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NDS Dynamics

Welcome to the NDS Dynamics newsletter!

Dear readers,
Welcome to 2022! For this year the teams at RUM&N and at NDS North America decided to move our newsletter from a bimonthly issue to a quarterly issue thus to always ensure the content to be of high interest for all our readers and providing more articles on key functions of NDS Professional.
In this first issue, professor Gregory B. Penner from the University of Saskatchewan (Canada) illustrates how rumen pH and, in particular, low rumen pH affects the nutritional performance of dairy cattle.
Furthermore, Kurt Cotanch from the NDS North America team, will discuss about the importance of forage particle size and on how this affects chewing activity, milk fat content and rumen function.
Please continue to follow us on our channels to receive updates on what is new and what is happening at RUM&N and NDS North America .

The Editor
Ermanno Melli

Regulation of Rumen pH and Nutritional Consequences of Low pH

By Gregory B. Penner
University of Saskatchewan

Ruminal acidosis is a common digestive disorder in conventional dairy production (Penner and Beauchemin, 2010). Using within herd-based sampling, prevalence rates are expected to range 19 and 40% depending on the stage of lactation (Krause and Oetzel, 2006); although some have speculated that the spot-sampling approaches may have underestimated prevalence rates (Penner et al., 2007, 2009b). It should be noted that ruminal acidosis can also occurs for cattle on pasture when cattle are fed high-quality fresh forages, especially when supplemental silage or grain is provided (Bargo et al., 2002; Kolver and de Veth, 2002; O'Grady et al., 2008). Holstein calves may also experience ruminal acidosis at weaning (Suarez et al., 2005; Laarman et al., 2012; Wood et al., 2015), suggesting that ruminal acidosis is not limited to lactating cows.

Ruminal acidosis can be classified as acute or sub-acute (SARA). Sub-acute ruminal acidosis (pH < 5.8) is arguably the most common form in dairy cattle. For SARA, the low pH is caused by rapid rates of SCFA production relative to acid removal. As such, when simply stated, ruminal acidosis occurs when the rate of acid production exceeds the rate of acid removal from the rumen. There is substantial variation in ruminal pH among cows within a herd, and for individuals within a day (Penner et al., 2007). Some cattle are also more tolerant of low ruminal pH than others (Penner et al., 2007 and 2009a). Thus, the ruminal pH thresholds used to characterize SARA and acute ruminal acidosis are used as a guideline rather than true biological threshold.

While pH is often used as a prominent indicator of SARA, the production and accumulation of short-chain fatty acids in the rumen increases osmolality and, with rapid fermentation, the concentration of microbial associated molecular patterns (MAMPS) increase (Gohzo et al., 2005; Ametaj et al., 2010). The latter cannot be

excluded in the pathogenesis of SARA (Plaizier et al., 2018; Humer et al., 2018). When considering conditions involved in SARA, there is no doubt that low pH (5.6), when measured in vitro, decreases NDF digestibility (Calsamiglia et al., 2002). But low pH (pH 5.2) reduces nutrient absorption across the rumen (Gaebel and Martens, 1988; Wilson et al., 2012; Schwaiger et al., 2014) and increases permeability of the tissue allowing non-desired compounds (e.g. MAMPS) to cross (Aschenbach et al., 2000; Penner et al., 2010) and enter circulation. Hyperosmotic conditions also acutely increase permeability of rumen tissue (Schwiegel et al., 2005; Lodemann and Martens, 2006). Recent data support the concept that increased permeability (driven by low pH and high osmolality) and exposure to MAMPS increases inflammation in the rumen epithelium (Kent-Dennis et al., 2018) and likely systemically.

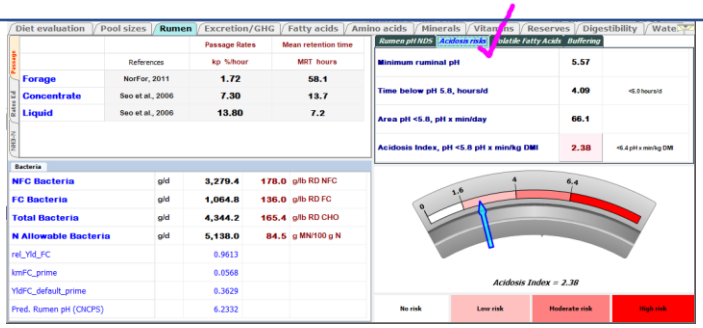
As the name SARA implies, the focus on responses has been in the rumen. It should also be noted that induction of ruminal acidosis causes a reduction in pH in more distal regions of the gastrointestinal tract (Gressley et al., 2012; Pederzolli et al., 2018). While this occurs, the relevance of reduced pH in the large intestine is still not fully understood, but it is expected that inflammation arising from SARA may be driven by intestinal regions rather than from the rumen. The previous speculation is based on the rumen being a tighter (less permeable) epithelia than intestinal regions (Penner et al., 2014).

As ruminal pH includes acid production and removal (Allen et al., 1997), it should be recognized that pH alone is a poor indicator of rumen function: more information is needed. Thus, low pH does not exclusively imply a challenge for ruminal function and high pH does not exclusively imply improved acid removal. For example, Zhang et al. (2013a) imposed exposure to low feed intake over 5 d and reported pH was increased in a dose-dependent manner. Moreover, following return to ad libitum feeding, ruminal acidosis was induced despite low intake (Zhang et al., 2013b). Thus, changes in DMI can have a profound effect on rumen pH by affecting both production and absorption, but affecting them differently. As such, evaluating pH in the absence of DMI or other dietary indicators may be misleading. To address this, pH area (the area (time by extent) of pH depression below a critical threshold) can be calculated and normalized with DMI (Penner et al., 2009). Using this approach, Zhang et al. (2013a,b) was able to confirm that the acidosis index was greater (more acid accumulation potential/unit DMI) for cattle exposed to a greater severity of feed restriction. Calculating the acidosis index ensures that interpretations of low and high pH account for the observed level of DMI and provide a more meaningful representation of pH. To gain further understanding of the acidosis index, 24 studies (81 treatment means) reporting continuous ruminal pH measurement and DMI intake were used to calculate the acidosis index in relation to milk yield and components. While the acidosis index is an abstract value, diets yielding a greater acidosis index tended to reduce milk fat yield and reduced milk fat percentage showing the practical utility of the acidosis index indicator.

Regulation of Ruminal pH

Regulation of ruminal pH is complex and involves aspects affecting SCFA production as the major driver for acid production and is counterbalanced by removal of acid from the rumen. Many factors can influence SCFA production (e.g. rate of fermentation, extent of fermentation, indigestibility of the diet (uNDF), peNDF, meal size and frequency, and fermentation pathway), strategies that remove acid from the rumen will be the emphasized. Most previous studies have investigated dietary strategies to promote chewing activity (Allen, 1997). Chewing increases the rate of saliva production and could greatly increase the supply of bicarbonate to the rumen. In fact, it is estimated that saliva contains 126 mEq/L of bicarbonate and may contribute to approximately 30% of the total ruminal buffering capacity (Allen, 1997). However, for cattle fed low physically effective fibre (peNDF) diets or diets high in concentrate, it could be expected that the salivary contribution is much

lower (Dijkstra et al., 2012). The other major contributor to the regulation of ruminal pH is SCFA absorption (Allen, 1997; Penner et al., 2009a; Aschenbach et al., 2011). Short-chain fatty acid absorption, alone, has been estimated to account for up to 53% of the ruminal buffering capacity (Gäbel et al., 1991; Allen, 1997). In addition, acid is removed from the rumen through passage and other relatively minor buffering reactions. Understanding how to optimize acid removal should help stabilize ruminal pH and increase energy delivery to cattle.



The RUMEN tab can show these calculations.

Extent and severity of rumen acidosis

Rumen pH 5.8 was used as the threshold of acidosis. However, the duration of rumen pH below 5.8 reflects how long of the occurrence of rumen acidosis, but it does not reflect the extent and severity of rumen acidosis. With a view to better assess the acidosis status, the extent and severity of rumen acidosis should also be considered.
It is proposed a goal of Acidosis Index < 6.4 pH x min/kg DMI to describe low to moderate SARA risks.

Further explanation on the online MANUAL.

Forage Particle Size: Considerations from field through rumen

By Kurt Cotanch
NDS North America

Forage particle size results from a number of factors including plant maturity, NDF digestibility and moisture at harvest and at consumption. Keeping in mind these factors and how they can affect nutrient quality, intake and rumen function, here are a few thoughts.

Forage particle size is often considered to be primarily a TMR, forage and grain feeding concern. However, we start talking about particle size from the moment we begin harvesting in the field, whether as "theoretical length of cut/chop" or as physically effective fiber in the rumen. It is critical when balancing for sufficient fiber relative to rumen fermentable starch in order to maintain proper rumen pH and animal health. Combined with possible mechanical separation and animal sorting behaviors, typically but not always, in favor of grain particles, the risk of rumen acidosis is elevated. As for sorting, it is a misconception to assume all animals sort for grain. Individual animals sort for and against forage particles. Though the preponderance of animals do "choose" to sort against forage in favor of consuming grains.

Particle size relative to chewing, milkfat and rumen function

Mertens (1997) eloquently derived the concept of physically effective fiber (peNDF) showing the relationship of forage particle size combined with fiber (NDF) on total chewing time, eating and rumination, and milk fat %. The basic premise is that the % of fiber (NDF) in particles longer than 1.18mm are those that require rumination and thus provide more rumen buffering through chewing and saliva production. According to the calculation, peNDF = pef (physical effective factor) x total % NDF, where pef equals the % of NDF in forage particles longer than 1.18 mm when dried and sieved using a vertical separation technique. The reference value of peNDF > 21% was established as the low-end benchmark in order to avoid milk fat depression

due to inadequate dietary fiber resulting in inadequate chewing and saliva production to avoid rumen acidosis that would then depress milk fat production. On farm measurements of forage particle size often rely on the Penn State Particle Separator (PSPS) system equipped with the 19, 8, and 4mm tiers. The PSPS is used on "as fed" forages, not dried samples. Research, at Miner Institute that I was involved with, demonstrated that the total % of "as fed" forage or TMR retained on and above the 4mm screen (>4mm) closely tracked with the amount of dry sieved sample >1.18mm as determined using same methods noted in the original paper from Mertens (1997). In other words, the pef value of "as fed" forages >4mm is very similar to the pef value of dry sieved material >1.18mm. The drying of forages shrinks the particles as well as making them more brittle and possibly easier to fracture. The dry sample, vertical sieving methods also separate particles based on particle width/diameter rather than length. The PSPS separates particles more on length than diameter. Neither system is perfect, but fortunately they show similar results of determining the pef value which is used in NDS/CNCPS for determining predictions of rumen pH and microbial yields.

The relevance of peNDF is to provide sufficiently long particles in the rumen to maintain a rumen mat, thus stimulating rumination and proper rumen contractions and gut motility to mix the rumen contents and maintain out flow of digesta to the lower gut; abomasum and small intestines.

Since Mertens 1997 peNDF paper, we have learned much more about the causes of milkfat depression involving the CLA fatty acids and the biohydrogenation process that is affected by low rumen pH. We can feed rations with peNDF in the 18% range and possibly lower, only if rumen health and rumen fermentable carbohydrates and NDF are properly balanced.

The rumen contents form layers of ingesta based on particle size and density as they progress through the various stages of particle size reduction resulting from rumination and microbial degradation of fiber. The rumen mat is comprised of newly ingesta feed and forage particles that are still buoyant in the aqueous environment. These floating particles create a "raft" of material requiring rumination to further ensalivate, reduce particle size and increase surface area exposure for microbial attachment and degradation of the fiber. Microbial degradation of forage fiber is generally from the inside out; bugs then need access to the inside of plant cells in order to attach and degrade forage cell walls. Structural integrity of the forage needs to be disrupted in order to get past the protective waxy cutin layers. This requires rumination.

A "healthy" rumen mat will optimize microbial growth, production of VFA (acetate and butyrate) from fermentation of the fiber and forage carbohydrates thus optimizing yields of microbial protein eventually digested in the lower gut of the animal. Microbial protein is the best source of amino acids for the animal and they do not represent a purchased item for the farmer.

NDS has a powerful tool to calculate peNDF values as long as the user performs the particle size determination using either the PSPS or Z Box method. We encourage you to determine the actual pef values of forages and TMRs. This will ensure more accurate peNDF inputs for NDS to predict rumen pH and microbial yields and thus MP allowable milk estimates.

Particle Size and Total Chewing Time (TCT)

It has long been understood that longer forage particles stimulate greater rumination than shorter particles. It turns out that particle size is but one variable in this concept. Fiber digestibility (NDFD) plays a significant role in determining rumination time. The less digestible the NDF (lower NDFD) the more time required to chew and

longer time required for microbial degradation before the forage particle attains proper size and density to sink and pass out of the rumen. We are now seeing that fiber digestibility along with size play a very large role in eating time as well. Moisture content, particle size and NDFD greatly influence time required to ensalivate and create a swallowable bolus. Schadt et al. (2012) showed that across a large range of initial particle lengths of dry grass hay, time required to consume/eat was decreased with shorter particles and that on average, particle length of the swallowed forage was about 10mm regardless of initial length of hay particle and also of TMR and corn silage.

This is not to suggest we feed only 10mm length forage, but to enlighten us that by feeding longer forage and especially long low digestibility forage, this likely requires longer eating times as well as longer rumination time and thereby limiting DMI and rumen fill capacity. The question then becomes, does the cow have the time and space to maximize intake as well as lay down and rest to process this forage? By using the NDS Management Tool, we can try to determine cows time budgets for resting and eating time.

Particle size at harvest

When putting up ensiled forages we know that long, dry material does not pack well. Air does not get excluded sufficiently to optimize anaerobic fermentation. For optimal ensiled packing density, consider plant maturity affecting not only NDFD when fed but the ability to pack dense enough to maximize exclusion of air and optimize anaerobic fermentation. If it is mature forage, tough low NDFD, make sure to minimize the amount of particles >19mm while still keeping most >8mm in the PSPS system. When putting up dry hay, again keep in mind particle length and plant maturity on how long it will take animals to consume this long, tough forage as well as length of time it will stay in the rumen. Low fiber digestibility feeds should be harvested shorter in order to minimize time for consumption as well as maximizing surface exposure for microbial attachment. Help her out, don't make her do all the particle processing to make use of lower quality forages.

If possible, use hay processing knives when harvesting forages, especially mature forages as either dry hay or wet ensiled forage. This will help improve packing density, air exclusion, reduce sortability of high forage rations and optimize DMI, rumen fermentation and microbial yields.

Whether feeding TMR, "All Grass" rations or pasture-based dairying, forage particle size matters for a number of reasons both in forage preservation, animal consumption and rumen fermentation. Particle size influences rumen dynamics, fiber digestion, microbial yields and thus VFA production, rumen and animal health, eating time budgets which affect DMI, along with quality of fermentation of ensiled forages.

Send us your comments on this topic! Emiliano Raffrenato is at emiliano.raffrenato@rumen.it; Giulia Esposito is at giulia.esposito@rumen.it; Dave Weber is at rumendvm@gmail.com

Note that the features and utilities developed by the NDS team are not components of the underlying CNCPS model. None of the original CNCPS structures or equations have been changed in the NDS platform. NDS does provide sub-models and utilities to provide enhanced predictions based on the original CNCPS model. ***Questions about the use of these features should be directed to the NDS support team, and not to the CNCPS group at Cornell.***