Second Edition

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D.C. Church

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D.C. Church, Ph.D.
Ruminant Nutritionist
Senior Author & Editor

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Preface to the Second Edition

It is a formidable task to present sufficient information in a readable and understandable form on the topic of feeding livestock. This is particularly so because the background knowledge of the users of this book will vary from that of students with little knowledge of the topic to readers in the feed industry, farmers, ranchers, veterinarians and others with a rather wide range of knowledge and experience in the raising, feeding and husbandry of animals.

Information presented in this book is, for the most part, given without a great deal of theoretical explanation. This has been done for two reasons: (a) because many readers, particularly less advanced students, may easily lose sight of the primary topic if excessive explanations are given; (b) secondly, a considerable amount of space devoted to explanations would result in an appreciable expansion of the book size.

Information on chemical composition and animal utilization of feedstuffs and diets is being accumulated continually. In addition, more exact information is now available on nutrient needs of animals as affected by genetic and environmental factors, although much still remains to be developed. Data presented throughout the text have been given in either English or metric units. Both types have been used because many readers will be from countries which use the metric system. Secondly, sooner or later, the USA will be forced to go to the metric system. More exposure to it will do no harm and might help to encourage the change. Hopefully, such usage will not be confusing to the reader.

In addition to the 24 chapters which present information on feeds, feed processing, additives, ration formulation, etc., or on needs of different species and classes of domestic animals, tabular data are given in the Appendix on feed composition and nutrient requirements of animals. This information on revised nutrient requirements will be updated in subsequent printings as it becomes available.

D. C. Church

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PART I. INTRODUCTION

Chapter 1—Introduction

Information available in print on the nutrition and feeding of livestock has been developed from countless experiments that have been carried out on a world wide basis, primarily in the past 100 years. The bulk of this information has been developed by public institutions (land grant universities in the USA for example). More limited studies have been done by private institutions or individuals and all of it is backed up by observations of herdsmen, farmers, ranchers, veterinarians and nutritionists. As pointed out by Cuthbertson (1), "In no field of agriculture has more outstanding progress been made in recent times than in the nutrition of farm livestock . . . " As a result of the accumulation of this vast amount of data we can, within reasonable limits, define animal needs in terms of specific nutrients and we can classify and describe most animal feeds with regard to their nutritional value.

Even though the science of animal nutrition and feeding has been advanced significantly by this type of information, our knowledge is still incomplete. The need for more complete information and better understanding of animal requirements, the nutritional value of feedstuffs and appropriate rations is quite obvious in view of the increasing human population and the diminishing resources throughout the world. Competition between humans and animals for feedstuffs often used for feeding animals (i.e., cereal grains) is almost inevitably going to become keener in the years to come. Thus, if large scale human famines are to be avoided, while at the same time livestock flocks and herds are maintained, more efficient use must be made of rangelands, forages and other materials such as agricultural and industrial wastes in the feeding of animals. Livestock feeders and nutritionists must learn to be more conservative of ration components and nutrients in critical supply and to utilize those in surplus more effectively.

Subject matter in this book which will be emphasized will be nutritional value of feedstuffs, critical nutrient requirements and ration formulation in practical feeding situations. Thus, this book is intended to provide for the reader and student a better understanding of and practice in integration of these important factors in livestock feeding.

INFORMATION NEEDED FOR SUCCESSFUL FEEDING

The fundamental principles in economical feeding were outlined very well by Professor W.O. Atwater (2) in 1878: "The right feeding of stock, then is not merely a matter of so much hay and grain and roots, but rather of so much water, starch, gluten, etc., of which they are composed. To use fodder economically, we must so mix and deal it out that the ration shall contain just the amounts of the various nutrients needed for maintenance and for the particular form of production that is required. . . . we must consider: What is the chemical composition of our fodder materials? How many pounds of . . . (nutrients) . . . are contained in a hundred pounds of hay, clover, potatoes, meal, etc.? Of these various ingredients of food, what proportions of each are digestible and consequently nutritious? What part does each of these food ingredients play in the animal economy? . . . How much of each do different animals, as oxen and cows, need for maintenance of life and production of meat, milk, etc.? And finally, how must different kinds of fodder be mixed and fed so that the digestible material shall be most fully digested and utilized, and the least quantity wasted?"

The statements by Professor Atwater which were published more than 100 years ago are still quite applicable in our modern agriculture. However, some additional comments and elaboration of some of the factors are in order at this point.

A knowledge of the nutrient needs of animals is of primary importance if we wish to achieve maximum performance on minimal nutrient intake. This need is well recognized and there is a constant and continual research effort to refine and extend existing knowledge of animal requirements. In modern agriculture it is obvious that many factors may affect animal nutrient requirements over and above those normally considered. For example, two factors may operate to cause a reduction in nutrient needs. In one case herd health has been improved by control of many diseases and parasites. In addition, livestock management, in general, has improved in recent years. Both of these factors should result in less wastage of feeds and nutrients. On the other hand, there has been a general increase in the genetic capabilities of animals, allowing improved production. This may alter requirements, perhaps resulting in a higher requirement in terms of nutrient concentration/unit of feed. However, if an animal grows more rapidly, the amount of feed needed/unit of gain is nearly always less.

On the other hand, the development of large livestock operations undoubtedly puts more stress of various types on confined animals. Greater emphasis on the production of high yielding crops may sometimes result in trace mineral deficiencies or higher levels of toxic compounds such as nitrates in some plants. In addition, increasing use of waste and by-product feedstuffs requires an improved knowledge of nutrient requirements as some of these products may be quite deficient in some nutrients or they may contain excesses of nutrients which are toxic. Also, there has been an increasing utilization of synthetic and purified products, such as urea, which require that other components of the ration must be examined more critically.

As Professor Atwater pointed out, animal needs are best described in terms of specific nutrients. While animal needs could be described in terms of weight units of feedstuffs, this is not feasible under many situations primarily because feedstuffs vary in composition due to environmental factors such as soil fertility, weather, varietal differences, harvesting methods and so forth. Consequently, a kilogram (kg) of alfalfa hay produced in one area may have a different feeding value than hay produced in a different locality or at a different time. In addition, with the wide variety of feedstuffs available in some locations, there would still be a need for some means of relative evaluation; i.e., if a kg of alfalfa is worth so much, how much is corn worth if half alfalfa and half corn are fed? Thus, it is more feasible to express requirements in terms of nutrients.

For maximal production, something must be known of different animal species and which feedstuffs are preferred because this becomes more critical when it is desired to achieve high levels of feed intake. By the same token we must be knowledgeable of different feed preparatory and preservation methods as they may affect feed consumption and utilization in the gastrointestinal tract.

The feeder and/or nutritionist must be aware of feedstuffs which are harmful. For example, cottonseed meal has a relatively high amount of gossypol. This compound is relatively toxic to swine and poultry, thus cottonseed meal must be restricted in rations for these animals or a more expensive type must be used which is produced from varieties of cotton which have low levels of gossypol.

When formulating and evaluating rations, it is quite useful to have a general knowledge of nutrient concentration in groups of similar feedstuffs. For example, a student of this subject should learn the general similarities of the cereal grains, the oil seed meals and different types of hays.

It is certainly necessary to have some background knowledge of supplemental feedstuffs—those used in relatively small amounts to make up for inadequacies in the principal ingredients. It is a must to have some knowledge of different non-nutritive additives in commun usage—antibiotics, hormones, medicants and others. Last, but certainly not least, the cost of different sources of nutrients must be given due consideration. When it is realized that feed is the major cost in production of all livestock enterprises, it is easy to visualize that cost of individual feedstuffs and rations may determine if the feeder can stay in business or ends up in bankruptcy.

This brief discussion is meant to highlight some of the factors necessary for a complete knowledge of this subject. The beginning student will understand that it is a complex problem, but these factors will be discussed in other chapters in more detail so that a gradual understanding should be developed.

FOOD PRODUCTION AND ANIMAL CONSUMPTION

Food and feed production vary each year depending on governmental regulatory practices, price of the product and estimated future price, environmental factors, particularly weather, and the cost of other factors such as labor, fertilizer, machinery and money.

In order to give some perspective to the world and national feed production and consumption, some recent statistics will be presented on this topic. In the 81/82 crop year, it has been estimated (3, 4) that world production was about 1.5 billion metric tons of food and feed grains (Table 1-1) and 92 million tons of oil seeds and meals. In 1974, the percentages accounted for by major crops were: wheat, 28; corn, 23; barley, 13; oats, 4; others, 32. Current data have not been summarized in this manner.

Table 1-1. World supply of some agricultural products, 1981/82 crop year.[a]

Product	Production	Consumption[b]
	. . millions of metric tons . .	
Wheat	453.2	444.1
Coarse grains	772.1	746.5
Rice, milled	276.2	275.6
Total grains	1,501.5	1,466.2
Oilseeds and meals	91.7	------
Fats and oils	58.7	------

[a]From USDA (3)
[b]Data were not provided on animal feed usage

Additional information is given on world production of feed grains in Table 1-2. Undoubtedly, some of the data are more accurate than others, but estimates do have some value in predicting future changes and needs. Note that in the past 5-year period that estimated production of feed grains has increased by about 69 mil. tons (43.2 from the USA) and that consumption has increased by 51.8 mil. tons (17.5 in the USA).

Statistics on production and consumption of feed grains and forages for 1980 are given in Table 1-3. Of the total grain production, feed usage accounted for 51% and corn, itself, for 42% or 81.2% of feed grain usage in that particular year. The feed grains were grown on about 106.9 million acres (43.4 mil. ha)

Table 1-2. Estimated world production and consumption of feed grains.[a]

Country or Region	1977-78	1978-79	1979-80	Preliminary 1980-81	Projected 1981-82
	. . . .	. . . .	million metric tons	. . . .	. . . .
Production					
Canada	22.3	20.4	18.6	21.8	25.7
Australia	4.3	7.0	6.2	5.1	6.7
Argentina	18.3	17.2	10.6	21.1	18.6
S. Africa	11.0	8.4	11.7	14.9	11.8
Thailand	2.2	3.3	3.6	3.5	4.2
PRC	70.7	79.1	83.0	82.5	82.0
West Europe	87.5	94.1	91.1	94.8	88.2
USSR	92.6	105.3	81.2	80.5	77.0
East Europe	59.2	60.5	63.3	61.6	62.5
Others	127.1	135.9	133.4	142.7	144.0
Total Non-USA	495.2	531.6	502.7	528.5	520.7
USA	205.7	222.1	238.7	198.4	248.9
World total	700.9	753.8	741.4	726.9	769.6
Consumption					
USA	138.3	157.2	161.4	147.2	155.8
USSR	108.3	113.2	99.6	100.5	101.0
PRC	70.8	82.2	85.0	85.7	83.7
Others	375.1	394.9	394.6	408.3	403.7
World total	692.4	747.6	740.6	741.7	744.2
End stocks					
Total Foreign	42.7	43.9	35.8	34.1	33.1
USA	41.5	46.4	52.7	34.6	64.9
World total	84.2	90.3	88.6	68.7	108.0

[a]From USDA (5)

Table 1-3. Estimated production of forage and feed grains in the USA, 1980 data.[a]

Feedstuff	Amount Produced	Feed usage
	. . millions of tons . . .	
Feed grains[b]		
Corn (maize)	186.1	121.8
Barley	8.6	4.2
Oats	7.3	7.2
Rye	0.6	0.5
Sorghums	16.4	11.2
Wheat	71.1	4.1
Total	190.1	149.0
Roughage production		
All hay	143.1	
Alfalfa & mixtures	83.7	
Other hays	59.4	
Straws, stovers, etc.	40.0±	
Corn silage	111[c]	
Sorghum silage	8[c]	
Pasture harvested by livestock	?	

[a]From USDA (5)
[b]Differences between the amount produced and that fed may be accounted for by that which is used for various manufacturing purposes, loss in storage, exports and reserves in storage.
[c]Wet basis

Table 1-4. Estimated total feeds consumed in the USA, 1980.[a]

Source	Amount[b] millions of tons	%
Concentrates	201	37.6
Harvested roughage	102	19.1
Pasture	232	43.3
Total	535	

[a]From USDA (5)
[b]Values are expressed in equivalent feeding value to corn grain.

and the food grains (wheat, rye, rice) on 85.4 mil. acres (34.7 mil. ha). An additional 66.7 mil. acres were used for soybean production.

With regard to roughage production, hay production amounted to 143.1 mil. tons of which alfalfa or mixtures containing alfalfa accounted for 58% of the total. Corn and sorghum silage, which were grown on 10.0 mil. acres, amounted to about 119 mil. wet tons. Data are not readily available on production of grass or grass-legume silages and other roughages. Typically, hay, silage, pasture and rangeland are produced on nearly one billion acres (406 mil. ha) in the USA.

Total feed units (all feed equillibrated to the value of corn) consumed in the USA in 1980 are shown in Table 1-4. Note that

Table 1-5. Feed concentrates consumed by livestock and poultry.[a]

	Year beginning October[b,*] 1979	1980[c]	1981[d]
	. . . .	million tons	
Annually:			
Concentrates			
Supply	334.7	298.2	334.0
Fed			
Feed grains	139.9	131.2	133.0
Wheat	4.1	3.8	4.1
Rye	0.2	0.2	0.3
By-product feeds	34.7	33.3	34.6
Total, fed	178.9	168.5	172.0
	. . . . . .	million	. . . . . .
Grain-consuming animal units (GCAU's)[e]			
Dairy cattle	12.1	12.1	12.2
Cattle on feed	18.8	17.8	16.0
Other cattle	4.6	4.8	5.0
Hogs	23.8	22.5	20.5
Poultry	21.1	21.6	21.6
Other livestock	1.9	2.0	1.9
Total	82.3	80.8	77.2
	. . . .	tons	. . . .
Concentrates fed per GCAU	2.13	2.08	2.24

[a]From (6)
[b]Except oat and barley supplies which start June 1.
[c]Preliminary
[d]Projected
[e]Livestock and poultry fed during the October-September feeding year weighted by relative consumption of grain and other concentrates; 1 unit is equal to 1 milk cow.
*Note: the total feed grain supply should be the same in Table 1-3; however, values for 1980 were still preliminary and the particular values used depend on which publication was used for the source of information.

Table 1-6. Primary feed production in the USA by years and for different species.[a]

Type of feed	Year, millions of tons								1981 as % of 1980
	1974	1975	1976	1977	1978	1979	1980	1981	
Starter/grower layer/breeder	11.1	12.1	11.9	12.0	12.4	12.8	12.8	12.8	100
Broiler	12.4	12.7	14.2	14.6	15.5	16.9	16.8	17.2	102
Turkey	3.4	3.1	3.4	3.3	3.4	3.8	4.0	4.1	103
Dairy	11.9	14.2	14.1	14.1	14.2	14.4	14.6	14.9	102
Beef/sheep	19.4	17.2	16.5	15.7	15.3	14.4	14.7	14.8	100
Hog	9.9	9.8	11.5	12.1	12.4	13.9	13.7	12.8	93
All other	4.1	4.6	4.7	4.7	4.9	5.0	5.1	5.1	101
Total, all feeds	72.3	73.8	76.4	76.6	78.1	81.3	81.9	81.9	100

[a] 1975 data from USDA (4). Other years estimated by the Miller Pub. Co. Research Dept. (6).

concentrates account for only 37.6% of the total when calculated in this manner. If expressed on a straight tonnage basis, the percentage for concentrates would be considerably lower.

Estimated feed consumed by livestock and poultry for 1979-1981 is shown in Table 1-5. Note that the feed grains account for a very high percentage of the total concentrate consumed.

FEED PRODUCTION BY THE FEED MILLING INDUSTRY

The milling and feed industries are very important segments of the livestock industry in any highly industrialized country. This is evident by the amounts of manufactured feeds which are produced. Manufactured feeds are frequently listed as primary or secondary feeds. A primary feed is defined as one which is mixed with individual ingredients, sometimes with the addition of a premix at a rate of less than 100 lb/T of finished feed. Production (estimated) of primary feeds from 1974 through 1981 is given in Table 1-6. Note that production is at a level of 81.9 mil. tons in the USA. Of this tonnage the poultry industry accounted for 34.1 mil. tons. Consumption by dairy cattle has increased slightly while that by beef cattle has declined in recent years. Consumption of hogs has, overall, increased.

A secondary feed is defined as one which is mixed with one or more ingredients and a formula feed supplement. Supplements normally are used at a rate of 300 lb or more/T of finished feed, depending on the protein content of the supplement and the percentage of protein content desired in the finished feed. Estimated consumption of secondary feed for 1981 was about 32 mil. tons. Thus, if feed concentrate usage totaled 172 mil. tons in 1981 (Table 1-5), about 58.1 mil. tons of concentrates were mixed or fed free choice by farmers/feeders on their own premises [172 - (81.9+32) = 58.1]. Concentrates include feed grains, wheat, rye and any by-product feed ingredients.

The production of by-product ingredients is a substantial part of the milling and feed industry. Quantities of important by-products produced over the past 3 years are shown in Table 1-7. Note that the oilseed meals account for the largest amount of feed and of this, soybean meal is by far the most important. Production of animal protein sources has generally declined while that from plant sources has generally increased. Products from milling of food grains have not changed greatly and usage of fats and oils and molasses have declined in recent years, partly because of relatively cheap grain prices.

Because of the complexity of the diets used, a high percentage of the feeds fed to poultry are prepared in feed mills. Only in very large units are growers likely to have their own feed mills. The same comments apply to pet foods. In other types of units, a smaller percentage of prepared feed will

Table 1-7. By-product feed ingredients: estimated use for feed in USA.[a]

Feed	Year beginning October[b]		
	1979	1980[c]	1981[d]
	...... 1,000 metric tons		
High-protein			
Oilseed meal			
Soybean[e]	17,113	15,646	16,012
Cottonseed	1,641	1,395	1,628
Linseed	146	117	100
Peanut	108	85	114
Sunflower meal	359	40	430
Total	19,367	17,683	18,284
Animal proteins			
Tankage and meat meal	1,728	1,972	1,395
Fish meal and solubles	337	342	340
Commercial dried milk products	144	146	150
Non-commercial milk products	132	137	130
Total	2,341	2,597	2,015
Grain protein feeds			
Gluten feed and meal	566	630	700
Brewers' dried grains	379	361	370
Distillers' dried grains	554	580	1,073
Total	1,500	1,571	2,143
Other			
Wheat millfeeds	4,150	3,810	4,100
Rice millfeeds	472	470	450
Dried and molasses beet pulp	1,292	1,300	1,090
Alfalfa meal	1,179	1,000	1,100
Fats and oils	635	630	544
Molasses, inedible	2,812	3,251	2,540
Miscellaneous by-product feeds[f]	907	1,000	1,425
Total	11,447	11,461	11,249
Grand Total	34,655	33,312	33,691

[a]From Anderson (6)
[b]Adjusted for stocks, production, foreign trade and non-feed uses where applicable.
[c]Preliminary
[d]Forecast
[e]Includes use in edible soy products and shipments to USA territories.
[f]Allowance for hominy feed, oat millfeeds and screenings

normally be used. Dairy producers may buy concentrates or supplemental feeds to mix with grains and roughages. Swine producers may buy complete feeds or supplemental feeds to go along with corn or other grains. Large beef feeders generally have their own milling equipment and normally would only purchase supplemental feed containing proteins, minerals and additives of various types.

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Chapter 2—The Gastro-Intestinal Tract and Nutrient Utilization

The gastro-intestinal tract (GI tract) is, obviously, important in utilization of foods and nutrients. Furthermore, some knowledge of its anatomy and function is helpful in evaluating feedstuffs and in formulation of rations and, thus, is of some concern to those who are interested in the nutrition and feeding of animals.

This is particularly true because losses in digestibility are a very important factor in feed utilization. In addition, many feed related factors may alter normal functioning of the GI tract. Consequently, some degree of familiarity with its anatomy and function are important for a reasonable understanding of practices and problems in feeding livestock. Information presented in this chapter will be very brief. For more detail, the reader is referred to other texts (1, 2, 3).

The GI tract of simple-stomached mammalian species includes the mouth and associated structures and salivary glands, esophagus, stomach, small and large intestines and the pancreas and liver. These various organs, glands and other structures are concerned with procuring, chewing and swallowing food, and with the digestion and absorption of nutrients as well as some excretory functions.

Digestion and absorption are terms which will be referred to frequently in this and other chapters. **Digestion** has been defined simply as the preparation of food for absorption. It may include mechanical forces such as chewing or mastication or muscular contractions of the GI tract; chemical action of HCl in the stomach or bile in the small intestine; or enzymic activity from enzymes produced in the GI tract or from microorganisms in various sites in the tract. The overall function of the various digestive processes is to reduce food particles to a size or solubility which will allow for absorption. **Absorption** includes various processes that allow small molecules to pass through the membranes of the GI tract into the blood or lymph systems.

As might be imagined, the GI tract of different types of domestic animals varies considerably; they are generally described as being represented by simple-stomached animals, avian species and ruminants. Other types may be represented in animals such as fish, amphibians or reptiles. Further detail is given on the three major types.

MAJOR ANATOMICAL FEATURES OF THE STOMACH AND INTESTINES

A picture of the stomach and intestines of the pig is shown in Fig. 2-1; it will serve as our model for simple-stomached or **monogastric** species. The shape of the stomach of different animals varies as does the relative size. In swine, for example, the stomach is relatively large with a capacity in the adult on the order of 6-8 liters. This is about 4% of body weight as compared to 1% in humans.

Most of the stomach is lined with mucosal cells which produce mucus that serves to protect the stomach lining from gastric secretions. In the central part of the stomach there are gastric glands which produce mixed secretions of HCl, enzymes and mucus. These

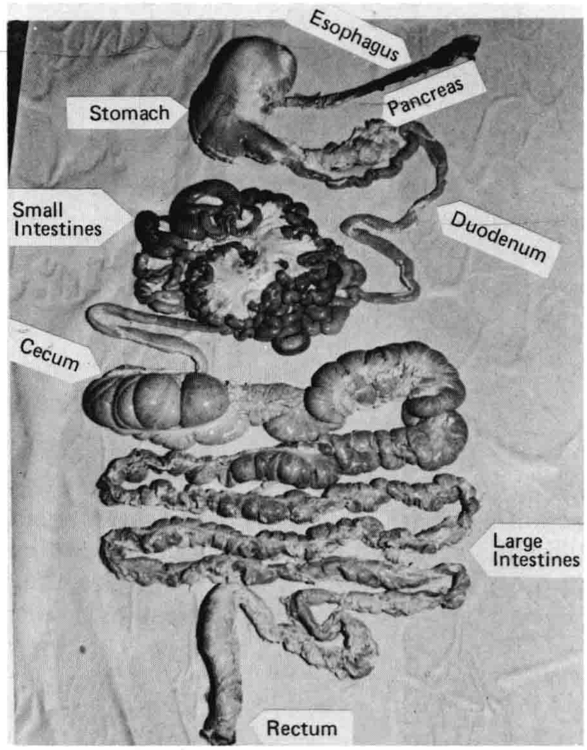

Figure 2-1. The esophagus, stomach and intestines of the pig.

Figure 2-2. A scanning electron micrograph showing the intestinal villi of the baby pig. Courtesy of H. Moon, National Animal Disease Laboratory, Ames, Iowa.

gastric juices are effective in initiating digestion in the stomach.

In the pig the small intestine is relatively long (15-20 m), but the small intestine is generally much shorter in carnivores. The first short section, the duodenum, is the site of production of various digestive juices and other juices enter the duodenum from the bile duct. These latter juices are derived either from the liver (bile) or the pancreas. The small intestine is lined with small, finger-like projections, the villi, which serve to increase surface area for absorption (Fig. 2-2).

The large intestine is made up of the cecum, colon and rectum. The relative length, diameter and sacculation differ considerably in different species of animals. These organs tend to be much larger (relatively) in herbivorous species.

In avian species, the crop, proventriculus and gizzard replace the simple stomach found in monogastric species (Fig. 2-3). Even here there are variations between different types of birds because most insect-eating species have no crops.

Where a crop is present, ingested food goes directly to it and the crop serves as a temporary storage site; it is an organ which in many species has great capacity for expansion. The proventriculus of birds is the site of production of gastric juices. The gizzard is a very muscular organ with a tough lining. It normally contains grit–small stones and other hard materials. The gizzard serves some of the same functions of teeth in mammalian species, acting to physically reduce particle size of food. With regard to the intestinal

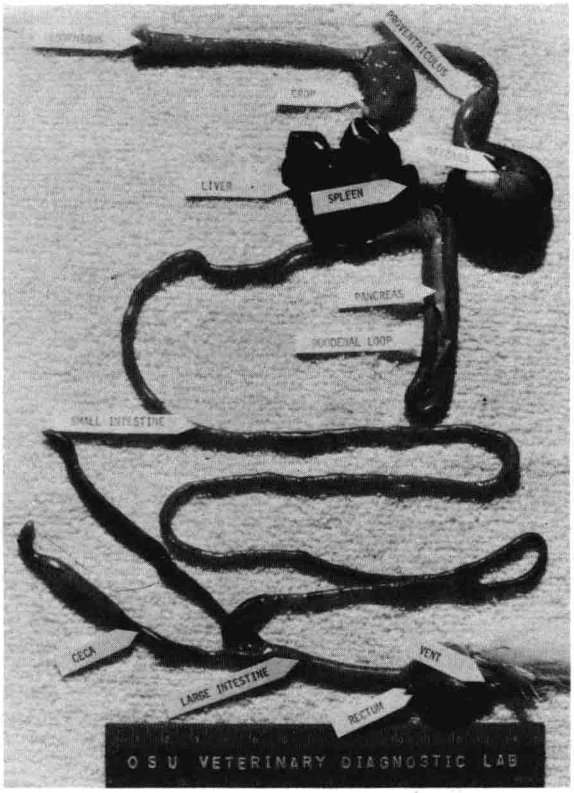

Figure 2-3. The digestive tract of the chicken. Photo by Don Helfer, Oregon State U. Diagnostic Laboratory.

tract, birds have a relatively long small intestine, two rather large ceca and a very short section of large intestine. Birds also differ from mammals in that urine is excreted in semi-solid form along with the feces.

In ruminant species the major modification of the GI tract is in the stomach which is more complex than that of other domestic animals. The stomach is divided into four compartments–reticulum, rumen, omasum and abomasum (Fig. 2-4).

The stomach of the ruminant is quite large when compared on the basis of the total GI tract or on the basis of body weight. Whereas the stomach of the pig is about 4% of body weight, the stomach of sheep and cattle will be more on the order of 25-28%. If expressed as a percentage of the total GI tract, the pig stomach is about 14% while those of sheep and cattle are about 37 and 45%, respectively.

The first three compartments of the ruminant stomach are lined with cell types (stratified squamous epithelium) which are not normally associated with organs which have absorptive surfaces. Yet research evidence

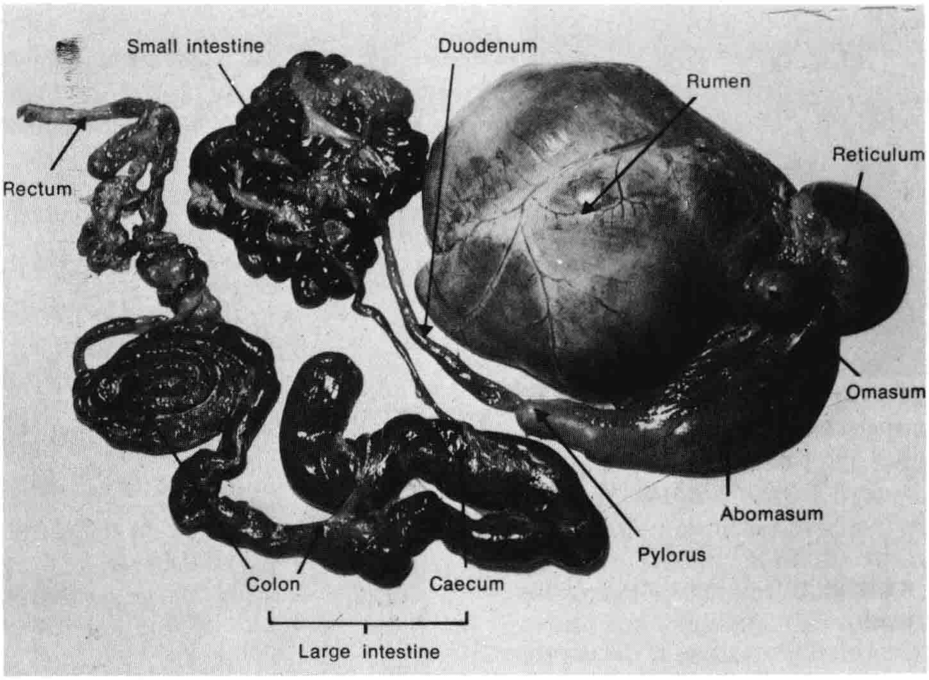

Figure 2-4. The stomach and intestines of the sheep. Courtesy of C.S.I.R.O.

indicates that substantial amounts of some materials may be absorbed here.

The reticulum gets its name from a lining of cells arranged in a network resembling the cell shape of a honeycomb, thus its common name of honeycomb. The rumen, or paunch, is lined with papillae which cover most of the surface, but are more dense in the ventral parts of the rumen of most species. It is partially divided into different sacs by pillars which function to control contractions of the organs. The omasum is a spherical-shaped organ containing leaves of different sizes and it is normally tightly packed with fine particulate matter. The omasum empties into the abomasum which is comparable in function to the monogastric stomach in that it produces the usual gastric juices. It differs physically in that there are spiral folds, about 12 in number, extending around the interior of the organ; these apparently act to provide more surface area for proliferation of the gastric glands.

As with other herbivorous species, the intestinal tract of ruminants is relatively long and moderately complex. The cecum is large, but relatively smaller than that of other herbivourous species such as the rabbit or horse. The large intestine is also relatively large as compared to omnivorous species, although relatively smaller than in the horse.

The rabbit is one example of herbivorous species which has a simple stomach (Fig. 2-5) accompanied by a very voluminous cecum. Both the cecum and colon are sacculated. The horse is another example of a herbivore with a relatively large sacculated cecum and an extremely large sacculated colon. Both species are examples of animals in which extensive microbial fermentation occurs in the large gut (cecum and/or colon).

FUNCTIONS OF THE GASTRO-INTESTINAL TRACT

Monogastric and Avian Species

In mammalian animal species, the mouth and associated structures–tongue, lips, teeth–are used for grasping and masticating food. The degree of use of any organ depends on the species of animal and the nature of its food. In omnivorous species–those that consume both plant and animal food–such as humans or swine, the incisor teeth are used primarily to bite off pieces of the food and the molar teeth are adapted to mastication of non-fibrous materials. The tongue is used relatively little. In carnivorous species the canine teeth are adapted to tearing and rending, while the molars are pointed and adapted to only partial mastication and the crushing of bones. Herbivorous species (plant eaters),

Figure 2-5. The digestive tract of the rabbit.

such as the horse, have incisor teeth adapted to nipping off plant material and the molars have relatively flat surfaces which are used to grind plant fibers. The jaws are used in both vertical and lateral movements which shred plant fibers efficiently. Ruminants, on the other hand, have no upper incisors and depend on an upper dental pad and lower incisors for biting off plant material. With regard to avian species, they have no teeth, thus the beak and/or claws serve to reduce food to a size that may be swallowed.

In the process of mastication (chewing), saliva is added, primarily from three bilateral pairs of glands. Saliva aids in forming food into a bolus which may be swallowed easily and it has other functions such as keeping the mouth moist, aiding in the taste mechanisms, and providing a source of some enzymes which contribute to the digestive process.

In the stomach, gastric juices continue the gestive processes initiated by mastication ensalivation in the mouth. Hydrochloric provides for an acidic pH and the enzymes initiate digestion of protein and, in young mammals, of fats. The partially digested food, now called chyme, passes into the duodenum where it is subjected to the action of intestinal juices and bile which gradually raises the pH into the alkaline range. Bile also aids in emulsification of fats, a necessary step in their solubilization and absorption. Enzymes from the pancreas continue enzymic digestion of proteins, fats and carbohydrates and these are complemented by additional enzymes produced by glands in the wall of the duodenum. Enzymic activity continues as the food passes into the jejunum and ileum, the other segments of the small intestine. These sections are also the site of most of the absorption of nutrients which occurs in the intestinal tract. Most of the organic nutrients which are absorbed have been absorbed by the time the digesta passes into the cecum. The cecum, although a blind sac, appears to empty and refill itself by means of rhythmatic contractions.

In the ileum, cecum and colon bacterial growth develops; by the time the digesta reaches the cecum there is a high population of many different organisms, the amount and type depending upon the species of animal and its diet. Absorption of some organic acids and other organic compounds such as ammonia occurs in the cecum and large intestine. Large amounts of water are absorbed by the large intestine, also. This may be one of the major functions of the cecum and of large (or long) and sacculated colons (3).

In addition to the digestion and absorption which occurs, the GI tract is the major route of excretion of many compounds. This statement applies particularly to bile which is produced by the liver. The liver is a very active site of detoxification of many toxins found in plants or microbes or drugs which may be administered to the animal. The liver also excretes many metallic elements and it is the site of degradation and excretion of many body compounds such as most of the hormones. These different compounds or detoxified chemicals are excreted via the bile. In the large intestine some net excretion of mineral elements occurs, particularly Ca, Mg and P.

One other important activity which occurs in the GI tract is that of nutrient synthesis. Many different research studies have shown that the microbial population in the cecum and large gut are capable of extensive