This circular explains the anatomy and functions of the ruminant stomach. It was prepared in response to the many questions and requests for information concerning this subject, and because it is important for livestock producers to understand the ruminant digestive processes and their relationships to feeding practices.

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Principles of Ruminant Digestion

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Animals with two distinct types of digestive systems are referred to in this circular. They are ruminants (cud-chewing animals, such as cattle and sheep), and monogastric animals (those having only one principal digestive cavity, such as swine and chickens). A brief discussion of the monogastric digestive tract is included mainly for comparison.

Description and Comparison of Systems

Some basic differences between ruminant and monogastric digestive systems are:

1. Ruminants have a relatively large digestive system (large rumen plus other compartments) which enables them to use enormous amounts of roughage-type feeds in comparison with most monogastric animals.

2. Ruminant animals have a much greater ability than nonruminants to digest roughage before it enters the intestinal tract.

3. The alimentary tract system in the ruminant animal is far more efficient than that of the monogastric animal in the utilization of crude fiber.

This efficiency is indicated by the following figures showing the extent of crude fiber digestion of alfalfa hay by four different animals:

<table>
<thead>
<tr>
<th>Animal</th>
<th>% Digestion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle</td>
<td>44</td>
</tr>
<tr>
<td>Sheep</td>
<td>45</td>
</tr>
<tr>
<td>Horse</td>
<td>39*</td>
</tr>
<tr>
<td>Swine</td>
<td>22</td>
</tr>
</tbody>
</table>

*Mainly in the cecum (see pages 6 and 7).

The ability of ruminants to use great amounts of roughage depends almost entirely upon the microbial reactions which take place in the rumen compartment of the stomach and to a lesser extent in the intestines. In addition to making roughage nutrients available to the
animal, the rumen microrganisms are capable of synthesizing (producing or putting together in usable form) proteins, B-complex vitamins, and vitamin K.

With all of the activity involved, and the handling of so much roughage, it is not surprising that the rumen is so large.

**Structure and Size of the Ruminant Stomach**

The ruminant stomach consists of four distinct compartments — (1) the **Rumen**, or “paunch,” as it is commonly called, (2) the **Reticulum**, or “honeycomb,” (3) the **Omasum**, or “manyplies” (so-called because of the plies or folds), and (4) the **Abomasum**, or “true stomach.”

When feeds are taken in, the normal pathway they follow is in the order just listed, with portions being returned to the mouth for chewing before they enter the omasum. These four compartments do not lie in a straight arrangement; they are bunched and joined together to form a compact structure.

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The ruminant stomach is large in relation to the size of the animal. Its four compartments are bunched and joined together to form a compact structure.
An idea of the tremendous size of the ruminant digestive system is given in this example showing capacities of the four compartments of the bovine stomach:

<table>
<thead>
<tr>
<th>compartments</th>
<th>Gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rumen</td>
<td>20-48</td>
</tr>
<tr>
<td>Reticulum</td>
<td>1-3</td>
</tr>
<tr>
<td>Omasum</td>
<td>2-5</td>
</tr>
<tr>
<td>Abomasum</td>
<td>2-5</td>
</tr>
<tr>
<td><strong>Total stomach capacity</strong></td>
<td><strong>25-61</strong></td>
</tr>
</tbody>
</table>

The ranges shown allow for different animal breeds and ages.

In the digestive process most feed materials follow the pathways indicated by the arrows. The rumen, consisting of several different regions, is much larger than the three other compartments combined.
The Monogastric Digestive Tract

The principal parts of the digestive tract of a monogastric animal are the mouth, esophagus, stomach, small intestine, cecum (divider between the small and large intestine), and large intestine. There are other parts, such as the tongue, salivary glands, etc., but they are not as important as the ones listed in understanding the basic operations of the digestive system.

Digestion begins in the mouth as the feed is chewed and saliva is added. The saliva contains enzymes which help to digest starches. The esophagus carries the feed to the stomach where digestive juices are produced by the gastric glands. These juices, along with the enzymes present in the stomach, speed up the digestive process.

When the feed has been mixed and partly digested it moves into the small intestine where several more secretions and enzymes become involved. The small intestine is a rather long, folded tube, in which the feedstuff undergoes more complete digestion as it is moved toward the cecum by muscular contractions.

The cecum has little function in the digestive process except in

The stomach of a monogastric animal is much smaller than that of the ruminant stomach in relation to the size of the animal and other parts of the digestive tract.
horses and rabbits, which consume rather large amounts of roughage-type feeds. In these animals the cecum functions much as does the rumen of the ruminant.

The large intestine, which is also tubular in shape but much shorter than the small intestine, removes water from the material as it nears the end of the digestive system. In addition, a small amount of bacterial action takes place in the large intestine.

In contrast with the ruminent system, the stomach of monogastric animals has only one principal digestive cavity, including one nonglandular and three glandular regions.
Development of the Ruminant Stomach

In young ruminant animals the abomasum is the only functioning compartment of the stomach. Milk and other liquid materials pass from the esophagus to the abomasum through an esophageal groove and the undeveloped omasal area. This process continues until the other compartments of the stomach are developed and the young animal has started to consume more solid or dry feeds.

 Movements occur in the reticulum and rumen of the young ruminant even though they do not contain solid foods. A regular cycle of contractions begins within these organs after the animal begins to take in solid foods.

The rumen at birth is a very small organ found in the upper left area of the abdominal cavity. According to research findings to date, it develops in a series of fairly definite stages. When the animal is about 2 months old the rumen descends from the upper left location to its normal position in a mature animal. Also, the reticulum and omasum grow and develop rapidly during this first 2-month period. During the first 3 months the rumen enlarges and develops the physical characteristics found in the mature animal.

Functions of the Ruminant Stomach

The feeds taken in by ruminant animals are mixed with a heavy flow of saliva, which is needed to help in the chewing and swallowing of dry materials. The saliva of ruminants, unlike that of nonruminants, does not contain enzymes to aid in the digestion of starches.

The flow of saliva, estimated to be about 120 pounds per day in a mature cow, has enough buffers (sodium bicarbonate) to neutralize the fatty acids produced in the rumen and maintain the rumen contents at approximately a neutral pH (7.0).

Functions of the Rumen

A large, complex fermentation vat. Digestion in the rumen accounts for roughly 70-85 percent of the total utilization of digestible dry matter. The rumen is considered an excellent "fermentation vat" because of the continual flow of feed materials into and out of the rumen, constant introduction of saliva which controls the pH, absorption of the end products of the microbial actions, and a population of microorganisms which develop in accordance with the amount and type of feed taken in.
To be more specific, the rumen includes the following six characteristics of a good fermentation vat:

1. Desirable temperature.
2. Buffered medium — to help maintain the proper acid-alkaline relationship.
3. Mixing motions.
4. Anaerobic condition — making bacterial action possible in the absence of oxygen.
5. Good nutrient supply.

The rumination process reduces the particle size of the ingested feedstuff, thus exposing more surface area to bacterial action and allowing the material to pass more rapidly through the rumen. The material stays in the rumen and reticulum about 24 hours, more or less depending on the type of feed, until it is broken down into extremely small particles, and then passes on to the lower regions of the digestive tract in a relatively small, slow-moving stream. The breakdown and processing in the rumen enables the reticulum and omasum to perform their function (see pages 13-15) of assisting the rumen in the total digestion and utilization process.

The interior wall of the rumen is covered with finger-like projections called papillae. This interior lining aids in the process of homog-
The most important products of the rumen “fermentation vat” process, illustrated here in diagrammatic form, are the volatile fatty acids (VFA’s), which represent the major source of energy derived from feed in usable form.

The rumen of a mature cow may contain up to 250 pounds of material. Generally the material is drier at the esophageal end than at the point where it leaves the compartment. It is drier on top than at the lower levels in the rumen.
VFA's vary with feeding practices. The total concentrations of VFA's in the rumen, and the amounts of the individual acids present, are largely dependent on the composition of the ration being fed and the feeding system. The rate of absorption of these VFA's is directly related to their concentration.

This raises the question of how feeding practices can be adjusted for more efficient utilization of the feeds. The higher the heat increment or body heat loss in the ruminant animal, the greater the waste of energy, except in very cold weather. Since acetic acid causes about three times as much heat loss as does propionic, it would be desirable from the standpoint of finishing cattle to shift the ratio to produce less acetic and more propionic acid in the rumen.

Factors that might affect this ratio are (1) kind of feed, (2) amount of feed, (3) frequency of feeding, and (4) kind of bacteria present. Concentrates, when added to the ration, tend to increase the amount of propionic acid whereas high-roughage rations tend to increase the acetic acid.

Any method — such as flaking, grinding, or pelleting — that allows a more rapid breakdown of the feeds taken in results in a shift to a higher percentage of propionic acid. The theory involved in frequency of feeding is based on the fact that less heat is involved if the animals get smaller amounts of feeds at a time and eat more frequently. The increased heat which results from consuming a larger amount of feed in a relatively short time is similar to that found in humans after eating a heavy meal.

Rumen microorganisms. The main functions of the rumen microorganisms are to utilize cellulose, synthesize protein from non-protein nitrogen, and synthesize vitamins.

The enormous microbial population of the rumen may be broadly divided into these basic types:

— Rumen bacteria.
— Rumen protozoa.
— Microorganisms that make up the yeasts group, present in smaller numbers than the others, and whose functions are not yet well defined.

For a rumen organism group to be considered important it must (a) be capable of carrying out a reaction known to occur in the rumen, and (b) be present in sufficient numbers to account for the reaction. Generally there must be 1 million bacteria per milliliter (30 million in about one ounce) of rumen fluid for them to have any importance.
There are three general types of rumen bacteria which play important roles in the digestion process. They are *Streptococci*, *Lactobacilli*, and a group of cellulolytic bacteria. The *Streptococci* and *Lactobacilli* attack and ferment readily available carbohydrates and produce the end products of various volatile fatty acids. These bacteria are found in greatest numbers when the ration consists of high concentrates and young, tender forage.

The cellulolytic group includes bacteria with the less commonly known scientific names of *Bacteriodes-succinogenes*, and *Ruminococcus-flavefaciens*. This group performs the important function of attacking and fermenting the cellulose portions of the feeds, and the organisms are found in largest numbers in the digestion of high-roughage rations.

Rumen protozoa, although not as essential as bacteria in the rumen activities, also play an important part. They are the last microorganisms to develop in the rumen of the young calf.

Functions of the protozoa include storage of polysaccharides (readily available carbohydrates), production of protozoal protein, and fermentation of cellulose-type material.

The volatile fatty acids produced in the rumen, as previously discussed, are derived from microbial fermentation of feedstuffs, mainly carbohydrates.

**Protein synthesis.** It has long been recognized that protein synthesis by rumen microorganisms occurs in the ruminant animal. More recent observations have shown that the biological value of proteins (percentage of true digestible protein utilized by the animal) and urea or nonprotein nitrogen (NPN) is approximately the same for ruminants. This is not true for monogastric animals. For example, milk has a very high biological value for rats but only a moderate value for ruminants. However, urea, which is very poorly utilized by rats, has a value comparable to protein when fed to ruminant animals. The basis for this phenomenon is that the rumen microbes break down either protein or urea and produce bacterial protein from the residues of microbial action.

Research studies indicate that the following procedures are involved in protein utilization by ruminants:

1. Bacterial breakdown of protein and nonprotein nitrogen in the ration, which produces ammonia.
2. Synthesis of this ammonia into bacterial protein.
3. Digestion of the bacterial protein in the lower digestive tract of
The action of rumen microorganisms on urea or nonprotein nitrogen is the first step in the process of supplying amino acids, the "building blocks" of proteins.

the ruminant, which supplies both the essential and nonessential amino acids required.

Since the ruminant animal is capable of converting and utilizing nonprotein nitrogen to supply its specific amino acid needs, it is not necessary to supply these amino acids in the ration.

Vitamin synthesis. Vitamins A and D are dietary essentials and are not synthesized in the rumen. When adequate sunlight is not available or the diet is low in carotene, from which vitamin A is derived, these vitamins must be added to the ration.

The mature ruminant animal is able to produce the B-complex vitamins and vitamin K, one of the fat soluble vitamins, in excess of its requirements. Therefore, under normal feeding conditions it can be assumed that the ruminant will synthesize the necessary amounts of these vitamins.

Ruminants do not require dietary sources of vitamin C (ascorbic acid). This vitamin is produced in the body tissue, not in the rumen. Vitamin C placed in the rumen is quickly destroyed.

Vitamin E is essential for normal reproduction in many animal species, but no effect of a deficiency has been recognized in connection with the reproductive capacity of ruminants. However, vitamin E deficiency has been directly implicated in the occurrence of "white muscle" disease in cattle and "stiff lamb" disease in sheep.

Functions of the Reticulum

The main function of the reticulum is its action as a screening device. The reticulum, which is connected to the rumen, is lined with honeycomb-like projections somewhat similar to those found in the rumen. Regular and brisk contractions of the reticulum cause a backward movement of the ingested feedstuffs into the rumen. A flushing
action between the rumen and the reticulum allows the small food particles to become separated from the mass in the rumen — the coarse material is held in the rumen while the fine particles pass on to the omasum.

A coordinating contraction between the reticulum and rumen occurs two to three times per minute. At each movement the orifice between the reticulum and omasum opens and allows 50-60 grams of fluid materials to pass from the reticulum to the omasum.

**Functions of the Omasum**

Less is known about the functions of the omasum than of any of the other compartments of the ruminant stomach. It is extremely difficult to study this organ.

It is generally stated that the primary functions of the omasum are to (1) reduce the water content of the feedstuffs, and (2) exert a re-grinding and squeezing action on the material. Neither of these functions is clearly defined, but it is known that the feed material leaving the omasum is roughly 60 to 70 percent drier than that which is entering, and that the folds and leaves found on the inside of the omasum could very likely produce a grinding and squeezing action. This action may exert the necessary force to cause the “back-flushing” which occurs in the omasum.

The contents in the omasum are maintained at a rather constant

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Folds or plies are characteristic of the interior lining of the omasum, as illustrated in this drawing of a small section. The surface is covered with tiny spine-like projections (see inset, lower right). The abomasum lining is somewhat similar, but has a rather smooth, spineless surface.
pH of approximately 7.2, and little or no digestion is known to occur within this organ.

Functions of the Abomasum

The abomasum is often referred to as the "true stomach" because its action is similar to the stomach action in monogastric animals. In the abomasum the pH figure is lower (3.5 to 4.0) than in the omasum, probably as a result of the high acidity of the digestive juices.

As in the monogastric stomach, digestive juices are added and the moisture content of the feed material is increased. The digestive juices contain enzymes, resulting in protein digestion in the abomasum. Little or no digestion of fat, cellulose, or starch occurs in this organ.

The feed material leaving the abomasum is highly fluid in nature. This material is passed out of the stomach through the small intestine, where additional digestion occurs, and the unabsorbed material is then excreted by way of the large intestine.
COMMON RUMINANT NUTRITION TERMS

Abomasum — compartment of the ruminant stomach, commonly called the "true stomach." Functions similar to the stomach of a monogastric animal.

Biological value (protein) — the percentage of true digestible protein utilized by the body.

Chyme — the food material leaving the stomach and entering the intestinal tract. It has a fluid-like consistency and is acid in reaction.

Mastication — the grinding, mixing action in the mouth, involving saliva, to chew and reduce food materials to smaller size.

Metabolism — the process by which absorbed nutrients are (a) used in synthesis of body tissue, and (b) broken down or used for maintenance functions of the animal.

Nonprotein nitrogen (NPN) — nitrogen derived from sources other than protein (such as urea).

Omasum — compartment of the ruminant stomach, commonly called the "manyplies." Functions to reduce the water content of the feedstuffs and provides regrinding and squeezing with a "back-flushing" action.

Prehension — grabbing food and starting it down the alimentary canal. In cattle the tongue is the major organ involved in getting food into the body (teeth are important in sheep).

Reticulum — compartment of the ruminant stomach, commonly called the "honeycomb." Functions as a screening device to hold back coarse materials and allow the fine particles to pass into the omasum.

Rumen — the largest compartment of the ruminant stomach, in which the major roughage utilization occurs.

Rumen bacteria — single-cell members of the plant kingdom, which ingest food when in solution. Their main functions are to utilize cellulose and synthesize protein and vitamins.

Rumen protozoa — simplest members of the animal kingdom. Single-cell, but much larger than bacteria. Can ingest solid particles of food, including bacteria.

Rumination — the process whereby food materials from the rumen and reticulum are regurgitated into the mouth, remasticated, mixed with saliva, and again swallowed.

Volatile fatty acids (VFA's) — the major energy sources for ruminants.