RUMEN ACIDOSIS IN DAIRY CATTLE

Kees Plaizier, George Gozho and **Denis Krause**
Department of Animal Science, University of Manitoba

plaizier@ms.umanitoba.ca

Milk yields of North American dairy cows have increased substantially during recent years. This has created challenges, because, in order to meet the increased potential for milk production, dairy diets have to contain more grain and less forage. Feeding these high concentrate diets can result in high concentrations of organic acids in the rumen and a reduction in chewing, saliva production and rumen buffering (Kleen et al., 2003; Stone, 2004). This can lead to an increase in rumen acidity and a drop in rumen pH. When rumen pH is reduced for prolonged periods each day, subacute ruminal acidosis (SARA) can occur (Kleen et al, 2003; Stone, 2004). This metabolic disease affects rumen fermentation and digestion, but also impacts many other aspects of production and health of dairy cows.

Definition And Symptoms

There is some disagreement as to a precise definition of SARA, but our research team uses a definition of rumen pH between 5.2 and 5.6 for at least 3 hours per day. Cooper et al. (1999) measured pH of rumen fluid with in-dwelling pH probes and defined SARA as daily episodes of rumen pH between 5.2 and 5.6. Beauchemin et al. (2003) used the same technique for the measurement of rumen pH, but defined a pH of 5.8 as a threshold for SARA. Garett et al. (1999) used a threshold pH of 5.5 when rumen fluid samples were collected by rumenocentesis. Duffield et al. (2004) observed that the pH of rumen fluid samples obtained using a stomach tube (oro-ruminal probe) and collected from the ventral sac of the rumen through a cannula were, on average 0.35 and 0.33 pH units higher than the pH of rumen fluid sample collected by rumenocentesis. These authors, therefore, proposed that thresholds for abnormal pH indicating SARA are 5.5, 5.8 and 5.9 when rumen fluid sample are collected by rumenocentesis, through a cannula from the ventral sac and using an oral probe, respectively. Our group uses a threshold pH of 6.0 when rumen fluid samples are collected using a stomach tube. Figure 1 shows the diurnal variation in rumen pH that is seen during SARA.

Cows affected with SARA may show feed intake reduction, milk fat depression, diarrhea, dehydration, laminitis, and reduced fiber digestion (Nocek, 1997; Plaizier et al., 2001; Kleen et al., 2003; Stone, 2004). These signs are

currently not specific to SARA and this has led to SARA being explained as a consequence of poor forage quality or poor bunk management (Nocek, 1997). As a result, SARA often goes untreated. Kleen et al. (2003) suggests that the high levels of volatile fatty acids (VFA) that are present in the rumen during SARA result in parakeratosis of the rumen epithelium, resulting in inflammation of the rumen wall (rumenitis), and a reduction in the barrier function of the rumen epithelium. The impairment of the barrier function can result in the movement of bacteria and bacterial endotoxins from the rumen to the liver. These movements may be responsible for liver abscesses, and could, possibly, also contribute to laminitis (Nocek, 1997). The effect of bacterial endotoxin on laminitis has been explained by the damage and subsequent hemorrhaging that these toxins can cause to the capillaries of the corium of the hoof (Nocek, 1997). The reduction in fiber digestion that occurs during SARA is the result of the acid sensitivity of the gram-negative rumen bacteria that digest fiber. These bacteria generally cannot tolerate low rumen pH, which will reduce their numbers in the rumen and, subsequently reduce fiber digestion (Shi and Weimer, 1992). If SARA is caused by an increase in concentrate and a decrease in fiber in the diets, then the population of amylolytic bacteria will increase and the population of fibrolytic bacteria will decrease due to changes in the substrates that these bacteria ferment.

The reasons for the reduction in feed intake that SARA causes are unclear. This reduction might be caused by high levels of VFA and acidity in the rumen (Allen, 2000), but the inflammation that results from SARA (Gozho et al, 2005a) might also contribute. Griinari et al (1998) observed that a reduction in rumen pH results in the production of trans-fatty acids, e.g. trans-10 C18:1, that limit milk fat synthesis. This theory is thought to give a better explanation of the milk fat depression that occurs during SARA than effects mediated through acetic acid and insulin (Griinari et al., 1998).

Our group demonstrated that inducing SARA by feeding excess grain increased free bacterial endotoxins (LPS) in rumen fluid and the acute phase proteins serum amyloid-A (SAA) and haptoglobin (Hp) in peripheral blood. LPS is a component of the cell wall of gram-negative bacteria that is released, i.e. becomes “free”, when these bacteria die. Fast growth of gram-negative bacteria can, however, also increase free LPS in the rumen (Wells and Russel, 1996). Acute phase proteins are released by the liver during inflammation. Both SAA and Hp are among the most reactive acute phase proteins in cattle. Abrupt induction of SARA by excess grain feeding in steers on an all forage diet increased free LPS endotoxin, SAA and Hp from 3,714 to 12,589 endotoxin units (EU)/mL, from 33.6 to 170.7 μg/mL and from 0.43 to 0.79 mg/mL, respectively (Gozho et al., 2005a). When steers had been adapted to a diet containing 60%

concentrate, inducing SARA increased free LPS, SAA and Hp from 6,542 to 32,275 EU/mL, from 36.5 to 131.3 μg/mL, and from 0.54 to 2.39 mg/mL, respectively (Gozho et al., 2005b). In lactating dairy cows fed a diet containing 60% concentrate, the first induction of SARA increased free rumen LPS from 21,373 to 86,772 EU/mL (Figure 2). A second induction of SARA two weeks later increased LPS to 145,383 EU/mL (Gozho et al., unpublished) (Figure 2). In this experiment, SARA did not affect Hp, and the first and second induction of SARA resulted in a similar increase in SAA from 343.5 to 498.8 μg/mL. In these experiments, LPS was not detected in peripheral blood. This data suggests that previous exposure to a high grain diet amplifies the increase in free LPS and reduces the increase in SAA and Hp due to induction of SARA. The mechanisms through which this occurs are still unclear, but it is assumed that they are related to changes in the populations of rumen microbes during the first exposure to high grain diets.

Diagnosis

Diagnosis of SARA is done on a herd basis and involves assessment of feed intake, and milk production records of the herd as well as ruminal pH measurements of some animals. Signs such as irregular feed intake, loss of body condition, intermittent diarrhea, dehydration, abscesses, milk fat depression and laminitis are not specific to SARA. Measuring rumen fluid pH is currently an important tool used to confirm a diagnosis of SARA in a herd, and is in fact the only differential tool available. However, the measurement of rumen pH to provide a diagnosis of SARA on a herd basis is problematic because of the difficulty in obtaining a rumen sample from a large number of cows, and current methods are either unpractical or dangerous to the animal. Rumenocentesis involves percutaneous needle aspiration requiring puncture of the rumen to collect rumen fluid, and might require surgical preparation of the centesis site and local anesthesia (Duffield et al, 2004). Samples obtained by rumenocentesis are not contaminated with saliva (as is the case with stomach tubing) and are regarded as more representative of rumen pH than samples obtained using a stomach tube (Duffield et al, 2004). However, health problems resulting from rumenocentesis, such as abscesses and other infections around the puncture site, and a reduction in milk production make this method problematic (Aceto et al., 2000). A less invasive method is the collection of rumen fluid through a stomach tube but samples are usually contaminated with saliva, which increases the pH. Also stomach tubing large numbers of animals is unpractical because of animal handling issues (Duffield et al, 2004).

Rumen pH fluctuates considerably throughout the day in relation to feeding. The timing of the rumen fluid collection, therefore, has a significant effect on the pH of these samples. It is suggested that rumen fluid be collected between 5 to 8 hours after feeding, as this typically coincides with low rumen pH (Garrett et al, 1999; Beauchemin et al., 2003). Failure to standardize the collection of rumen fluid relative to the time of feeding will reduce the accuracy of the diagnosis of SARA.

Incidence

Only limited information on the prevalence of SARA is currently available. A survey on 15 dairy farms in Wisconsin showed the presence of SARA in 19% of early lactation cows and 26% of mid-lactation cows (Garrett et al., 1997). Another survey on 14 dairy farms in Wisconsin detected SARA in 20.1% of early and peak lactation cows (Oetzel et al., 1999). The impact of SARA was demonstrated by a field study on a large dairy farm in New York State that found that SARA reduced milk yield, milk fat and milk protein production by 2.7 kg/d, 0.3 percentage points and 0.12 percentage points, respectively (Stone, 1999). The percentage reduction on milk fat and milk protein may not seem great but applied to an entire lactation these reductions can amount to a financial loss of as much as $400 per cow. These costs exclude cost due to increased culling and veterinary treatments.

Currently, no data on the prevalence of SARA in Western Canada exists. However, in Western Canada, barley grain and barley silage are common ingredients in dairy diets. Barley is digested more rapidly in the rumen than corn, and barley-based diets therefore pose a greater risk for SARA. It is recommended that at least 40% of feed particles of dietary ingredients in total mixed rations (TMR) for dairy cows be longer than 8 mm (Plaizier et al., 2004). A survey on Manitoba dairy farms revealed that on at least 25% of farms TMR were finer than recommended (Plaizier et al., 2004) which would put the cows on these farms at risk for SARA (Heinrichs, 1996). Taken together, this data suggest that because of the high prevalence of SARA risk factors in Western Canada this disease is likely a common occurrence on dairy farms.

Causes

Rumen acidity will increase and rumen pH will drop when organic acids such as VFA and lactic acid, accumulate in the rumen, or if rumen buffering is reduced. Feeding more concentrate will increase rumen acidity because digestion of grain in the rumen produces more organic acids than digestion of forages (Mertens, 1997). Also, as grains are digested more rapidly in the rumen than forages, feeding high concentrate diets will lead to a more rapid production of VFA after feeding and more diurnal variation in rumen acidity compared to feeding high forage diets (Mertens, 1997).

The clearance of VFA from the rumen is dependent on the size and density of the rumen papillae, as these determine how fast these acids can be absorbed. A reduction in absorption, e.g. by inflammation or parakeratosis of the rumen wall due to low rumen pH, puts cows at increased risk of SARA. Fresh cows are also at a higher risk of developing SARA compared to cows in mid and late lactation, as the absorption capacity of VFA of the rumen can decrease by 50% during the dry period and it will take several weeks for this capacity to be restored after high concentrate diets are reintroduced (Dirksen et al., 1985). This might explain why monitoring rumen pH during the transition period showed lower rumen pH during the first week after calving than during the third week after calving (Plaizier et al., 1999).

In order to prevent a drop in rumen pH after the digestion of carbohydrates, the rumen needs to be buffered. The buffers in the saliva are critical for rumen buffering. Sodium bicarbonate is the main buffer in the saliva of cows. Chewing, both during eating and ruminating, increases saliva production and rumen buffering (Mertens, 1997). Dietary fiber promotes chewing activity. Guidelines for the minimal dietary fiber content have, therefore, been developed. The National Research Council (NRC, 2001) recommends a minimum of 25% dry matter as neutral detergent fiber (NDF), of which 75% must be from forage sources, for diets containing corn grain. When diets contain barley grain, which contains more non-fiber NDF than corn grain, a minimum fiber content of 34% of dry matter has been recommended (Beauchemin, 1991).

A problem with formulating diets for adequate rumen buffering based on dietary NDF is that not all fiber sources are equal in their rumen buffering capacity (Mertens, 1997). The amount as well as the physical and chemical characteristics of fiber in a diet affects animal performance (Mertens, 1997). It is, therefore, imperative that a validated unit or measure be established for the buffering capacity provided by a diet (Mertens, 1997). Physically effective NDF is a measure that reflects the ability of physical characteristics of fiber, mainly particle size, to stimulate chewing and saliva buffering in the rumen (Mertens,

1997). The amount of physical effective NDF in a diet is based on forage chop length, concentrate to forage ratio, and dietary NDF content (Mertens, 1997). The physical effective NDF value of a feedstuff has been calculated as the product of the NDF content of the feed, and tabular physical effectiveness factor ($peNDF_M$; Mertens, 1997). Yang et al. (2001) determined $peNDF_{>1.18}$ as the dietary NDF content multiplied by the percent of DM remaining on a 1.18 mm screen, using a dry sieving technique, as it was assumed that DM passing through a 1.18 mm screen would not stimulate chewing activity (Mertens, 1997). Yang et al. (2001) measured a $peNDF_{PS}$ as the proportion of DM retained by the 8 and 19 mm screens of the Penn Sate Particle Separator (PSPS), multiplied by total dietary NDF content. As NDF varies among PSPS fractions (Calberry et al., 2003), $peNDF_{NDF}$ has been determined as the amount of NDF retained on the 8 and 19 mm PSPS screens, multiplied by the respective DM% of the individual sieves (Calberry et al, 2003). The different methods for the estimation of physically effective fiber result in very different values. In the study from Yang et al. (2001) $peNDF_{PS}$, $peNDF_M$ and $peNDF_{>1.18}$ were not significantly correlated with rumen pH. Beauchemin et al (2003) observed that $peNDF_M$ and $peNDF_{>1.18}$ were positively correlated with time spend chewing and time spent ruminating, but not with time spent eating. In the same study $peNDF_{PS}$ was not significantly correlated with time spent ruminating, but this measure was negatively correlated with time and area below pH 5.8. It is yet unclear which measure of physical effective NDF provides the most accurate estimate of chewing, saliva production and rumen buffering (Beauchemin et al., 2003). It is believed that a measure of physical effective fiber based on measurement of dietary particle size will allow a more accurate estimation of rumen buffering capacity then a measure of physical effective fibre based on tabular values. Of the measures of physically effective fiber described here, $peNDF_{PS}$ is the easiest to use on farm. This measure was, therefore, used in several studies by our research group.

The effect of changing dietary particle size distribution by altering the forage chop length, the dietary forage to concentrate ratio, and by replacing coarse forage by finer forage were determined in several studies. In these studies rumen pH was determined by collection of rumen fluid through an oral probe at 4 hr after feeding. Plaizier (2004) showed that in a diet containing alfalfa silage, alfalfa hay and barley grain a $peNDF_{PS}$ lower than 12.5% of dry matter induced SARA. Calberry et al. (2003) observed that reducing $peNDF_{PS}$ of a diet containing alfalfa hay, alfalfa silage, corn silage and barley grain from 23.2 to 20.6% of dry matter reduce rumen pH without inducing SARA. By reducing the chop length of barley silage from 19 mm to 10 mm and by increasing the forage to concentrate ratio from 58.0 or 41.4% of dry matter, Einarson et al. (2004) reduced the $peNDF_{PS}$ of a barley silage and barley grain based total mixed ration from 29.5 to 18.9% of

dry matter. The reduction in forage to concentrate ratio increased feed intake and decreased rumen pH. The reduction in chop length increased feed intake, but did not affect rumen pH. None of the diets used in this study induced SARA. Einarson et al., (2005) reduced the $peNDF_{PS}$ of a barley grain and barley silage based total mixed ration from 21.9 to 16.2% of dry matter. This reduction increased feed intake, but did not affect rumen pH or induce SARA. Bhandari et al. (2004) reduced the chop length of alfalfa silage and barley silage from 19 mm to 10 mm. These authors found that these changes in chop length reduced $peNDF_{PS}$ from 19.1 to 16.4% of dry matter, but did not reduce rumen pH. In a similar study chop length of alfalfa silage and oats silage was reduced from 19 mm to 6 mm (Bhandari et al., unpublished). This reduction in chop length reduced $peNDF_{PS}$ from 19.1 to 16.4% of dry matter, but also did not reduce rumen pH. The results of these experiments are summarized in Figure 3.

Figure 3 shows that when $peNDF_{PS}$ exceeds 16.2% of dry matter, it is not an accurate predictor of rumen pH. This is due to the multitude of animal and dietary factors other than $peNDF_{PS}$ that affect rumen pH. Among these factors forage source, concentrate source, feeding frequency, and the inclusion of inorganic buffers are prominent. A rumen pH below 6, which was used as a threshold for SARA was only reached when $peNDF_{PS}$ reached 12.5% of dry matter. Mertens (1997) also observed the lack of an effect of dietary physical effective fiber content on rumen pH in coarser diets. A difficulty in comparing the different studies is that $peNDF_{PS}$ is not only affected by forage particles size, but also by dietary forage to concentrate ratio. In the studies from Calberry et al (2003) and Einarson et al. (2004), changing dietary forage to concentrate ratio resulted in a larger effect on rumen pH, than changing forage particles size. As mentioned earlier, the accuracy of determining rumen pH by measuring pH in samples collected using an oral tube is not as accurate as measuring the pH of rumen fluid samples collected from rumen fistulated cows. However, studies using rumen fistulated cows commonly have a low number of experimental animals, which limited the statistical power of these studies. NRC (2001) concludes that “At the present time, the lack of a standard, validated methods to measure effective fiber of feeds or to establish requirements for effective fiber limits this concept”. This conclusion still holds true.

Prevention

Important considerations in diagnosing SARA are dietary characteristics, which predispose animals to low rumen pH. These include rapid increases in the concentrate inclusion rate in the diet, high levels of feed intake, excessive variability in meal patterns, high inclusion rates of dietary concentrate, insufficient coarse fiber in the diet, and errors in diet formulation (Kleen et al., 2004; Stone 2004). Even sorting against long particles in favor of shorter particles has been identified as a potential problem (Leonardi and Armentano, 2003). A higher dietary dry matter content increases sorting. For this reason, if the dry matter content of TMR is higher than 50 to 55%, adding water to the TMR should be considered. Component feeding puts cows at greater risk of developing SARA than the feeding of total mixed rations because animals are at risk of over-consuming concentrates and increased diurnal variation in rumen pH (Kleen et al., 2003; Stone, 2004). In order to guarantee that diets contain sufficiently coarse fibre, diets should be formulated to contain sufficient physical effective NDF, i.e. fibre that contributes to rumen buffering (Mertens, 1997; Beauchemin et al., 2003). Once SARA has been detected on a farm, options are available to prevent the disease from reoccurring. Some of these options are adapting close-up dry cows and fresh cows to higher concentrate diets, increasing the dietary contents of peNDF and buffers, feeding of additional coarse hay, increasing the chop length of forages, the use of slower fermenting non-structural carbohydrate sources, feeding total mixed rations instead of component feeding, prevention of gauging and division of the herd in different feeding groups (Kleen et al, 2003; Stone, 2004).

Recommendations

Feed enough fiber. Diets containing corn grain should contain at least 25% of dry matter NDF. Diets based on barley grain should contain at least 34% of dry matter NDF. Diets should not contain more that 42% of dry matter of non-structural/non-fiber carbohydrates (NRC, 2001).

Feed enough physically effective fiber. Diets need to be balanced based on physically effective fiber as well as on the basis of NDF to prevent SARA. At present, there are no generally agreed recommendations for dietary physically effective fiber content. It has been recommended that ¾ of dietary NDF or 20% of dietary dry matter should originate from the forage (NRC, 2001). Research from our group suggests that SARA can occur when the proportion of DM retained by the 8 and 19 mm screens of the Penn State Particle Separator (PSPS) multiplied by total dietary NDF content ($peNDF_{PS}$) of barley grain based diets is lower than 16.2% of dry matter. Heinrichs (1996) recommended that between 5 and 10% of

TMR should be retained by the top 19 mm PSPS screen and that no more than 40 to 60% of TMR should pass the 19 and 8 mm PSPS screen. Mertens (1997) concluded that the requirements for physical effective fiber determined by tabular values ($peNDF_M$) are 22% of dry matter to prevent a drop in average rumen pH below 6 and 20% of dry matter to prevent reduction if milk fat percentage in early to mid lactation cows below 3.4%. Excess mixing of diets should be avoided as this can reduce forage particles size and rumen buffering.

Prevent sorting. In order to prevent sorting diets should not be too dry. If dietary dry matter of TMR exceeds 50%, then adding water to the TMR should be considered.

Adapt the rumen by lead feeding close-up dry cows. It is recommended to start feeding close-up dry cows more grain starting 3 weeks before calving, as this will adapt the rumen microbes and the rumen papillae to the high concentrate diet that will be fed after calving. Close-up dry cows should receive diets with 8-10 lbs of grain by calving time.

Include forages with higher buffering capacity. Independent from their particle size, forages differ in their rumen buffering capacity. Alfalfa silage has a higher intrinsic buffering capacity, also referred to as cation exchange capacity, than corn silage (McBurney et al., 1983). As a result, increasing the dietary inclusion of forage with a high cation exchange capacity can prevent SARA.

Include inorganic buffers in the diet. Inorganic buffers, such as sodium bicarbonate, can be included in the diets to provide additional rumen buffering. An inclusion rate of sodium bicarbonate of between 0.6 and 0.8 % of dry matter is recommended by NRC (2001).

Use TMR feeding instead of component feeding. TMR contains both forage and concentrate. Component feeding will result in separate meals of concentrate and forage. These separate meals will create more diurnal variation in rumen conditions than meals of TMR. Less diurnal variation in these conditions will reduce the risk of SARA.

Feed at least twice daily. The provision of fresh feed will stimulate eating (DeVries et al., 2003). As a result, supplying feed more than once daily will spread out the meals of cows during the day. This will reduce diurnal variation in rumen pH and, therefore, reducing the risk of SARA. Other conditions that reduce rumination and the distribution of meals throughout the day, such as insufficient bunk space, or limited access to feed, long milk parlor holding times, will also increase the risk of SARA (Stone, 2004).

Check the composition of the diet regularly. Diets that are fed can differ considerably from the diet are formulated, especially if actual forage dry matters differ from the forage dry matters that were used for the diets formulation. This difference can result in excess non-structural carbohydrates and lack of fiber in the diet. Regular checking of forage dry matter is, therefore, crucial.

Implications

Subacute ruminal acidosis is a common metabolic disease in dairy cattle. During this disease, rumen pH is depresses for several hours each day. Symptoms can include erratic and decreased feed intake, milk fat depression, loss of condition, laminitis, diarrhea, liver abscesses, inflammation and an increase in bacterial toxins in the rumen. Major causes for subacute ruminal acidosis are lack of coarse fiber and/or excess concentrates in the diet, feed sorting, rapid diets changes, and engorging. As the collection of rumen fluid for pH measurement remains troublesome, and most symptoms of this disease are not specific, subacute ruminal acidosis is often not diagnosed. Management strategies that are recommended to prevent this disease are: feed enough fiber and physically effective fiber; prevent sorting by avoiding excessively dry diets; do not change diet composition rapidly and adapt the rumen by lead feeding close-up dry cows; include forages with a high buffering capacity; include inorganic buffers in the diet; use TMR feeding instead of component feeding; feed at least twice daily; check the composition of the diet and forage dry matters regularly.

Literature Cited

Aceto, H., A.J. Simone, and J.D. Ferguson, 2000. Effect of rumenocentesis on health and production in dairy cows. J. Dairy Sci. Vol 83 (Suppl.1): 40.

Allen, M. S. 2000. Effects of diet on short-term regulation of feed intake by lactating dairy cattle. J. Dairy Sci. 83: 1598-1624.

Beauchemin, K. A. 1991. Effects of dietary neutral detergent fiber concentration and alfalfa hay quality on chewing, rumen function, and milk production of dairy cows. J. Dairy Sci. 74: 3140-3151.

Beauchemin, K. A., W. Z. Yang, and L.M. Rode. 2003. Effects of particle size of alfalfa based dairy cow diets on chewing activity, ruminal fermentation, and milk production. J. Dairy Sci. 86: 630 -643.

Bhandari, S.K., J.C. Plaizier, K.O. Ominski, and K. M. Wittenberg, 2004. Effect of chop lengths of alfalfa and corn silage on productivity of dairy cows fed total mixed rations. Can. J. Anim. Sci. 84: 760.

Calberry J.M., J. C. Plaizier, M. S. Einarson, and B. W. McBride. 2003. Replacing chopped alfalfa hay with alfalfa silage in a high barley concentrate total mixed ration. J. Dairy Sci. 86:3611-3619.

Cooper R.J., T.J. Klopfenstein, R.A. Stock, C.T. Milton, D.W. Herold, and J.C. Parrott. 1999. Effects of imposed feed intake variation on acidosis and performance of finishing steers. J Anim Sci. 77:1093-1099.

DeVries, T.J., M.A.G. von Keyserlingk, D.M. Weary, and K.A. Beachemenin. 2003. Measuring the feeding behavior of lactating dairy cows in early to peak lactation. J. Dairy Sci. 86:3354-3361.

Dirksen, G., H. G. Liebich, and W. Mayer. 1985. Adaptive changes of the ruminal mucosa and their function and clinical significance. Bovine Pract. 20:116-120.

Duffield, T., J. C. Plaizier, R. Bagg, G. Vessie, P. Dick, J. Wilson, J. Aramini, and B. McBride. 2004. Comparison of techniques for measurement of rumen pH in lactating dairy cows. J. Dairy Sci. 87: 59-66.

Einarson M.S., J. C. Plaizier, J. M. Calberry and K.M. Wittenberg, 2005. Effects of replacing chopped alfalfa hay with alfalfa silage in a barley grain based total mixed rations containing different forages on production and rumen conditions in lactating dairy cows. Can. J. Anim. Sci. 85: 251-253.

Einarson, M.S., J. C. Plaizier, and K.M. Wittenberg, 2004. Effects of barley silage chop length on productivity and rumen conditions of lactating dairy cows fed a total mixed ration. J. Dairy Sci. 87: 2987-2996.

Garrett E.F., M.N. Pereira, K.V. Nordlund, L.E. Armentano, W.J. Goodger, and G.R. Oetzel. 1999. Diagnostic methods for the detection of subacute ruminal acidosis in dairy cows. J Dairy Sci. 82:1170-1178.

Garrett, E.F., K.V. Nordlund, W.J Goodger, and G.R. Oetzel. 1997. A cross-sectional field study investigating the effect of periparturient dietary management on ruminal pH in early lactation dairy cows. J. Dairy Sci. 80 (Suppl.1): 169.

Gozho, G., J. C. Plaizier and D. Krause, 2005b. Effects of graded levels of wheat-barley concentrate on subacute ruminal acidosis (SARA), lipopolysaccharide endotoxins (LPS) and acute phase proteins in steers J. Dairy Sci. 88 Suppl. 1: 434.

Gozho, G.N., J.C. Plaizier, D.O. Krause, A.D. Kennedy and K.M. Wittenberg, 2005a. Subacute ruminal acidosis induces ruminal lipopolysaccharide release and triggers an inflammatory response. J. Dairy Sci. 88:1399-1403.

Griinari, J.M., D.A. Dwyer, M.A. McGuire, D.E. Bauman, D.L. Palmquist, and K.V. Nurmela. 1998. Trans-octadecenoic acids and milk fat depression in lactating dairy cows. J. Dairy Sci. 81:1251-1261.

Heinrichs, J. 1996. Evaluating particle size of forages and TMRs using the Penn State Particle Size Separator. Pennsylvania State University, University Park. PA. pp 1-9.

Kleen J.L., G.A. Hooijer, J. Rehage and J.P Noordhuizen. 2003. Subacute ruminal acidosis (SARA): a review. J. Vet. Med. A Physiol. Pathol. Clin. Med. 50:406-414.

Leonardi C, and L.E. Armentano. 2003. Effect of quantity, quality, and length of alfalfa hay on selective consumption by dairy cows. J Dairy Sci. 86:557-564.

McBurney, M.I., P.J. Van Soest and L.E. Chase 1983. Cation exchange capacity and buffering capacity of NDF. J. Sci. Food Agric.34: 910-916.

Mertens, D. R. 1997. Creating a system for meeting the fiber requirements of dairy cows. J. Dairy Sci. 80: 1463-1481.

Nocek, J.E. 1997. Bovine acidosis: implications on laminitis. J. Dairy Sci.80: 1005-1028.

NRC. 2001. National Research Council. Nutrient requirements of dairy cattle. 7th rev. ed. National Acad. Sci. Washington, D. C.

Oetzel G.R., K.V. Nordlund, and E.F. Garett. 1999. Effect of ruminal pH and stage of lactation on ruminal lactate concentration in dairy cows. J Dairy Sci.82 (Suppl 1):35.

Plaizier, J.C., A. Martin, T. Duffield, R. Bagg, P. Dick and B.W. McBride, 1999. Monitoring acidosis in the transition dairy cows. J. Dairy Sci. 82 Suppl.1 1 :110:

Plaizier, J.C., J. E., Keunen, J-P. Walton, T.F. Duffield and B.W. McBride, 2001. Short Communication: Effect of Subacute ruminal acidosis on in situ digestion of mixed hay in lactating dairy cows. Can. J. Anim. Sci. 81:421-423.

Plaizier, J.C., T. Garner, T. Droppo, and T. Whiting, 2004. Nutritional practices on Manitoba dairy farms. Can. J. Anim. Sci. 84:501-509.

Plaizier. J.C., 2004. Alfalfa as chopped hay or silage in alfalfa based total mixed rations for lactating dairy cows. J. Dairy Sci. 87: 2495-2505.

Shi, Y., and P.J. Weimer. 1992. Response surface analysis of the effects of pH and dilution rate on Ruminococcus flavefaciens FD-1 in cellulose-fed continuous culture. Appl. Environ. Microbiol. 58:2583-2591.

Stone, W.C. 2004. Nutritional approaches to minimize subacute ruminal acidosis and laminitis in dairy cattle. J. Dairy Sci. 87(E.Suppl.):E13-E26.

Stone, W.C., 1999. The effect of subclinical acidosis on milk components. Pages 40-46 in Cornell Nutr. Conf. Feed Manuf. Cornell Univ. Ithaca, NY.

Wells, J.E., and J.B. Russel. 1996. Why do many ruminal bacteria die and lyse so quickly? J. Dairy Sci. 79:1487-1495.
Yang, W. Z., K.A. Beauchemin, and L.M. Rode. 2001. Effects of grain processing forage to concentrate ratio, and forage particle size on rumen pH and digestion by dairy cows. J. Dairy Sci. 84:2203-2216.

Figure 1. Diurnal variation in rumen pH during SARA in cows fed at 9:00 hr and at 13:00 hr

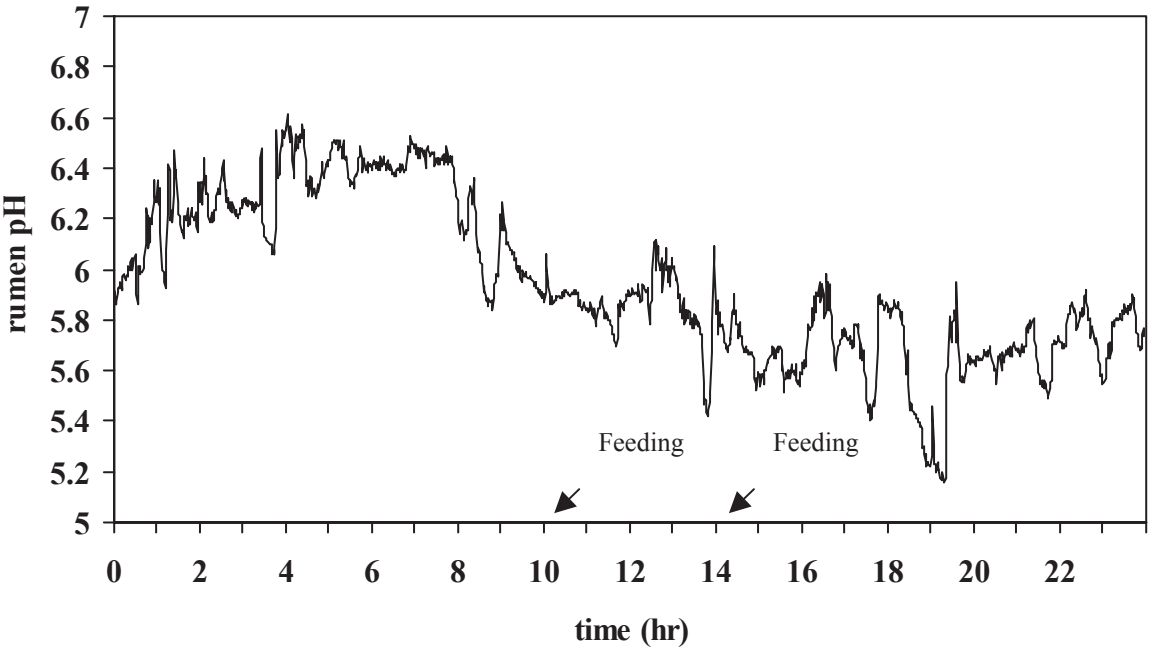

Figure 2. Ruminal free bacterial endotoxins (LPS) concentration in dairy cows during control (60% concentrate) and SARA (80% concentrate) periods. Week 1: all control; Week 2 & 4: Mia and Jinny SARA, Bea and Jude Control; Week 3 and 5 Mea and Jinny Control, Bea and Jude SARA

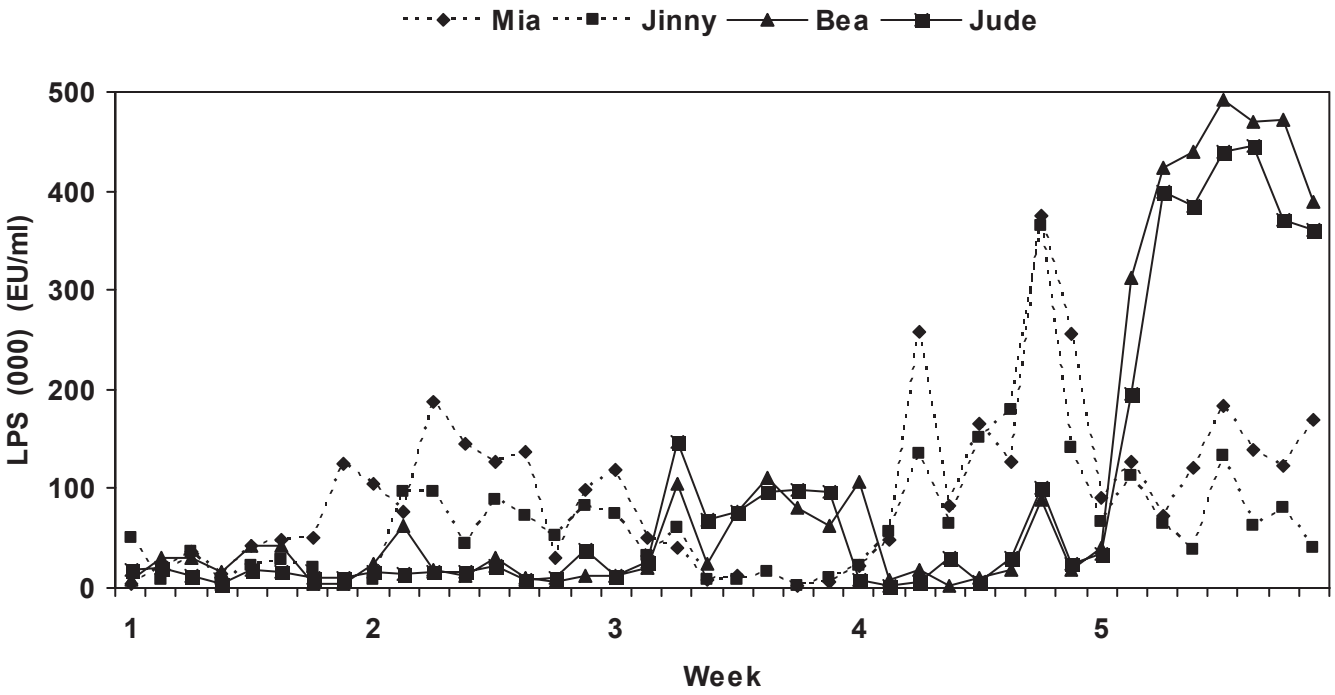

Figure 3. Relationship between $peNDF_{PS}$ and rumen pH obtained in six different experiments