LALLEMAND ANIMAL NUTRITION

Lallemand Animal Nutrition is committed to optimizing animal performance and well-being with specific natural microbial product and service solutions. Using sound science, proven results and knowledge from experience, Lallemand Animal Nutrition:

- Develops, produces and markets high value yeast and bacteria products including probiotics, silage inoculants and yeast derivatives.
- Offers a higher level of expertise, leadership and industry commitment with long-term and profitable solutions to move our partners *Forward.*

Lallemand Animal Nutrition ***Specific for your Success***

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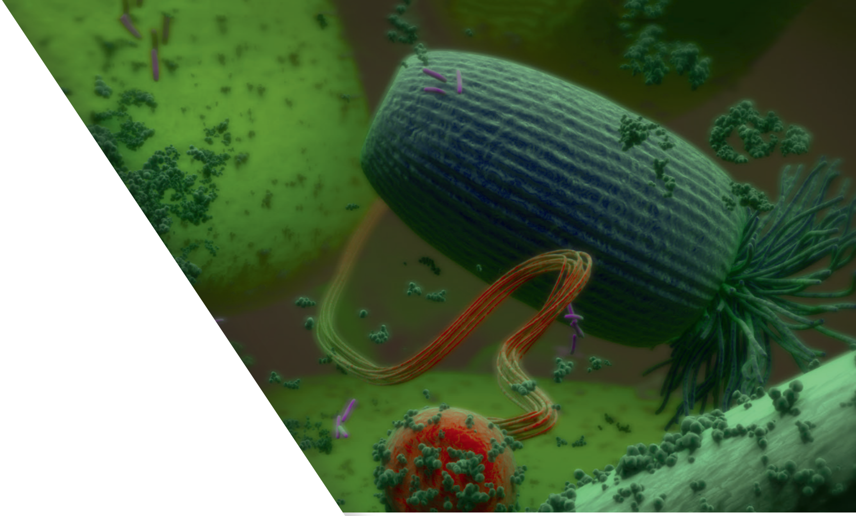

RUMEN HEALTH

TECHNICAL GUIDE

LALLEMAND FORWARD

To outline the fundamental principles of rumen function, the role of microorganisms inside the rumen and the impact on the host, demonstrate visible indicators of rumen disorders and describe the performance impact on health, behavior and profitability.

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LALLEMAND FORWARD

SPECIFICALLY CHOSEN SERVICE SOLUTIONS THAT ENHANCE PEOPLE, KNOWLEDGE AND PRODUCTION PRACTICES

At Lallemand Animal Nutrition, a high value is put on creating and maintaining strong customer relationships. Lallemand is raising the bar and setting new standards to benefit animals and create better customer experiences. Lallemand *Forward* represents our ideals while keeping an eye on the future.

LALLEMAND ANIMAL NUTRITION IS:

- At the forefront of providing modern yeast, bacteria and microbial solutions;
- Advancing toward a mutual goal with our customers to improve practices, optimize production and enhance satisfaction;
- Proving performance at every turn;
- A responsible and trustworthy partner;
- Growing as a company and as an industry leader;
- Investing in agriculture's next generation;
- Adding value to move customers and ourselves *Forward*.

RESEARCH AND DEVELOPMENT

No Lallemand product is brought to market without a substantial base of research and proof of performance. Lallemand applies *Forward*-thinking in which research results in quality products with practical application.

EDUCATION, ON-FARM SERVICES AND INDUSTRY SUPPORT

Lallemand uses its company resources to better serve customers and partners, from our production facilities, to our experienced network of experts, to the energy and innovative spirit of our people. Lallemand supports the advancement of animal nutrition's current and future generations of innovators. Knowledge is paid *Forward* to help customers improve their practices.

We're delivering specific solutions and service to drive you *Forward*.

RUMEN HEALTH

TECHNICAL GUIDE

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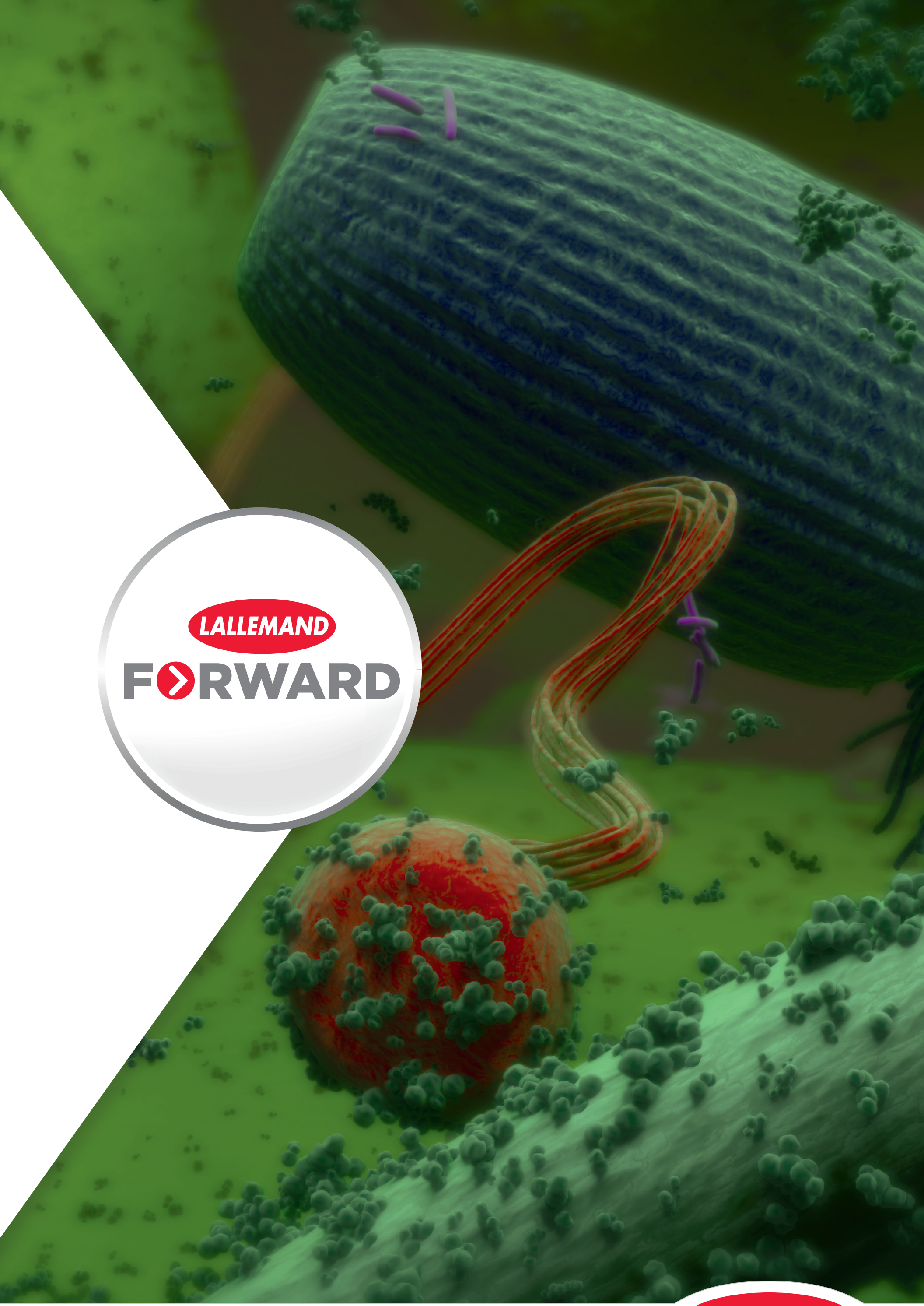
Additional information on factors affecting the ruminant digestive system can be found on http://www.RuminantDigestiveSystem.com



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INTRODUCTION

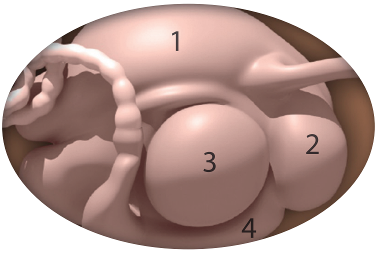
Ruminant animals have evolved with a unique, four compartment stomach, in which feed digestion, occurs before going to the hind gut. Ingested feed travels down the esophagus and is deposited in the **rumen** through the **reticulum**.

1 The **rumen** is the largest compartment, with a capacity of 150 to 200 liters, or 30 to 50 gallons, and is inhabited by a very abundant and diverse microbial community. The microbial community digests, absorbs nutrients and ferments 70 to 80 percent of the feed ingested by the animal. The rumen is the major site of microbial fermentation which produces volatile fatty acids (VFA), based on the changing microbial paterns.

2 The **reticulum** is a small but distinct pouch on one side of the rumen. Small broken- down feed particles are then moved from the reticulo-rumen to the omasum, but larger particles are forced back up to the mouth for further particle reduction. This activity is known as rumination. The reticulum plays a key role in particle sieving and rumination.

3 The **omasum's** primary function is to further filter the feed particles. Large particles are trapped in the folds of the omasum until they are flushed back to the rumen where they are further fermented and ruminated. The omasum is also an important site for water absorption.

4 The **abomasum** is commonly called the "true stomach" and is comparable to the stomach of a human, where acid secretion and enzymatic digestion occurs. Finally, the digesta is directed out of the stomach and into the small intestine.

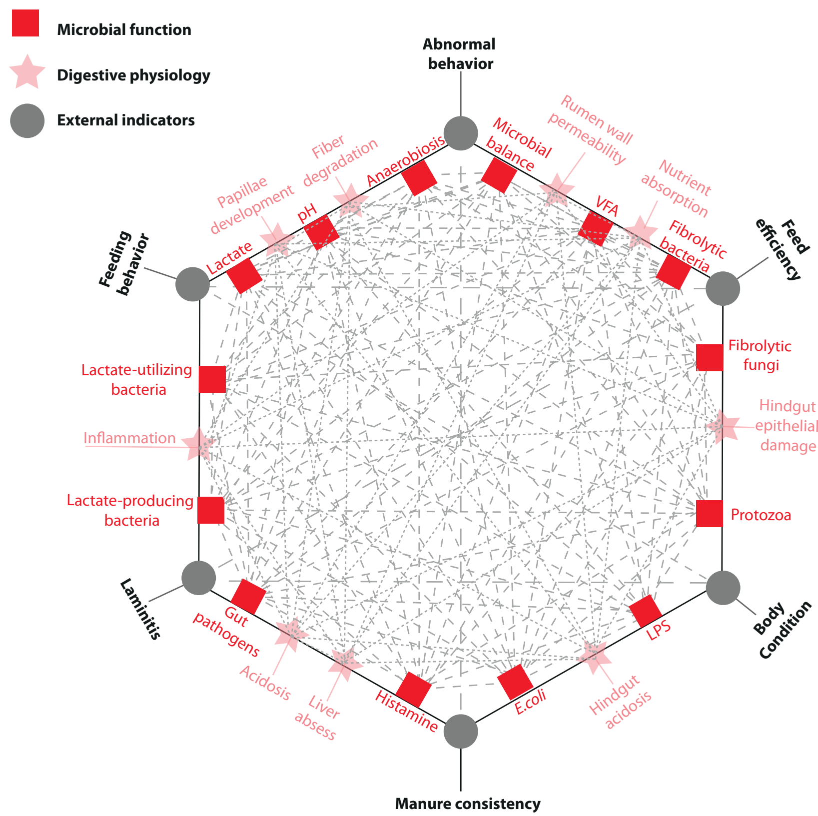


Based on the number and type of microorganisms, the rumen pH commonly fluctuates between 5.5 and 7.0. It is almost completely devoid of oxygen, as measured and monitored by scientists by the redox potential. The redox potential is the measurement of oxygen levels within the rumen and is a metric that can measure the dynamic changes of the microorganisms and the fermentation process. The lower the redox potential reading, the less oxygen is present. The presence of the microbial populations within the digestive system are vital for the animal's survival. Ruminant animals would not be able to digest feedstuffs, especially forages, without them. Thanks to this unique symbiotic relationship, ruminants can convert plant materials into milk, meat or wool.

Digestive comfort is directly linked to the balance of the different microbial communities in the digestive tract. These communities are changed in their function and activity according to dietary factors, but also to management and environmental conditions. It has also been demonstrated that when the rumen microbiota is challenged, a ruminal microbial imbalance occurs which impairs fiber digestion, increases acidosis risk, and may trigger inflammation which negatively impacts digestive comfort and well-being.

Better understanding rumen function and its relationship between the microbial community, environment and the host is Lallemand's mission to improve animal health and production performance.

Complexity of relationships between microbial function, digestive physiology and visible ruminant signs



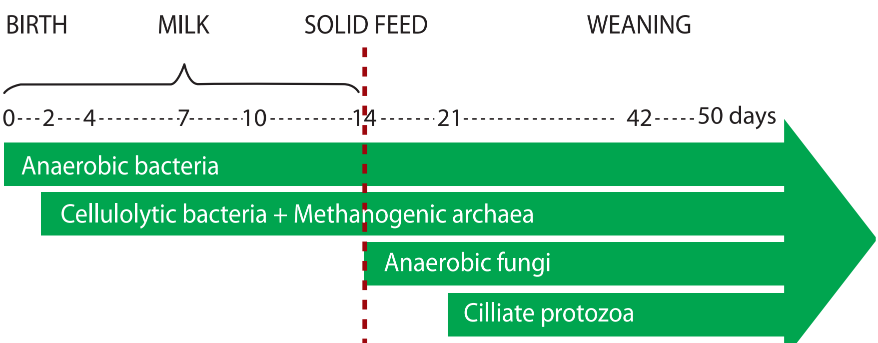
1- RUMEN HEALTH

RUMEN DEVELOPMENT

When a young ruminant is born, its rumen is considered a sterile environment that contains no bacteria or other microbial life. The young ruminant is naturally exposed to different microbes through the dam's birth canal and vagina, saliva, skin and feces.[1]

- Anaerobic bacteria appear a few hours after birth
- Cellulolytic bacteria and methanogenic archaea appear at 2-4 days of age
- Anaerobic fungi colonize the rumen during the second week
- Ciliate protozoa begin to be established only during the third week.

Pre-ruminant colonization sequence of rumen microflora (lamb model) [1,2,3,4,5,6,7,8]



The separation from the dam may occur early; the newborn ruminant naturally undergoes stress, suppressing immunity and delaying rumen development.
The transition from milk to solids can also occur when microbial colonization is incomplete[3] and result in frequent digestive disorders in the young animal.

A mature microbial ecosystem is necessary to ensure the full capacity to digest solid feed. Optimal animal growth and performance relies on:

- Rapid establishment of microbial populations,
- Development of an abundant and functional microbiota,
- Stimulation of intake and digestive activity,
- Maximizing the absorptive capacity of the rumen wall.

Immature rumen wall with poorly developed papillae

Mature rumen wall with well-developed papillae

Diversity of microbial communities in the rumen depends largely on diet composition.[9] The development of the rumen (weight, wall thickness and papillae number, integrity and length) is highly dependent on the level of complexity of its microbiota. Grain feeding increases the concentration of butyric acid in the rumen, which stimulates papillae growth.

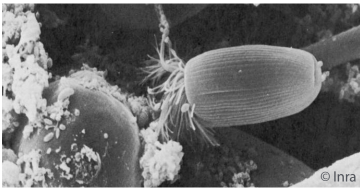
RUMEN MICROFLORA

Bacteria: rumen bacteria account for 10^{10} organisms/mL of rumen fluid and several hundred species have been characterized to date. By volume, they comprise up to 50% of the total microbial biomass. Bacteria species are an important source of microbial protein, which supply the ruminant with 75-80% of its metabolizable protein. Bacteria are also important for producing enzymes that digest fiber (cellulose, hemicellulose), starch and sugars.

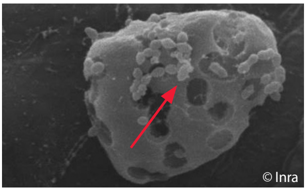
Protozoa: ciliate protozoa are organisms larger than bacteria and account for 10^6 organisms/mL of rumen fluid, however they still make up to 50% of the total microbial biomass. They have various activities:
- Cellulolytic and helicellulolytic protozoa can digest plant particles
- Different protozoa have a positive role, digesting starch (more slowly than bacteria)
- Other protozoa can consume lactic acid, thereby limiting the risk of acidosis
- Some types of protozoa are able to remove oxygen so they have a stabilizing effect upon anaerobiosis.

However, most of them degrade proteins very efficiently and release ammonia, so they can waste dietary protein. These proteins represent around 25% of the microbial protein available for the animal. Ciliate protozoa produce large amounts of hydrogen, which is a substrate for methanogens. The ciliate species are predators of other rumen microbes. In fact, a single protozoal cell can swallow up to several thousand bacteria in an hour so they play a very important role in rumen microbial population stability.

Fungi: rumen fungi comprise up to 8-10% of microbial biomass and are strictly anaerobic. They play an essential role in fiber digestion due to the production of filamentous rhizoids which invade plant tissues, and their efficient enzymatic activities. This physical action to plant cell walls, can facilitate access to more digestible tissues and help release polysaccharides, which are linked to lignin increasing the pool of digestible energy for the rumen microflora.[2,10,11]



The rumen has a very diverse community called the microbiota



Streptococcus bovis adhere to a corn starch granule

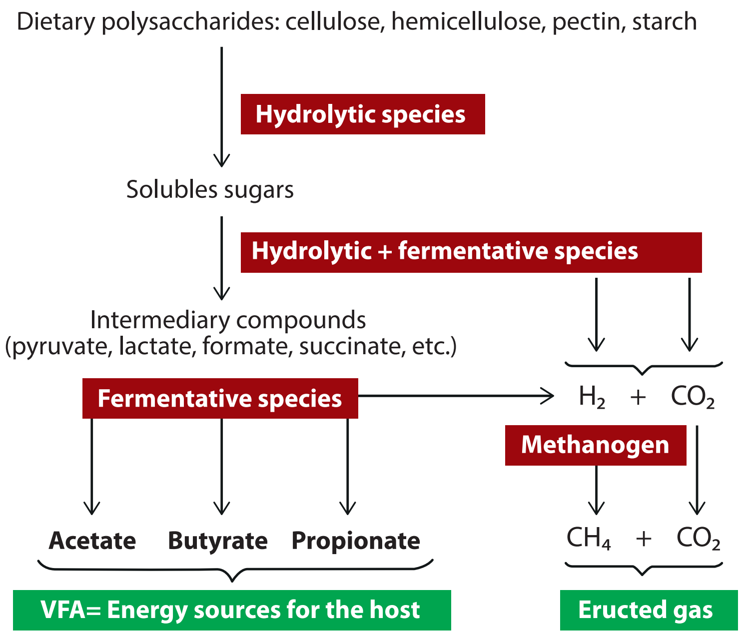
RUMEN FERMENTATION

Rumen fermentation is a process that converts ingested feed into energy sources for the host. Fiber scratches the rumen wall to start a series of contractions. These contractions lead to rumination, which is the process that physically breaks down the fiber source. Feed is then regurgitated, chewed and swallowed usually 50 to 70 times during rumination before passing through the next compartment of the stomach.

Microbial populations ferment feed and water into volatile fatty acids (VFA) and gases (methane and carbon dioxide). When fermentable carbohydrate in the diet is digested too rapidly, the bacteria will increase the production of both VFA and lactic acid.[12] To sustain growth and the activity of fibrolytic microbes, it is crucial to maintain ruminal pH above 5.8, which will prevent the decline of fiber digestion and subsequent problems.[13] Strategies that limit acid load, notably by competing with lactate producing bacteria, help to optimize fiber digestion.[14]

Frequent changes in management practices or diet composition can alter the balance of the microbes and consequently, the profile of the fermentation end products.

Rumen fermentation pathways

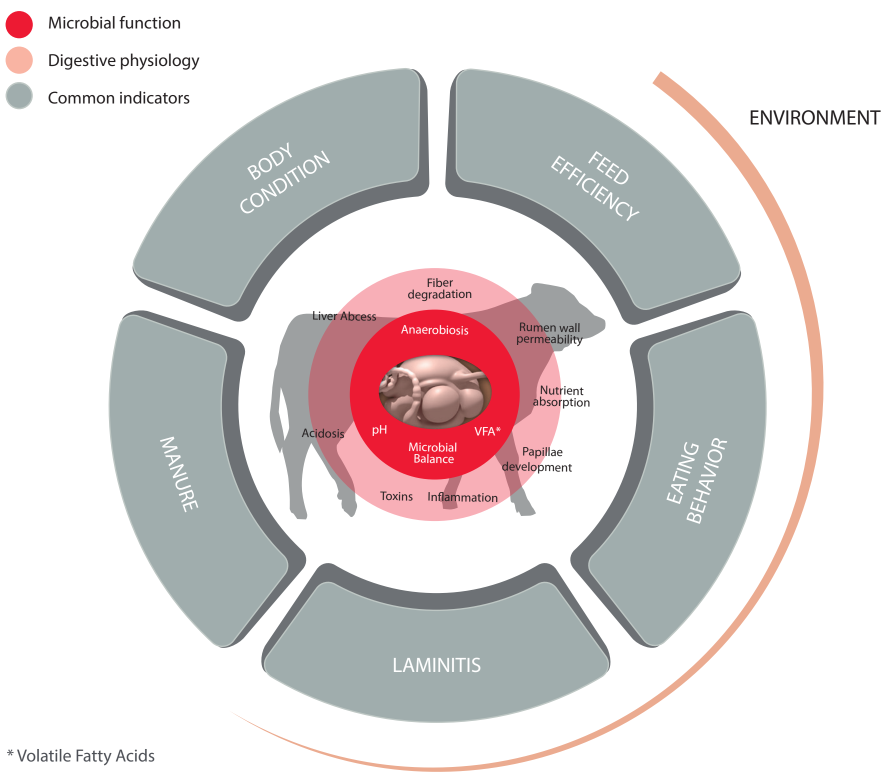


2- RUMEN CHALLENGES

Rumen efficiency is a key parameter for productivity and longevity, but is very difficult to assess on the farm. Key components of rumen efficiency, such as rumen pH and diet digestibility are not measured routinely. Rumen disorders are the tip of the iceberg. When they clearly appear, animals are already under acute acidosis.

In order to help ruminant producers and nutritionists to better appreciate their herd's rumen function, practical indicators can be used to detect poor rumen efficiency, such as feed efficiency, eating behavior and manure consistency.

Direct and indirect consequences on animal nutrition and health



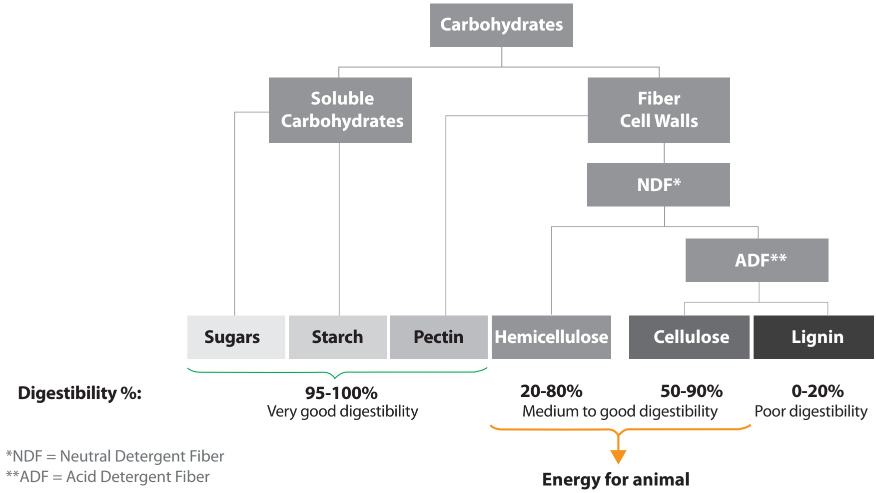
* Volatile Fatty Acids

POOR FIBER DEGRADATION

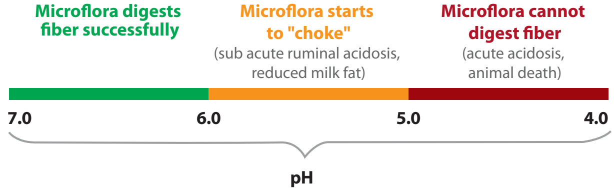
Ruminants depend on microbial fermentation within the rumen to acquire energy from plant material.[15] The different fractions from plant cells walls are not entirely physically accessible and achieve various degrees of digestibility in the rumen. To improve animal productivity, a portion of the forage diet is increasingly substituted with readily-fermentable carbohydrates. However, the supplementation of diets with readily-fermentable carbohydrates is known to depress rumen fiber degradation.[16] Additionally, the major fiber-degrading bacterial species *Fibrobacter succinogenes, Ruminococcus albus* and *R. flavefaciens,* as well as rumen fibrolytic fungi, are particularly vulnerable to rumen pH at 5.8 or lower.

The challenge for ruminant nutritionists is to maximize a balanced nutrient intake and availability, digestion and ultimately the efficiency of this process to convert to milk, meat or wool.

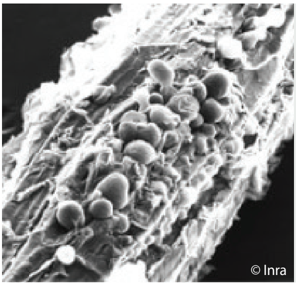
Digestion of fiber in the rumen can depend on carbohydrate type



Fiber degradation depends also on rumen pH



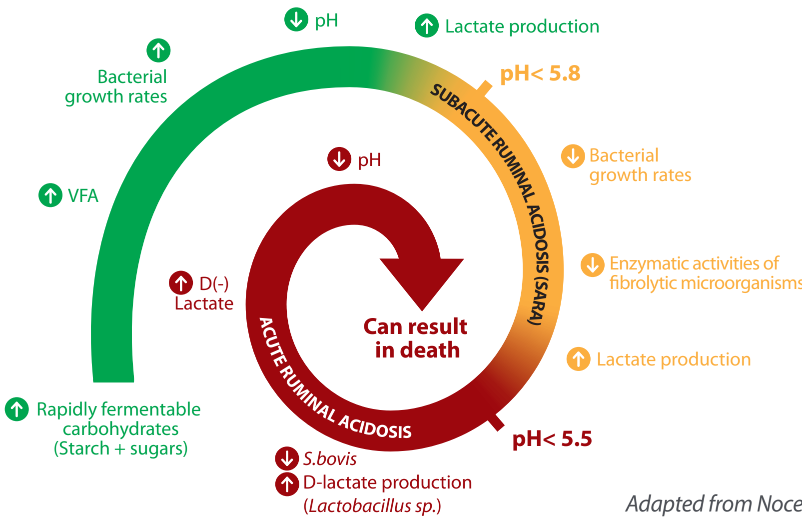
INDICATORS AND RISK PARAMETERS	GENERAL REASONS
↓ ANIMAL PERFORMANCE	- Reduced average daily gain and feed conversion ratio may be due to impaired rumen fermentation in beef cattle. - Low milk production, milk fat and a reduced fat/protein ratio may be due to impaired rumen fermentation in lactating dairy cattle.[17,18,19]
↑ LIQUID MANURE & UNDIGESTED GRAIN	Undigested processed grains in the feces because of poor rumen efficiency may be due to an increased passage rate due to an imbalanced or low diet digestibility.[20,21]
↓ BODY CONDITION	Thin animals can indicate poor rumen efficiency due to poor diet digestibility and decreased intake.[22,23,24]
↑ HEAT STRESS	Heat stress (temperature and / or humidity) increases the risks of acidosis and low fiber degradation because: > Eating behavior is negatively affected: cattle prefer to eat during cooler times of the morning and later evening. > Dry matter intake is decreased: cattle sort the diet with a lower proportion of forage and higher levels of fermentable carbohydrates. > High loss of saliva (from drooling and open-mouthed breathing) in hot weather decreases the amount of natural buffers to the rumen.[25]



Rumen fungi attached to a plant cell wall

CLINICAL & SUBCLINICAL DIMENSIONS OF RUMEN ACIDOSIS

Different degrees of acidosis appear when the fermentation profile of the rumen is unbalanced by high levels of lactic acid or butyric acid.[26,27,28,29]



Adapted from Nocek.[12]

Sub Acute Ruminal Acidosis (SARA)

- More common, results from excessive volatile fatty acid (VFA) production that exceeds the ability of the rumen to neutralize and it exceeds the absorption capacity of the ruminal papillae.
- Rumen pH drops below 5.8 and remains bellow this threshold for three or more hours within a 24-hours period.
- Animals generally have mild diarrhea, lowered dry matter intake and laminitis.
- Can develop into acute acidosis if the pH is never able to recover.

Acute Ruminal Acidosis

- Less common, more severe, usually occurs when pH falls below 5.5.
- Usually associated to a drastic diet change.
- Animals have depressed productivity, go off feed, have elevated heart-rate, diarrhea and may die.
- Severe lactic acidosis may cause irregular feeding behavior and gorging, which creates more spikes of acid production.

INDICATORS AND RISK PARAMETERS	GENERAL REASONS
↓ ANIMAL PERFORMANCE	- Reduced average daily gain and feed conversion ratio may be due to impaired rumen fermentation in beef cattle. - Low milk production, milk fat and a reduced fat/protein ratio may be due to impaired rumen fermentation in lactating dairy cattle.[17,19]
↓ RUMINATING ACTIVITY	A lack of ruminating activity may be due to reduced rumen motility during acidosis.[18,30]
↓ LOCOMOTION	Lame animals can indicate high levels of rumen histamine production and bacteria endotoxin release.[12]
↓ RUMEN FILL	An empty rumen can indicate poor rumen efficiency because of irregular intake.[22]
↓ MANURE CONSISTENCY	Liquid feces can indicate poor rumen efficiency due to an increased passage rate, from an imbalanced diet and more lower gut fermentation.[20,21,22]
↓ CLEANLINESS	An increased passage rate from an imbalanced diet and low digestibility can lead to unclean animals
↑ UNDIGESTED GRAIN	Undigested processed grains in the feces because of poor rumen efficiency may be due to an increased passage rate due to an imbalanced or low diet digestibility.[20]
↑ HEAT STRESS	Heat stress (temperature and / or humidity) increases the risks of acidosis and low fiber degradation because: > Eating behavior is negatively affected: cattle prefer to eat during cooler times of the morning and later evening. > Dry matter intake is decreased: cattle sort the diet with a lower proportion of forage and higher levels of fermentable carbohydrates. > High loss of saliva (from drooling and open-mouthed breathing) in hot weather decreases the amount of natural buffers to the rumen.[31]

Rumen wall damaged by acidosis

Healthy rumen papillae

Financial impacts

The financial impact of rumen acidosis is staggering.

In lactating dairy cows, economic loss can be attributed to: lower milk fat content (-0.76%), depressed milk production (-10%), poor reproductive performance and increased risk of secondary metabolic disorders. One study estimates the overall impact to the U.S. dairy industry is between $500 million and $1 billion per year.[32] Another study estimates sub acute ruminal acidosis costs $34,750 per 100 cows.[33]

In growing and finishing beef cattle, economic loss can be attributed to: lower growth rate (-78g/hd/d; -0.17 lbs/hd/d), reduced feed-to-gain conversion, lower meat grades, and increased risk of secondary metabolic health events.[34]

MANURE CONSISTENCY

Manure consistency is often considered by producers and farm advisers as a predictor of rumen digestion. Different aspects are usually taken into account when observing manure consistency.[21,35]

Content

When the presence of large portions of undigested, but processed, grain and/or forage particles are visible in manure, it may be an indication of poor rumen fermentation. Low rumen pH (which impairs rumen microflora activity) coupled with a high passage rate, can lead to a reduction of starch and fiber digestion in the rumen.[20]

The presence of large amounts of undigested grain may be an indication of:

- Improper processing (i.e. hard kernels from corn silage) or
- Poor rumen digestion (even if well-processed). This could be due to inadequate fiber intake, which stimulates rumination and maintains optimal rumen pH.

Manure with visible grain and/or large forage particles

Color and Consistency

An example of non-optimal rumen digestion is when: finely ground grain passes quickly through the rumen, which can appear as a yellow color in dried manure; this grain can ferment in the lower gut inducing a mucus layer on the surface of the manure, which is a sign of chronic inflammation or injury to the gut tissue. Manure that contains bubbles or foam may indicate acidosis or excessive hindgut fermentation, which causes gas production.[20]

Manure consistency scale

LAMINITIS

- The etiology of laminitis is multi-faceted, but is generally the result of prolonged exposure to low rumen pH that is caused by nutritional factors that lead to acidosis.[12,36,37]
- The initial activation of laminitis starts with the low rumen pH, lysis or death of gram-negative bacteria lead to the release of lipopolysaccharide (LPS), a cell wall component which is a very potent stimulator of inflammation.
- Histamine is also produced by some rumen bacteria under low pH, and by an animal under stress. Histamine is also an inflammatory compound. Due to repeated acid insults on the rumen and the hindgut wall, the epithelial barrier is disrupted and these inflammatory molecules can be transferred to the bloodstream.
- Histamine production leads to an inflammatory condition in the animal that can weaken the laminar structure in the hoof wall, thus leading to laminitis.

Poor locomotion is visible signal of lameness

BLOAT

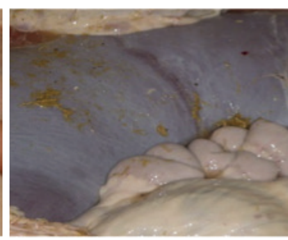
- Intensively fed cattle typically have a high proportion of cereals in their diet, which quickly produces gas during digestion.[38, 39]
- Cattle on these diets are not able to expel gas fast enough during rumination, due to the small quantity of long fiber in the diet.
- The foamy substrate is comprised primarily of polysaccharides secreted by rumen bacteria and released from disrupted bacterial cells. This happens when large populations of bacteria die in a short period of time.
- More efficient rumen fermentation means less energy is wasted as methane and also less protein is lost as ammonia.

LIVER ABSCESS

When the rumen wall is damaged by the effects of acidosis, bacteria can enter the bloodstream and proliferate throughout the liver.[38]

Abscessed liver

Damage to the **rumen wall** allows pathogens into portal bloodstream



Healthy liver

- The most common causative agents are: *Fusobacterium necrophorum* (100% of cases) and *Arcanobacter pyogenes* (35% of cases).
- Both are part of the normal microflora found in the rumen.
- Toxins produced by these bacteria lead to a coagulative necrosis that develop into encapsulated abscesses over time and the form of a fibrous scar (up to 15cm in size).

3- CONCLUSION

The cornerstone of digestion and performance is the rumen, where forage and feed are converted into energy and microbial protein thanks to the activity of the rumen microflora: bacteria, protozoa and fungi.

Good rumen efficiency (healthy rumen and good microbial balance) can also be predicted by observing visible signs on the herd; rumen efficiency is key for optimal feed efficiency, reproductive performance, overall productivity and longevity.

Additional information on factors affecting the ruminant digestive system can be found on http://www.RuminantDigestiveSystem.com

The microorganisms in the digestive system and the ruminant animal have a unique and dynamic symbiotic relationship

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