of the ingested protein is degraded to amino acids, with further dissimilation by microbial deamination to ammonia. Microorganisms incorporate both amino acids and ammonia into microbial protein, but ammonia is the major precursor. Efficiency of capture of degraded nitrogen (N) is known to vary, and depends upon the availability of N substrates (e.g. ammonia or amino acids) and energy (ATP). When ruminally degradable N is supplied in excess, the efficiency of microbial N capture falls, absorption of ammonia from the rumen increases and microbial protein flow to the small intestine is reduced (in relation to N supply).

The supply and absorption of starch from the small intestine is low on most diets, the most notable exception being diets containing ground maize, where up to 30% of the ingested starch can escape rumen degradation and be

absorbed as glucose from the small intestine. Protein and lipid digestion and absorption are the other major activities occurring in the small intestine, whilst processes in the caecum and colon are confined largely to the fermentation of residual carbohydrates, with the resultant production of some VFAs to augment the major contribution from the rumen.

Thus, degradation and fermentation in the rumen and digestion in the hind-gut influences the quantity and quality of nutrients absorbed, and these processes are affected by nutrient interactions especially with respect to energy and protein.

At the tissue level, nutrient utilization depends upon the nature and quantity of the absorbed nutrients and the physiological and hormonal status of the animal. A priority of the animal is maintenance of body function, which requires the supply of ATP via oxidation, with acetate being a major precursor. Equally, obligatory protein turnover requires the diversion of some absorbed amino acids to refurbish existing tissues. These costs can be considered as essential maintenance costs but, due to other inefficiencies within the tissues, they do not reflect the total loss of energy and protein at the tissue level.

The mechanisms controlling protein synthesis and protein degradation have yet to be fully elucidated. There have, however, been many attempts to manipulate protein metabolism by the use of exogenous hormones to widen the gap between synthesis and degradation, so permitting an increased deposition of tissue protein. Protein synthesis *per se* is influenced by the quantity of amino acids arriving at the productive tissues and the composition of these amino acids in relation to the amino acid composition of the tissue or milk being synthesized. Inefficiencies in the transfer of absorbed amino acids to tissue (or milk) protein occur, and this has led to the development of specific amino acids (methionine and lysine) as feed additives protected from degradation in the rumen.

The synthesis of milk fat and body fat from acetate requires glucose to supply glycerol-6-phosphate and NADPH, as an essential cofactor. Propionate augments the supply of glucose absorbed directly from the gut whilst, in situations of acute glucose insufficiency, gluconeogenesis of amino acids occurs. In excess of requirements, the efficiency of acetate disposal declines, excessive oxidation of acetate occurs via futile cycles, and heat production ensues. This in turn acts as a negative feedback on voluntary feed intake, along with plasma acetate levels, which increase under such conditions.

METHODS USED IN FEED EVALUATION

Once the nutrient requirements of the animal have been established, a diet that provides the correct balance of nutrients can be formulated if accurate information on the feedstuffs is available. The vast majority of feedstuffs consist of plants and plant products, though products of animal origin such as fish meal, meat and bone meal, and milk are also fed.

Ruminants are fed predominantly on forages, either in the form of grazed pasture or after conservation, usually as silage. Most silage is made from grass

but, increasingly, alternative crops such as forage legumes, forage maize, whole crop cereals, kale, etc. are being used as a source of conserved feed. Concentrate feeds, high in carbohydrates, e.g. cereal grains, or in proteins, e.g. soybean, may also be fed, depending on the level of animal performance required.

Due to their very nature, concentrate feeds generally show little variation in composition. Forages, however, are extremely variable, their composition being highly dependent upon the stage of growth at harvest (or at grazing), the plant species, the proportion of leaf to stem, the fertilizer treatment, etc. Young grass, especially if heavily fertilized, is high in protein and non-protein nitrogen compounds but low in soluble and cell wall structural carbohydrates; the cell wall is relatively unlignified and is therefore highly degradable. At the other extreme, mature grass is high in structural carbohydrates but the cell walls are highly lignified and of low digestibility. Moreover, mature grass, although generally high in available carbohydrates, such as fructans, is low in protein.

The composition of silage tends to reflect that of the crop at the time of ensilage, at least with regard to the structural plant cell wall components. Important differences include (i) the low pH of the silage brought about by fermentation of the soluble carbohydrates to form organic acids, mainly lactic acid, by the ensilage bacteria (lactic acid bacteria) and (ii) the fact that proteolysis (partially mediated by plant enzymes) has increased the proportion of non-protein nitrogen in the resultant silage. Similar considerations apply to alternative crops such as forage legumes and forage maize for example, except protein and starch, respectively in these crops survive the ensilage process and are important available protein and energy constituents of the resultant silages.

Chemical Analysis

The analysis of ruminant feeds generally involves determining the dry matter (DM), organic matter (OM), structural carbohydrate (fibre or non-starch polysaccharide, NSP), soluble carbohydrate, starch (where applicable) and crude protein (CP) content of the feedstuff. Silages require further analysis, notably for their pH, ammonia N and organic acid contents; recent research suggests that their true protein content should also be characterized.

The DM of a feedstuff is usually determined by oven drying at 60 or 100°C, whilst silages require special treatment (e.g. toluene DM determinations) due to their high content of volatile organic acids; thus DM is usually determined by distillation. OM is determined by dry ashing (at 500°C until all the carbon has been removed); the residue or ash can be used to determine the content of individual mineral elements in the feedstuff.

The most widely used methods for analysing the structural constituents, or fibre, are the detergent extraction methods of Van Soest. These methods involve extraction of plant biomass with neutral detergent to leave a fibrous

residue of predominantly cellulose, hemicellulose and lignin (i.e. the neutral detergent fibre or NDF of plant cell walls) or with acid detergent to leave a residue of cellulose and lignin (i.e. the acid detergent fibre or ADF of plant cell walls). As these are gravimetric procedures, the exact composition of the NDF and ADF residues is not known. The fibre content of a feedstuff may be described more accurately by NSP analysis, whereby alditol acetate derivatives of carbohydrate monomers derived from acid hydrolysis of washed, polymeric, de-starched samples are quantified by gas chromatography. With NSP analysis in addition to obtaining details of the chemical composition of the fibre, the values measured are independent of food processing and storage, and hence the amounts present can be quantified more accurately.

Crude protein content is calculated from the nitrogen (N) content, determined by the Kjeldahl procedure involving acid digestion and distillation. More recently, Dumas methods, involving combustion and determination of released gaseous N, are being used. Ammonia N in fresh silage is determined on water extracts by either distillation or use of specific ion-sensitive electrodes. These methods measure N rather than protein; the quantity of N is therefore multiplied by 6.25 (assuming the N is derived from protein containing 16% nitrogen) to obtain an approximate protein value.

In recent years, near infrared reflectance spectroscopy (NIRS) has also been adopted for determining the composition of feedstuffs. In terms of accuracy, precision, speed and unit cost of analysis, the NIRS technique, provided it is calibrated correctly, is preferable to traditional laboratory methods. However, the technique ultimately relies on a set of stan ard samples whose composition has been determined by traditional methods.

Digestibility

In addition to chemical composition, several methods have been developed to characterize feedstuffs in terms of their digestibility. These comprise *in vivo*, *in situ* and *in vitro* methods. *In vivo* measurements provide the standard measure of digestibility as they represent the actual animal response to a dietary treatment. However, such trials cannot be considered routine in most laboratories, and cannot be carried out for all the possible feeding situations found in practice. Therefore, a number of *in vitro* and *in situ* methods (e.g. batch culture digestibility, enzyme digestibility, gas production, polyester bag) have been developed to estimate digestibility and the extent of ruminal degradation of feedstuffs, and to study their variation in response to changes in rumen conditions. Thus *in vitro* and *in situ* techniques may be used to study individual processes, providing information about their nature and sensitivity to various changes. This information is of great importance in the development of mechanistic models.

SYSTEMS OF FEED EVALUATION

Despite the apparent complexity of nutrient metabolism, current systems (see, for example, AFRC, 1993) to predict energy and protein utilization and voluntary intake are relatively simple. This *per se* does not suggest that they are inadequate, as the value of such must be judged against their ability to predict animal performance accurately in practice.

Energy Concepts

Metabolizable energy (ME) is the currently accepted unit of energy, representing an approximation of the total amount of energy available for metabolism, without characterization of that energy with respect to specific nutrients. In practice, few direct estimates of ME contents are available, and many are derived from digestibility and urine output measurements, conducted at maintenance levels of feeding with mature sheep, and adjusted for estimates of methane production. Alternatively, for forages and compound feeds, frequently ME contents are predicted from laboratory assessments (e.g. *in vitro* digestibility) and previously derived relationships.

It is difficult to assess to what extent these procedures bias the estimate of ME content. In general, however, current approaches to determine ME content and hence ME intake are considered satisfactory, but estimates of the efficiency of utilization of ME for maintenance (k_m), growth (k_f) and lactation (k_l) are subject to doubt. Currently, estimates of diet metabolizability (ME gross energy^{-1}, or q) are used in predictive routines to determine efficiencies of energy utilization, with some recognition of different dietary classes (e.g. primary and re-growths of forage; mixed diets) being reflected in the equations used to predict k_f. This is probably an oversimplification of the processes involved. From the data on growing cattle in Table 1.1, it can be seen that energy retention predicted by the AFRC system is substantially greater than that obtained from comparative slaughter, suggesting that the metabolism of growth is represented insufficiently. A major criticism of current energy

Table 1.1. Comparison of energy retention (MJ day^{-1}) obtained by comparative slaughter (CS) and predicted by AFRC.

Diet		Energy retention (MJ day^{-1}) estimated by	
Silage	Barley (g kg^{-1} total DM)	CS	AFRC
Late cut	0	5.5	9.5
Late cut	280	9.2	13.3
Late cut	560	14.6	15.7
Early cut	0	12.2	18.0

Source: Beever *et al.* (1988) and AFRC (1993).