PERFORMANCE PRO-BIOTICS
DIRECT-FED MICROBIALS

RUMEN FUNCTION

www.performanceprobiotics.com

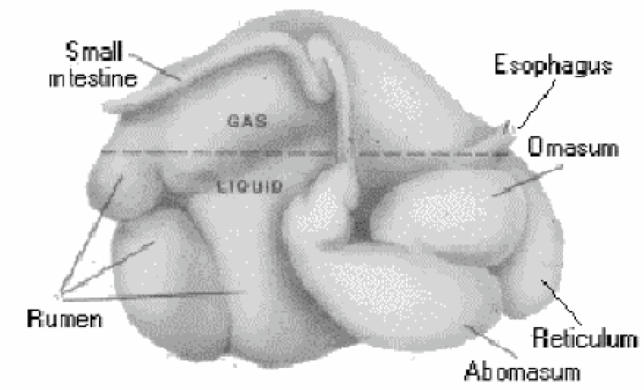
Last Updated **Nicola Brazier | March 2010**

Understanding the workings of the rumen, and the complex, symbiotic relationship between cows and the rumen microbes, is key to maximising feed efficiency and therefore maximising productivity on dairy farms. In order to better feed dairy cows we need to explore the structure of the rumen, the population of rumen microflora and understand how they fit together. This paper will discuss these topics, but for further information and more detail please refer to Nutritional Ecology of the Ruminant by P. J. Van Soest.

RUMEN ANATOMY

While ruminants are often said to have 'four' stomachs, in reality they only have one divided into four compartments. These compartments include the rumen, reticulum, omasum and abomasum. The rumen and reticulum (often considered together as the reticulorumen) is where most of the fermentation and nutrient absorption occurs.

Figure 1. View of rumen from right hand side
(from Dr. S. Blezinger 'Cattle Today' website)



The rumen itself is made up of a liquid phase (liquor), a rumen mat (or fibre raft), which floats above the rumen liquor, and gas sitting above the rumen mat. 'Pillars' divide the rumen into sacs, and it is the shortening of these pillars that cause rumen contractions. Gravity and rumen contractions ensure that feed bolus (chewed up ball of food!) is submerged in the rumen liquor where microbial fermentation takes place. The contractions ensure that ingesta is thoroughly mixed and exposed to rumen microbes, as well as ensuring that feed requiring further rumination is selectively regurgitated.

While the reticulum is part of the fermentation site, it plays a more important role in filtering larger feed particles and foreign objects. The position of the reticulum is close in proximity to where the oesophagus (and therefore food) enters the rumen. This enables the rumination and regurgitation of food, or chewing of the cud. Rumination is induced by sensors in the rumen wall reacting to the pressure of feed at the point where the oesophagus and rumen join.

The wall of the rumen is covered by many small, finger-like projections called papillae, whose purpose is to increase the surface area and therefore increase absorption area. The papillae change in number and size as diet changes, as does the rumen microbial population, and this needs to be kept in mind when implementing dietary changes.

The reticulum wall is covered with reticular ridges, which are believed to be involved in the sorting and handling of feed particles for regurgitation or passage to the omasum.

The omasum is a small, oval shaped organ connecting the reticulorumen to the abomasum. It is positioned close to the entrance of the oesophagus into the reticulorumen, so that when the oesophageal groove is closed (such as in young ruminants, who do not yet possess a functional rumen) ingesta can pass directly into the omasum bypassing the reticulorumen.

The interior of the omasum consists of 'leaves' or flaps, which absorb water and some nutrients, prevent the passage of large feed particles and potentially operate to physically grind and breakdown feed particles.

RUMEN MICROBES

The microbial population is regulated by the peculiar ecological balance that tends to prevail there (Van Soest). Temperature is regulated by the animal's homeothermic metabolism. pH remains relatively constant, despite the production of large amounts of acid, due to their removal via absorption across the rumen wall. Osmotic pressure and ionic concentrations are kept stable and end products and waste are removed. All factors that impact the microbial environment are regulated strictly in most circumstances.

The population of microbes in the rumen is complex and somewhat confusing! Some microbial species produce products that are then directly used by the host animal, while many produce products which are utilised by other microbes. Reality is that when feeding cows, we need to feed the rumen microbes first, and they then feed the cow.

Protein in the rumen is 'sacrificed' and broken down into ammonia (NH3) and amino acids, which are utilised for microbial growth and reproduction. The microbes themselves become the protein source for the host animal (referred to as microbial protein) and very little dietary protein is available directly to the animal (escape or 'bypass' protein). The use of protein fractions by the microbes is highly dependent upon carbohydrate availability, and thus 'dietary balance' becomes imperative.

Carbohydrates are broken down into volatile fatty acids, or VFAs (propionate, acetate and butyrate are the major three) as primary fermentation. Secondary fermentation and metabolism of some of these products also occurs, much of which does not occur in the rumen.

Rumen bacteria are predominantly strict anaerobes (no tolerance to oxygen) although a few facultative anaerobes exist, performing a key role in removing oxygen quickly from the rumen environment. The bacterial population is diverse ranging from those who digest carbohydrates (cellulose, hemicelluloses, pectin, starch, sugars) to those who use acids or hydrogen as energy sources. The bacteria are highly dependent on B vitamins, ammonia (NH3), carbon dioxide and VFAs. Given that the digestion of fibre (cellulose and hemicelluloses) is commonly thought of as the primary role of the rumen, it is the fibre digesting bacteria which receive the most press. Lignin, the third component of fibre, remains undigested.

Protozoa are the second type of microbial species in the rumen. Their exact role is poorly understood, due to the inability to effectively culture them in laboratories. Some are believed to be involved in starch and sugar digestion, while many are responsible for extensive ammonia production (although there are also bacteria shown to produce ammonia) and thus play an important role in protein metabolism and protein availability to the cow.

Fungi produce VFAs, gas and small amounts of other substances, including lactate. They play a large role in fibre digestion, but operate quite differently from the fibre digesting bacteria. Fungal bodies, called zoospores, attach to fibre particles and develop sporangia and rhizoid filaments which penetrate fibre cell walls. While they cannot digest lignin, the filaments can penetrate lignified surfaces. It has been accepted for over 20 years that inoculating the rumen with fungi can improve fibre digestion.

All of the microbial species are prone to passage, or wash, from the reticulorumen into the omasum. Their attachment to feed particles and to the rumen wall protect them for some time, but their contribution as 'food' in the abomasum is enormous. As mentioned earlier, their role in providing the host animal with microbial protein is particularly important.

VFA METABOLISM

The VFAs produced from microbial fermentation provide the cow with a major source of metabolisable energy. The major VFAs, in descending order of abundance, are acetate, propionate, butyrate, iso-butyrate, valeric acid and iso-valeric acid. The proportions of acetic, propionic and butyric acids are influenced greatly by diet and microbial populations. Other organic acids may appear as products of metabolism, namely lactic acid, which is itself fermented to acetate, propionate and butyrate under normal rumen conditions.

In most simplistic terms, and of relevance to dairy cow nutrition:

> Fibre (cellulose and hemicelluloses) is fermented to Acetate, which is the precursor for milk fat.

> Starch is fermented to Propionate, which is the precursor for glucose, and thus higher propionate producing diets tend to favour higher milk production and/or body condition.

The concentrations of VFAs within the rumen are regulated by a balance between production and removal via absorption. Acids are absorbed across the rumen wall in free form, due to a differential gradient, with the pH of the blood being higher than the pH of the rumen. Of note, the absorption of VFAs in the lower intestinal tract is similar to that in the rumen.

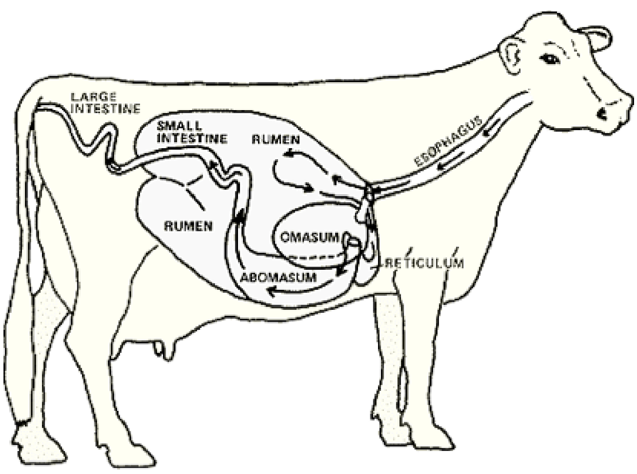


Figure 2. Anatomy of the adult digestive tract (From University of Minnesota)

THE LOWER GASTROINTESTINAL TRACT

Lower tract digestion is comparable to non-ruminants and is the site of digestion and absorption of nutrients. Digestion occurs in the abomasum, where gastric acids, or digestive juices are secreted. Carbohydrates are in low supply due to their removal in the rumen, so it is the digestion of microbial cells, which arrive from the rumen in a virtually living state, that is of most importance. The presence of VFAs and lactic acids stimulates gastric secretions and contractions.

Between 70% and 90% of starch is digested in the rumen, and about half the remainder is digested in the small intestine. Digesting food passes through the intestine, coming in contact with the villi along the intestine walls (similar to papillae in the rumen). Glucose and amino acids are absorbed here. Indigestible fibre and peristalsis (contractions) promote flow. Water, minerals, nitrogen and probably VFAs are absorbed in the large intestine. Digestion of carbohydrate, which has escaped rumen fermentation, also occurs in the large intestine.

The following table summarises the important parts of the cow's digestive tract:

Figure 3. Appropriate Fill Volume of the Digestive Tract of a 500kg cow (Adapted from Dr L. Sandles, BEST-Fed)

Compartment	Vol (1)	Vol (2)	Function
Reticulorumen	125	48	Fermentation. Absorption VFA's and NH3, absorpotion Mg and Ca. Synthesis of vitamins.
Omasum	20	7.5	Controls digesta (size, composition).
Abomasum	15	5.5	Secretion of digestive juices and enzymes. Hydrolysis protein. Solubisation minerals.
Total stomach	**160**		
Small intestine	65	25	Enzymatic digestion. Absorption glucose, VFA's, amino acids, lipids, vitamins, minerals.
Ceacum	10	4	Further bacterial fermentation.
Large intestine			Reabsorption water and nutrients including macrominerals. Some vitamin synthesis.
Total Gut	**260**	**100**	

While the structure and function of the individual parts of the cow's gastrointestinal tract can be confusing, the appropriate feeding of cows is relatively simple. If we provide the rumen, and its microflora, with sufficient starch, protein, fibre and vitamins and minerals, the bugs themselves provide the cow with the resources to effectively and efficiently produce milk and muscle. The same can be said for other ruminants including young dairy stock, beef cattle and sheep.