WORLD ANIMAL SCIENCE B
DISCIPLINARY APPROACH
FEED SCIENCE

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WORLD ANIMAL SCIENCE

B

DISCIPLINARY APPROACH

4

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Editor

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FEED SCIENCE

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General Preface

Several factors make it desirable at this time to collect and integrate existing knowledge in Animal Science in its widest sense.

Millions of people in the world are today suffering from starvation or malnutrition and the number will increase with the inevitable rise in the world population. This poses an inexorable challenge to all scientists involved in problems underlying the production of food for man. Yet the development of livestock industries does not only aim to improve the nutritional standards of the human population, important though that is. From man's point of view animals are multipurpose and their use can have different objectives: economic, social and ecological. In addition to being important as sources of food, clothing and certain forms of power, animals can also represent forms of wealth, recreation, means of employing labour, aesthetic enjoyment, and determinants of landscape.

Animal production must increasingly compete with other forms of production for resources, especially energy, but also for land, water, finance and labour. This creates a greater need than ever to develop systems which maximize efficiency. At the same time, these systems need also to meet other requirements. They must be environmentally beneficial, ethically defensible, socially acceptable, and relevant to the particular aims, needs and resources of the community they are designed to serve.

Rapid advances in knowledge within practically all areas of the animal sciences are now being made. Solutions to many of the problems which face the livestock producer, whether he is working in, say, a cattle feed-lot in the U.S.A. or in a traditional system of village goat production in West Africa, are now resulting from the research being carried out in the various disciplines of Animal Sciences. However, too often the results of this research remain confined to the specialized journals of different scientific disciplines when, increasingly, the approach of those working in animal production needs to be interdisciplinary and global. Furthermore, Animal Science has attained a new dimension in recent years. Whatever form it takes, animal production constantly influences and interacts with the other components of the total ecosystem within which it operates. New disciplines, like ecology, ethology and conservation have become important; new forms of production, such as aquaculture and the use of non-conventional feed resources are receiving increasing attention.

The scientists and planners in animal production have to work within the framework of these developments. Extensive inquiries among such specialists in many parts of the world have revealed the need for a comprehensive and up-to-date review of the Animal Science literature covering the entire range of technical knowledge that is now required in animal production and development. Therefore, Elsevier Science Publishers has initiated this major work of reference under the title 'World Animal Science'. Inevitably, such a task must cover many volumes and involve the collaboration of a great number of editors and authors. Through an elaborate preparatory phase and with continuous editorial guidance from the Chief Editors and the Editorial Advisory Board, including scientists from all parts of the world, the aim has been to produce an integrated series of volumes which, although not encyclopaedic and not intended to be exhaustive in each branch of knowledge, does give appropriate emphasis to coherence and applicability. With this in mind the series has been divided into three parts: the volumes in subseries A provide information on the anatomical, genetical, biochemical, behavioural, physiological and micro-biological bases of animal production; those in subseries B are each devoted to a particular discipline important to animal production, e.g. reproduction, breeding, feed science, bioclimatology and adaptation; and finally, in subseries C, production systems are described on a species basis, covering beef and dairy cattle, sheep, pigs, horses, buffaloes, poultry and some newly or partially domesticated animals.

Emphasis is laid throughout on the careful reviewing and integration of significant knowledge in the total field of animal production with the aim of reporting not only what is known but also of drawing attention to important gaps in our knowledge. Account is taken of current trends in thinking and development and controversial topics are also dealt with, e.g. ethical aspects of animal use. Traditional farm animals, i.e. cattle, horses, sheep, goats and pigs, are given major emphasis and their production systems are treated in special volumes. There are also separate volumes on the conservation and use of their genetic resources. Other forms of animal production, such as poultry and fur production, are given less attention in the early volumes but still have their special volumes dealing with production systems. Other topics of less over-all importance, or about which less is known, are treated in separate chapters within volumes. Because of the increasing importance of animal production in less developed areas of the world, attention is paid to domesticated mammals such as buffalo, camel, lama, alpaca, yak, reindeer and elephant, and to such newly or partially domesticated mammals as the eland, oryx, red deer and musk-ox. The series deals with both intensive and extensive animal production systems. In this way an attempt has been made to set the whole of world animal production into an appropriate and contemporary perspective.

Although, by editorial concept and by cross-referencing between volumes, the series functions as a single entity, each volume is nevertheless constituted as an independent unit, suitable for separate use. To achieve this and still avoid undue overlap, each volume only summarizes those essential elements of topics which are treated in detail in other volumes. Thus each volume aims to approach the breadth of World Animal Science from its own particular point of view, with supporting references to details in other volumes.

The series is written primarily for use by people who have a specialist interest in animal production as students, teachers, extension officers and consultants, policy-makers, and research scientists. The volumes are planned for world-wide use, which implies that the information presented covers systems and principles of more than local or national interest.

Preface

In recent years there has been a very rapid progress in knowledge on feed science and if the progress is equally rapid in the next two decades this book will soon be outdated. The main reason for the progress is the development of new tools which have enabled nutritionists to make new discoveries by viewing the subject from different angles. Even so the progress is obviously linked to past achievements and the authors of this book have both reviewed the subject and pointed to future goals and the first chapter is an excellent account of development of feed evaluation systems.

The new tools relate particularly to advances in microbiology and plant biochemistry which have enabled a much clearer description of the transformation of feeds to products of absorption. The transformation of cellulosic materials through a microbial fermentation in ruminants has been discussed together with the more simple digestion in monogastric animals. Energy metabolism in both ruminants and nonruminants has received a great deal of attention in the chapter here and the methods of feed evaluation which have been adapted by different countries. The greater understanding of animal physiology and biochemistry has also helped to point towards future methods of feed evaluation. New systems of protein evaluation have been described which enable much more precise estimates of protein supply and of the need of the animals.

The latter chapters describe practical aspects of feed preparation and processing and feed preservation and how different feeds can interact with each other when mixed. The use of nonconventional feeds and by-products is also discussed.

Each chapter is compiled by leaders in their respective fields of study and I would like to take this opportunity to thank the authors for their contributions.

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Chapter 1

Feed Evaluation Systems: Historical Background

WILLIAM P. FLATT

1. INTRODUCTION

For almost two centuries it has been the practice of farmers to calculate the rations of their domestic animals and to plan their needs for feeds by using feeding standards as a practical guide. The feed evaluation system used to express the nutritional value of feeds determines the manner in which the nutritional requirements of the animal are expressed. A feeding standard usually consists of a set of tables, one of which expresses the nutritional requirements of the animal and another that gives the nutritional value of feeds. The tables, or in recent years, the formulae used in the computer programs, must be used together, rather than using the table or formulae of requirements from one standard with feed composition tables from another feeding standard. The reason for this is that there are many ways of expressing the nutritional values of feeds, and the standards for nutritional requirements of animals have been derived based on these values.

Many of the errors associated with evaluating feeds are partially compensated for by the different estimates of the nutritional requirements of the animals. It is not within the scope of this chapter to discuss feed evaluation systems and feeding standards in detail, but to provide a brief historical background of the development of these systems.

If optimum results are to be obtained in the production of meat, milk, eggs or other livestock products, the animals must be fed a well balanced ration containing adequate supplies of protein, minerals, vitamins and energy. In most, if not all, animal production systems a limited energy supply more frequently retards growth and limits production than does a deficiency of any other nutrient. Crampton (1956) stated that "The basic need of animals fed normal rations is for energy and this demand is the basis for most, and perhaps all, of the other nutrient requirements." Therefore, much of the emphasis in animal nutrition has been on systems of evaluating feeds on an energy basis.

Accurate methods of evaluating feeds are needed for several reasons. Feed evaluation systems enable livestock feeders to calculate rations for animals, to plan for adequate feed supplies, or to decide which feeds are the most economical to purchase. Accurate feed evaluation systems are also necessary for those who plan the export and import of feed supplies, for those who are evaluating the effects of various management practices, and for assessing the value of new varieties of forages as types of feed. With recent advances in biotechnology, which will potentially enable scientists to alter the genetic structure of plants and animals, an accurate method of evaluating feed would facilitate the use of genetic engineering as a tool to increase the efficiency of use of resources to produce animal products.

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The effectiveness of any system of feed evaluation is dependent upon how accurately it enables one to estimate the amount of a given feed or combination of feeds that should be fed to meet the nutritional, and particularly the energy requirements of animals. Feeds vary widely in composition, ranging from very poor quality forages or waste products to feeds with highly concentrated nutrient content. The most effective feed evaluation system is one which can be used to evaluate feeds differing widely in composition, ranging from low quality forages to high concentrate feeds so that one can interchange or replace various ingredients without unknowingly altering the nutritional value of the ration.

From a practical view a feeding system must, according to Garrett and Johnson (1983):

1. enable the value of feeds to be appraised as substitutes for one another,
2. permit determination of the quantity of a feed of given quality to support a particular management goal and
3. enable an estimate to be made of animal performance if feed intake and feed quality are known.

No single feed evaluation system has yet been developed that is both accurate and simple. In general, most workers agree that some form of net energy system (productive energy, starch equivalents, Scandinavian feed units, fattening feed units, milk production units) is theoretically the most accurate way to express the nutritional value of feeds and the requirements of animals. However, for practical reasons, such as simplicity and the amounts of data, digestible energy, total digestible nutrients (TDN) or metabolizable energy is used by many workers.

2. TERMINOLOGY USED TO EXPRESS ENERGY VALUES

A glossary of energy terms used in expressing the nutritional energetics of domestic animals was published by the National Research Council (NRC, 1981). The terms that are used to express energy are ergs, joules, calories, kilocalories, megacalories, therms and BTU's (British thermal units). The joule has been adopted internationally as the preferred unit for expressing electrical, mechanical, and chemical energy. Gross energy, digestible energy, metabolizable energy, net energy, and productive energy values of diets are usually expressed as calories per unit weight of food or feed. TDN, starch equivalents (SE) and feed units are usually expressed in units of weight (kilograms or pounds). Some of the energy terms used in animal nutrition studies are as follows:

joule (J): The joule is 10^7 ergs, where 1 erg is the amount of energy expended in accelerating a mass of 1 g by 1 cm s^{-1}.

calorie (cal): The amount of heat required to raise the temperature of 1 g of water from 16.5 to 17.5°C. This is equivalent to 4.184 j. In practice, both the joule and the calorie are so small that nutritionists work with multiple units.

kilojoule (KJ): 10^3 times greater than the joule

kilocalorie (kcal): 1000 cal

megajoule (MJ): 10^6 times greater than the joule

megacalorie (Mcal): 1000 kcal or 10^6 times greater than the calorie

therm (T): Essentially the same as 1 Mcal. It is used to express the net energy or productive energy of rations, but it is an ambiguous term, and Mcal is preferred.

Gross Energy (E): The energy released as heat when an organic substance is completely oxidized to carbon dioxide and water. It is often referred to as 'heat of combustion' and generally measured in an oxygen bomb calorimeter. The total intake of food energy is IE where I is the amount of food consumed and E is the gross energy per unit weight of food.

Apparently Digested Energy (DE): The food intake gross energy (IE) minus fecal energy (FE), including undigested food and the bacterial residues fraction of the feces.

Total Digestible Nutrients (TDN): Comparable to apparently digested energy. TDN is defined as digestible crude protein (DP) plus digestible carbohydrates plus 2.25 times the digestible crude fat.

$$TDN = DP + DNFE + DCF + 2.25\,(DEE)$$

Metabolizable Energy (ME): The gross energy of feed consumed minus energy lost in feces (FE), urine (UE) and combustible gas (GE).

$$ME = IE - (FE + UE + GE)$$

Recovered Energy (RE): Commonly called Energy Balance is that portion of the feed energy retained as part of the body or voided as a useful product. In animals raised for meat, RE equals TE, whereas in a lactating animal, RE is the sum of tissue energy (TE), lactation energy (LE), and energy in the products of conception (YE).

$$RE = TE + LE + YE$$

Net Energy (NE): The difference between metabolizable energy and heat increment (H_iE). Heat increment is the increase in heat production (HP) following consumption of feed when an animal is in a thermoneutral environment.

$$NE = IE_i - FE - GE - UE - H_iE$$

Starch Equivalent (SE): A net energy system of feed evaluation used in Germany and other European countries. One Kilogram of SE is equivalent to 2356 kcal net energy for fattening (NE_f). The system is based on work by Kellner and his successors (1900, 1905, 1926, 1956, 1966). SE values are calculated based on digestible nutrients and crude fiber of the diet.

Feed Units (FU): A net energy system of feed evaluation used in Scandinavian countries. Values of feeds are measured and expressed in relation to a reference feed, i.e. barley. One kilogram of FU is equivalent to 1650 kcal NE_f.

3. EARLY REFERENCES TO FEEDING ANIMALS

Historical aspects of feed evaluation have been covered in numerous textbooks (Wood, 1927; Brody, 1945; Morrison, 1956; Kleiber, 1961; Blaxter, 1962; Tyler, 1964; Breirem and Homb, 1970; Maynard et al., 1979). In addition, some excellent review articles on feed evaluation systems have been written that include numerous references to the early literature (Blaxter, 1950, 1955, 1956; Tyler, 1956, 1975).

The exact origin of feeding standards is unknown, but for many years persons have been estimating the nutritional value of feeds and using these values to determine the amounts of various feedstuffs to feed to domestic animals. According to Tyler (1956) in his review of the development of feeding standards for livestock, as early as 2500 BC, the Egyptians force-fed their fattening stock, suggesting that they realized that extra food gave fatter animals. Several references in ancient literature are made about feeding practices of horses and oxen. These indicate that they had at least a rudimentary understanding that food requirements were related to activity. For instance, the Hittite chariot master Kikkuli wrote a treatise in 1350 BC which dealt with the careful feeding of chariot horses (Tyler, 1956).

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Hippocrates (460–370 BC) believed that although there were many kinds of foodstuffs, there was only a single kind of aliment. He stated, "It is the nature of exercise to use up material, but of food and drink to make good deficiencies." Aristotle recognized that most of the fat in the animal body is deposited after bone and flesh have developed. Lucretius, in his *Nature of the Universe* written in the first century BC indicated an understanding of the relationship between maturity and balance of matter. Columella in the first century AD recognized that more feed was needed when oxen were working than when idle. He recommended 40 lb of hay when oxen were tilling the ground and only 30 lb when not doing so.

It was not until the eighteenth century that there was evidence that a systematic feed evaluation system was used. In 1725 straw feed units were used as a standard in Bohemia to compare the nutritive value of straw and hay (Herzig, 1954; Tyler, 1975). E. Lisle's posthumously published book (1757), *Observations in Husbandry*, stated that one load of vetches was better than two loads of hay. Bergen (1781) compared the nutritive value of several feedstuffs for pigs and cattle. Potatoes, barley, vetch, corn, turnips, carrots, rye, and hay were among the feedstuffs he compared, and he evidently conducted feeding trials to evaluate the feeds.

The use of hay as a standard for comparing other feedstuffs for oxen was also reported by an Englishman, Captain Middleton of Teeston, near Maidstone, Kent (Young, 1793). In experiments with stall-fed cattle he reported that one ton of good hay was equal in feeding value to:

8.0 t turnips, roots only;
8.5 t turnips in autumn and spring, weighing green tops;
6 t of Scotch cabbage;
3 t of carrots;
1 cwt linseed oil cake.

Several others also reported comparative values of feeding stuffs, including hay, before the turn of the nineteenth century.

4. HAY EQUIVALENT SYSTEM

A German medical doctor, Albrecht Daniel Thaer (1752–1828), who became director of an agricultural institute at Möglin near Berlin, is often credited as being the originator of the hay equivalent system of evaluating feeds. Thaer published four volumes of his book, *Grundsätze der rationellen Landwirtschaft* in 1809, 1810, 1810 and 1812. In the first volume, published in 1809, Thaer included a table showing the relative values of different feeds. Thaer's colleague, H. Einhof, a chemist, measured the solubility of various feedstuffs and it was his data that Thaer used in calculating hay equivalents. He used good meadow hay as the standard because it was better known and was more widely used than other kinds of fodder. Although the system of analyzing feeds was crude, the comparative feeding trials measuring animal responses were limited, and the choice of a variable feedstuff, hay, as the standard was a poor choice, the fact remains that the hay equivalent system was adopted and widely used with only minor modification for almost half a century.

Albrecht Daniel Thaer was, according to Tyler (1956), more interested in the relationships of various feedstuffs to the production of manure than in animal nutrition. However, later workers have attributed to him and Einhof the distinction of having developed the first systematic feed evaluation system, hay equivalents.

Thaer's (1812) early recognition that nutritional requirements were dependent upon the size of the animal and level of production is worthy of note.