Basic Animal Nutrition and Feeding

Third Edition

D.C. Church / W. G. Pond

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BASIC ANIMAL NUTRITION AND FEEDING

Preface

THIS BOOK, AS WITH the first two editions, is intended for students or other readers interested in the principles as well as the application of animal nutrition. As such, it is assumed that the reader will have a minimal knowledge of general chemistry, preferably some exposure to organic and biochemistry, and some understanding of animal biology and husbandry.

Over the past 60 years there have been tremendous advances made in animal nutrition and related fields. We are at the point now where essentially all of the essential nutrients have been identified. It is still possible that some additional mineral elements may be determined to be essential, and it is also possible that one or more vitamins may be added to the list. However, all of the known nutrients appear to be adequate to sustain animals on purified diets, therefore, any unidentified nutrients surely are not too important or are required in extremely small amounts. This is not to say that all of the nutritionally-related problems have been solved because much remains to be learned about nutrition and infectious disease, nutrition and many different stresses, and about various nutritional interrelationships. One is reminded of the comment by an anonymous person "That meeting nutritional needs is like filling a barrel to the nearest knothole. When the knothole is plugged, you can then proceed to fill the barrel up to the next knothole". Consistent with other sciences, as the head of water builds up, it puts more stresses on small unseen or unknown holes which may then spring a leak. In the writers' view we have the big knotholes plugged, but many small leaks remain to be plugged and new leaks may be expected to appear from time to time.

In any event, with a book of this type there is always a question of how much and what type of detail to present to the reader. The authors' preconception of the audience for the book may be correct and then it may not. Consequently, it is a matter of picking and choosing what to include or exclude. For this reason historical coverage has been omitted. More space could have been allotted on any of the subjects. For some readers there may be more information on nutrient metabolism than they might desire. Others will probably wish for more complete coverage in Part III on applied nutrition, especially with respect to more complete discussion of the various species and classes of animals. Regardless of the approach, some areas or subjects must be slighted in order to keep the size of the book within bounds and at a reasonable cost. Whatever the deficiencies of this book may be, it is hoped that it will serve a useful purpose by covering in broad scope a complicated and voluminous subject, and that it will serve to guide the student through the important areas of basic and applied animal nutrition.

D. C. Church and W. G. Pond

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PART 1

INTRODUCTION

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Nutrition and Its Importance in Modern Agriculture

NUTRITION IS A SUBJECT that interests many casual readers simply because they must eat to live and because, for most people, eating and drinking are pleasurable social experiences. If one needs added incentives to become familiar with the subject, there is the profit motive if one is dealing with domestic animals, or simply the desire to know more about the animal body, its functions, and its needs. In animal agriculture, adequate feeding of animals for production of meat, milk, eggs, or fiber is an essential component of the total enterprise. With regard to human nutrition it can be demonstrated very easily that nutrition may affect health and welfare, emotions, physical capabilities, and susceptibility to and recovery from disease; there is also the likelihood that the infirmities of old age may be delayed by adequate nutrition.

What is nutrition? A dictionary may define nutrition as "being nourished" or "the series of processes by which an organism takes in and assimilates food for promoting growth and replacing worn or injured tissue." These are, obviously, very simplified definitions. Nutrition today, as practiced by competent professionals, requires that the nutritionist be knowledgeable with respect not only to the nutrients, their function, occurrence, and to various interactions, but also with animal behavior and management, digestive physiology, and some aspects of biochemistry and analytical chemistry. In addition, knowledge is required in the fields of crop and soil science, endocrinology, bacteriology, genetics, and disease as related to nutrient needs and dietary requirements.

Although a very wide base of knowledge may be necessary for a thorough understanding of the subject, this is not to say that most people will not benefit from some knowledge of the fundamentals of animal nutrition. For example, one does not need to be a complete nutritionist to appreciate that vitamins are important to the animal body and that they may be required in different amounts during growth, maintenance, or lactation.

Animal nutritional science is partly the outgrowth of observations by animal husbandryists and livestock feeders over many centuries and, more recently, by teachers and scientists. Consulting nutritionists and veterinarians also provide input, particularly on aspects of applied nutrition. The quantitative aspects—the ability to describe nutrient requirements for different species in various situations, definition of deficiency signs and symptoms, and the metabolism of nutrients—are the result of countless experiments carried out by scientists throughout the world, primarily with domestic and laboratory animals, but also with various animal tissues or microorganisms and, to a lesser extent, with humans. For example, the laboratory rat has made a tremendous (but involuntary) contribution to our knowledge of vitamins, amino acids, minerals, and toxicants. The dog played an important part in the discovery of insulin and the discovery of the role of nicotinic acid in the prevention and cure of pellegra, and the guinea pig was the animal model used to elucidate the cause and prevention of scurvy. Hamsters, monkeys, and other laboratory species have all played a role in expansion of the knowledge of nutrition.

Nutritional science has progressed at a rapid rate because of the availability of different types of models (tissue cultures, bacteria, laboratory animals, etc.) to substitute for various domestic species or humans. Such procedures have been used to collect and develop information that might be impossible to obtain with the target species. This may be so because of the cost or the inability to subject animals (humans, in particular) to a research regimen for a long enough time to get meaningful results.

Nutrition, as with other biological sciences, does not have the precision that is possible in a physical science. This is primarily because biological organisms are quite variable. In higher animals, geneticists say that no two are exactly alike; also, the environments that any two animals are exposed to are nearly always different, thus nutrient needs are apt to be different.

Animal nutrition, as practiced today, requires that the nutritionist be able to formulate diets, rations, or supplemental feeds that are sufficiently appetizing to ensure an intake adequate (but not necessarily maximal) for the purposes desired. He or she must nearly always take into account the cost of the supplemental or total mixture, and formulated rations should supply adequate nutrients without detrimental imbalances for the desired level of production. He or she must take into account the need for and required level of growth promotants, medicants, or other non-nutritive additives. In addition, the rations so formulated must have adequate milling, mixing, handling, and storage properties. A nutritionist may be called on to know or to do numerous other things, but these functions would seem to be the minimum that should be expected.

The great increase in the body of scientific nutritional information in the past 50 years has resulted in the specialization of nutritionists as with scientists in other fields. The first broad classification would be either human or animal nutrition. In human nutrition, clinical nutrition is an important field that deals with such subspecialities as weight reduction, dietetics, prenatal care, inborn diseases, diabetes, pediatrics, parenteral nutrition (given by means other than oral), and other similar topics. Community nutritionists are involved in such areas as nutrition education and school lunch programs, and those in commerce work in areas of marketing and nutritional evaluation of food products.

In the animal field, most nutritionists specialize in either nutrition or monogastric (simple-stomached) or ruminant (multicompartmented stomach) animals. Those dealing with monogastric species may be involved with poultry (chickens, turkeys, ducks, geese, etc.), swine, horses, pets (dogs, cats), fish and other aquatic species (relatively new), laboratory species (rats, mice, guinea pigs, monkeys, etc.) or captive animals in zoos. In the ruminant fields, specialities include sheep, goats, wild or captive species, dairy cattle, and beef cattle, the latter often being divided into cow–calf and feedlot specialities. As in other scientific areas, specialization allows the individual to become and stay more familiar with new literature and commercial practices than if one attempts to keep abreast of the total field of animal nutrition.

In addition to the previously mentioned specialities, it is rather common (particularly in the animal field) to find that one group of individuals tends to be highly oriented toward laboratory work and the biochemical metabolism of nutrients—often on a subcellular basis. Another group is more oriented toward animal production (whole animal or orientation toward organs rather than toward cellular or subcellular metabolism). Of course, different areas of expertise are required to do amino acid analyses of protein than are required to collect data on animal performance, egg quality, and so on. In practice, teams of individuals with different specialities often produce more complete and imaginative research results than the same people when working individually.

❑ CURRENT STATE OF THE ART

The great French chemist, Antoine Lavoisier (1743–1794), is often referred to as the founder of the science of nutrition. Following the early studies in the eighteenth century, progress was relatively slow in the nineteenth century. The need for protein, fat, and carbohydrates was recognized and most of the research emphasis was on these nutrients or energy utilization along with a gradual development of data for some of the mineral elements. The major portion of our knowledge of nutrition has been developed since the 1920s when some of the vitamins were first discovered. Since that time there has been a great accumulation of data on vitamins, the role of amino acids, essential fatty acids, macro- and microminerals, energy metabolism, and on nutrient requirements and nutrient deficiencies.

Today, we recognize more than 40 nutrients are needed in the animal diet (the number depends on the animal species) in contrast to the three nutrients that were recognized early in the nineteenth century. There is still some uncertainty on some of the mineral elements, and some nutritionists believe that additional vitamins will be discovered. Certainly, the unknown nutrients must not be highly important (or are needed in very small amounts) since domestic animals can be maintained through a complete reproduction cycle when fed purified diets made up of such ingredients as cellulose, starch, sugar, fat, purified proteins such as casein, mixtures of mineral salts, and purified vitamin sources.

Developments in nutrition have been facilitated greatly by improved analytical techniques (see Ch. 3) and a vastly greater knowledge of chemistry and biochemistry, animal physiology, and other related sciences. It has been only in recent years that data have been developed to show that some of the mineral elements may be required by animals. Information on mineral nutrition, in particular, has been greatly facilitated by instrumentation capable of detecting some of these elements in the parts per billion range.

Nutrient needs for chickens have been defined more precisely than for any other domestic species. The requirements of chickens for amino acids, essential fatty acids, fat- and water-soluble vitamins, energy, protein, and most of the minerals are known with reasonable certainty. Such information is less available for swine and even less so for horses and rabbits. Likewise, information for ruminant animals (cattle, sheep, goats) is less precise than that for chickens.

There are several explanations for these differences. One primary reason is that poultry are grown under much more uniform conditions than other domestic species. Broiler or layers are usually hybrids and many of the birds in a flock will be full sibs, both factors resulting in more uniform flocks. In addition, the age and weight of broilers that are marketed is relatively uniform and they usually are grown under rather similar conditions regardless of the geographical location. Furthermore, there is a tendency to feed them very similar diets, regardless of where the birds are grown. All of these factors make it less difficult to determine the nutrient needs of chickens (or turkeys) compared to other species.

There has been a gradual and continual improvement in commercial diets, resulting in more efficient animal production. One example of the effect of such changes is shown in Table 1.1, which compares performance of hens fed a diet typical of 1951 with a diet typical of 1977. This demonstration was done with 1977 birds fed 1951 and 1977 diets. Note that longevity, egg production, efficiency of feed utilization, and costs have been improved considerably during this period. Genetic improvements also have been made in the birds, but this example was not designed to show such changes. In general, the same trend in nutrient utilization and increased production is evident for the other domestic species, although the amount of improvement probably has been greater for poultry because of some of the reasons mentioned previously.

In the field of human nutrition, even with our relatively advanced knowledge on the topic, malnutrition remains a very important factor in the underdeveloped and developing countries and among the poor in other countries. Surveys that have been taken by world health organizations indicate that very important problems for the young include nutritional marasmus (deficiency of energy, protein and possibly other nutrients), kwasiorkior (deficiency of protein quality and/or quantity), and vitamin A deficiency. For all ages, iodine deficiency (goiter) and nutritional anemias (iron, vitamin B_{12}, folic acid, and other nutrients) remain severe problems.

TABLE 1.1 Egg production data on 1951 and 1977 formulas[a]

ITEM	FEED[b] 1951	FEED[b] 1977	1977 AS % OF 1951
Mortality, %	10.6	7.5	70.8
Egg production, %	65.9	76.4	115.9
Egg production, av.	104.5	123.2	117.9
Feed/doz, eggs, lb	3.57	3.12	87.4
Egg wt, oz/doz	23.1	23.9	103.5
Pounds feed/lb eggs	2.47	2.08	84.6
Return over feed cost/hen, $	1.58	2.04	129.1

[a]From Sherwood (1).
[b]Hens were on test for 24 weeks.

❑ THE ROLE OF ANIMALS IN MEETING WORLD FOOD NEEDS

There have been marked improvements in crop production in the past 40–60 years. The development of hybrid corn and sorghums has resulted in almost universal use of hybrids in all areas of intensive production. At the same time, important crops such as corn and soybeans have been modified so that they are more adaptable to a wider range of environments. The so called "green revolution," which resulted in the development of high yielding varieties of rice and wheat and their widespread use on a world-wide basis, has allowed substantial increases in foodgrain production. In addition, widespread use of higher levels of fertilizer, pesticides, herbicides, and other chemicals has added to the amount of food and feed that has been produced. The statistics and projections shown in Table 1.2 illustrate how world production has increased and how it must continue to increase if the human population is to be fed. These projections call for an increase of 188% for wheat

TABLE 1.2 World production and use of grains in relation to the world human population.

	YEAR			
ITEM	1960[a]	1980[a]	1985–86[b]	2000[a]
Population				
billions	3.038	4.415	4.845	6.098
Total Grains[c]				
Production	842	1,450	1,661	2,177
Food use	444	714		1,106
Food use per capita, kg	147	162		181
Other use	406	737		1,071
Total use	850	1,451	1,583	2,177
Coarse Grains				
Production	465	746	843	1,068
Food use	138	180		228
Food use per capita, kg	46	41		37
Other use	325	559		841
Total use	464	739	780	1,068
Wheat				
Production	237	442	503	682
Food use	175	292		486
Food use per capita, kg	58	66		80
Other use	70	157		197
Total use	245	449	490	682
Rice				
Production	140	263	315	427
Food use	130	243		393
Food use per capita, kg	43	55		65
Other use	11	21		34
Total use	141	263	313	427

[a]From ref. 2; data for 1960 and 1980 are averages of three years centered on 1960 or 1980. Values for 2000 are estimated on an standard rate of increase in population.
[b]Data from ref. 3. Projected production and consumption.
[c]Values expressed as millions of metric tons except for the per capita values on human use, which are in kg.

and 205% for rice production for a doubling of the human population.

Currently some countries such as India, Malaysia, and Indonesia, which were net importers of food grains for some time, are exporting surplus rice. At the same time there has been an increased consumption of animal products in many of the Asian countries.

Although increases in production of some cereal grains are probably higher percentagewise than those for animals, animal productivity has been improved considerably in the past three to four decades. Production of milk, meat, and eggs is markedly higher on a per animal basis, resulting in more efficient use of feed, labor, land, and capital. Aquaculture is becoming more important in a number of areas; where water is available, production of fish is more efficient than meats from our typical warm-blooded animals.

Even with the many marked improvements in crop and animal production, there is much concern that the population growth may outrun the world's capacity to produce food and feed because of limited arable land, usable water, and energy. Water for irrigation is in short supply in many areas. In some instances where ground water has been used for irrigation, the water level has been dropping, resulting in greater costs to get it to the surface. Increased energy costs, unless compensated for by comparable increases in product prices, will make it less feasible to use ground water for irrigation. Likewise, increasd prices for natural gas and other petroleum products directly affect fertilizer costs because some manufacturing processes use natural gas as a primary ingredient.

Many people feel the rising demand for food and feed can be met by continual technological developments, improvements in marketing, and reduction in wastage. However, the critical shortage of water predicted by some individuals may, in itself, be a very big hurdle to overcome.

Animal products seem certain to have a major role in meeting increased demands in the future, although it is to be expected that animals will be fed less and less of the edible plant materials that are used in feeds currently, particularly in some of the developed countries. One reason for predicting less use of animal products in human diets in the future is that it is less efficient to pass food (edible for humans) through an animal and then feed the meat, eggs, or milk to a human. Furthermore, grains sold for human food bring a higher price than animal feeders can usually afford. These statements apply to items that can be considered edible by humans, but not to many of the feed ingredients consumed by domestic or wild animals. This premise is illustrated in Table 1.3, which shows that food edible to humans can be utilized efficiently by domestic animals, the reasons being that the bulk of the animal's diet can be made up of ingredients that are not edible for humans. In fact, in most areas of the world, the milk and meat produced by cattle, sheep, buffaloes, and goats is derived directly from grazing land not in cultivation and from crop residues, milling by-products, or wastes that normally never get into the food chain. On the other hand, a considerable amount of feed fed to animals in some countries is directly competitive for human use. It has been estimated that feed fed to pets in the USA could feed some 40 million people, although some pet food ingredients (animal offal of various types such as lungs, condemned livers, etc.) generally are not considered as edible in the USA.

Future developments in animal and human nutri-

TABLE 1.3 Inputs and returns of animal production.[a,b]

	TOTAL ENERGY AND PROTEIN				HUMAN EDIBLE ENERGY AND PROTEIN			
	ENERGY		PROTEIN		ENERGY		PROTEIN	
PRODUCT	INPUT, MCAL	RETURN, %	INPUT, KG	RETURN, %	INPUT, MCAL	RETURN, %	INPUT, KG	RETURN, %
Milk	19,960	23.1	702	28.8	4,555	101.1	111.5	181.4
Beef	20,560	5.2	823	5.3	1,869	57.1	39.9	108.8
Swine	1,471	23.2	66	37.8	588	58.0	29.0	86.0
Poultry	23.2	15.0	1.2	30.0	11.2	31.0	0.48	75.0

[a]Data from Bywater and Baldwin (4).
[b]Inputs are calculated as digestible energy and digestible protein and include cost of maintaining breeding herds and flocks.

tion are not highly predictable because many unknowns cannot be forseen. However, we can be certain that animals will be important to man for many years to come and it is important to continue to expand our knowledge of the subject of animal nutrition in order to be able to take advantage of any conditions that do develop in the future. As the reader progresses through this book, it will be evident there are many remaining gaps in our knowledge. Given time and resources, the deficiencies will be remedied gradually by the students of today who are the scientists and livestock producers of tomorrow.

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