The Triangular Interaction between Dairy Cow Efficiency, Sub-Acute Ruminal Acidosis and Lifetime Production

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Introduction: Milk production per cow has increased dramatically in countries in the past 50 years (FAO, 2010). The increase in milk production per cow occurred for the most part in countries where stored feeds, grain supplementation and some degree of confined feeding became common practices. Energy intake by cows increased during this time as the result of rations with a greater proportion of fermentable carbohydrate sources from cereal grains, improved forage quality, and feeding management. However, innovation created new issues for the cow, producer, veterinarian and nutritionist.

For example, as milk output per cow increased dramatically from increased energy consumption so did the number of cows affected by the condition described as "Fat Cow Syndrome" (Morrow, 1976). This condition was described as obese cows with increased morbidity and mortality associated with the peri-parturient period. Fat cow syndrome occurred as producers moved cows from stanchion and tie-stall barns to loose-housing and feeding the same ration intended for early lactation to all cows, sometimes including dry cows. Ultimately, issues were resolved leading to improvement in feeding and management of cows. Complete feeds or total mixed rations, grouping of cows, and improved cow comfort were just some of the innovations that developed from lessons learned from feeding grain to cows.

Feeding the dairy cow is a science and an art. The science is described from a paper by Firkins et al., (1998) as follows: ***"Furthermore, ruminal organic matter (especially carbohydrate) digestibility has the greatest effect on microbial protein synthesis through energy availability for protein synthesis or through negative effects of reduced ruminal pH on fiber digestion and microbial efficiency."*** The art of feeding dairy cows involves continuous observation of cow behavior and feed bunk management (sorting, amount of feed refusal) to assure animal well-being.

Sub-acute ruminal acidosis (SARA) is the negative effects described by Firkins et al (1998). The negative effects of SARA go beyond reduced fiber digestion and microbial efficiency. Approximately 40% of the lameness in the United States is attributed to SARA. Foot health and lameness are currently second only to mastitis as the most expensive disorder affecting US dairy industry (Hutjens, 2006). SARA reduces dairy cow efficiency (conversion of feed into milk) and lifetime production efficiency through lost milk production, reduced fertility, costs associated with treatment of foot conditions and early removal from the dairy herd. This paper reviews implications of SARA on the cow and its impact on production and lifetime efficiency.

Acidosis - Rumen pH decreases following a meal due to the production of volatile fatty acids (VFA). Buffers (bicarbonates and phosphates) in saliva are mixed with feeds during eating and chewing to neutralize (buffer) the free hydrogen ion in the rumen. Forages of sufficient quantity and quality stimulate secretion of saliva resulting in neutralization of VFA. Lack in either quantity or quality in the diet produces a ruminal acidosis the seriousness of which is obvious (acute) or not (SARA).

Acute Acidosis: The name, D-lactic acidosis, was first proposed by Dunlop and Hammond (1965) to describe a condition which led to debilitating effects and death in ruminants following the ingestion of feeds rich in readily fermentable carbohydrates. Consumption of such a meal results in increased production of volatile fatty acids (VFA) and a decrease in rumen pH. Lactic acidosis is primarily a condition of beef cattle on finishing rations low in forage Diets rich in highly fermentable carbohydrates fail to stimulate cud chewing and saliva secretion that buffers ruminal VFA. Consequently, pH continues to decrease as fermentation continues with a concomitant shift in bacterial population from predominantly Gram positive bacteria to Gram negative bacteria, a loss of ruminal protozoa, and reduced rumen motility. VFA production continues unabated resulting in further drop in rumen pH (Figure 1). At rumen pH of 5.5 to 5.7, bacteria capable of consuming lactic acid disappear and, metabolic products of *Streptococcus bovis* shift to lactic acid. The concentration of VFA in the rumen decreases because of lower production and removal from the rumen through absorption and passage to the omasum. As pH continues its downward spiral, acid-tolerant Lactobacilii begin to dominate and reduce rumen pH below 5.0 (Nagaraja and Titgemeyer, 2007; Owens et al., 1998).

Extensive research much of which was conducted in feedlot cattle during the ensuing 30 years led to a better understanding of changes in rumen ecology and impact of acidosis on animals during an acidosis insult. Acidosis of this nature is generally a problem with individual animals rather than the herd. Acute acidosis places the animal in immediate danger for survival (Nagaraja and Titgemyer, 2007). Acidosis has severe and permanent consequences for surviving animals (Table 1). Excellent reviews on the etiology of acidosis and its impact on cattle are available (Nocek, 1997; Owens et al, 1998; Nagaraja and Titgemeyer, 2007).

Sub-Acute Ruminal Acidosis: Nordlund et al (1995) described a condition in lactating dairy cattle they named sub-acute rumen acidosis or SARA. In SARA, rumen pH decreases to a range of 5.5 to 5.8 following consumption of a ration formulated for high milk production. Reduced rumen pH is the result of total VFA production with little or no lactic acid present (Figure 2). Rumen pH remains low for a period of time following eating but, usually recovers to above 5.8 during the interval between meals. These rations are high (approximately 40% of dry matter) in non fibrous carbohydrate (NFC) and borderline (< 30% of dry matter) in neutral detergent fiber (NDF).

SARA is a herd problem with prevalence in some herds of 20 to 25% of the dairy cows affected in confined dairy cattle (Nordlund et al., 2004) and in pasture-fed cattle (O'Grady et al., 2008). Signs of SARA are not obvious and in general are not life threatening. Cows are at greatest risk for SARA during the transition period and early lactation (Donavan et al., 2004) and in the hot humid months of summer (West, 2003). The common feature for each of these is a significant and often sudden change in ration composition involving an increase in proportion of grain in the total ration.

The dairy cow in the transition period is especially vulnerable to SARA and other disease states around calving. Dry matter intake usually based on 60% or greater forage dry matter decreases in the days prior to calving. The cow in transition is at risk for diseases of metabolic and/or infectious origin that threaten the start and completion of a successful lactation. Additionally, the post-calving ration usually is based on a high energy starch-based diet that may be borderline adequate in effective fiber. The sudden ration change provides little or no time for adaptation of rumen bacteria to significant changes in fermentable carbohydrate type and amount.

Donovan et al (2004) constructed four treatment groups with two rations prepartum: PreLo (1.51 NE_{lact} Mcal/kg; 47.2% NDF) and PreHi (1.65 NE_{lact} Mcal/kg; 39.8% NDF) and two rations post-partum: PostLo (1.70 NE_{lact} Mcal/kg; 36.8% NDF) and PostHi (1.77 NE_{lact} Mcal/kg; 31.4% NDF). The Pre rations were fed for three weeks prior to calving; a standard fresh cow diet was fed for 3 to 5 days after calving; and then the Post rations were fed for three weeks of lactation. A single ration was fed to all cows beginning on day 25 to 27 post calving and continued to day 70 of lactation. Hooves were scored on days 45 pre and 28 and 70 post. Rumen pH was determined by rumenocentesis on days 14 pre and 8, 22, and 70 post. The PreLo:PostHi group of cows had higher hoof scores (indicative of hoof discoloration, hemorrhage and ulcer formation) at the end of the trial as compared to the other treatment groups. Rate of ruminal acidosis (pH less than 5.5) at 8 and 22 days for the PostHi group was 2X of that for the PostLo group. During lactation, 41% of cows in Post Hi groups experienced acidosis as compared to 24% in PostLo groups. Locomotion scores (Zinpro Corporation, 2009) were lower ($p < 0.1$) during summer (1.59) compared to winter (2.23) and for parities 1 & 2 (1.82) compared to ≥ 3 (1.99). These results demonstrate that a ration pushing the limits for fermentable carbohydrates and NDF for a short period of time can impact well-being. One can speculate that foot health from effects of SARA would have been greater had the rations been fed for an extended period of time.

Feet and legs are as important to the dairy cow as the digestive tract and mammary gland in the production of milk. Cows must walk to the feed bunk and milking parlor. Non-infectious lameness, current and previous bouts, is the result of SARA. The effects of SARA may not be observed for 2-3 months after the insult as demonstrated in seasonal effect in the trial of Donavan et al (2004). Lame cows spend more time lying and less time standing or walking (Gomez and Cook. 2010). Visual signs of estrus (restlessness, walking, etc) of reproductive events are less in lame cows (Walker et al., 2008). Locomotion scoring is used to detect cows that are experiencing or have experienced lameness (Nordlund et al. 2004). Personally, my first observation upon arrival at a farm is watching cows walk.

The Ration: In many cases, nutritionists may design a single ration based on nutrient requirements for about 10 kg more than average milk production of the herd. Allen et al (2006) estimated the average rumen fermentable organic matter (RFOM) intake ranged from 5.7 to 15.4 kg/d with average of approximately 9.8 kg/d. Based on acid production/ kg RFOM, daily acid in the rumen ranged from 42 to 114 equivalents per day. The impact of this daily acid production at any one time point during the day is dependent on numerous factors related to forage type, sources of starch, feed processing and feed delivery. Each of these pose a potential risk of SARA due to the physical and chemical nature of the final ration offered to and consumed by cows.

Forages have significant differences in chemical composition due to type (grass versus legume), maturity at harvest, temperature and rainfall. Chemical composition and energy value of a forage can be changed by method of harvest e.g. loss of highly digestible leaves during harvest as dry hay. Samples of alfalfa were collected and analyzed from rolled bales and the dry, mostly leaf material lost from during harvest. Crude protein averaged 20.1% and 26.7 for hay and leaves and NDF averaged 44.9% and 31.0% for hay and leaves. (McGuffey, personal observation, 2011). Likewise, processing of corn silage does not change the chemical values for NDF or starch of the silage but increases energy value through improved starch digestibility and reducing the cob to a particle size that cannot be sorted. For the corn silage example, the laboratory analysis does not differentiate processed and unprocessed corn silage but, not so for the cow.

Grasses are more digestible than legumes largely due to higher NDF:lignin ratio which affects NDF digestibility (Weiss and Shockey, 1991; Kammes and Allen, 2012). Higher NDF in grasses is associated with greater rumen retention time (Allen, 2000) and tends to limit feed intake of high producing cows (Broderick et al., 2002). Legume based-diets generally support higher levels of milk production because of greater intake (Oba and Allen, 1999; Broderick et al., 2002). Because of confounding of NDF source (grass versus legume) trials evaluating the risk of SARA for grass-based rations compared to legume-based rations should be interpreted with caution.

Starch sources have different rates of digestion in the rumen due to physical and chemical properties (Firkins et al, 2001). Rate of starch fermentation in the rumen based on grain source is wheat > barley > corn > sorghum. Starch from all sources must be processed to expose starch to rumen microorganisms. Processing methods and the order of starch availability include steam-flaking > grinding > rolling. Steam-flaking of sorghum improves starch fermentation in the rumen and total tract digestibility compared to dry ground sorghum. In the same comparison for corn, steam flaking shifts the increases ruminal starch fermentation but, total tract digestibility ability as compared to dry ground. Starch from corn and sorghum is more rumen available when these grains are stored as high moisture (> 25%) compared to dry (Owens et al 1998). Finally, recent research has demonstrated that starch in corn silage becomes more fermentable with increasing time in storage (Sniffen and Ward, 2011). Differences in rates and site of digestion of starch sources must be considered in ration formulation to reduce the riskand impact of SARA.

The effect feeding method and RFOM on rumen pH is demonstrated in the research of Maekawa et al. (2002a). They fed a barley silage based ration in F:C of 60:40; 50:50, and 40:60 DM basis and a ration where barley silage and concentrate were fed separately (SI) with a targeted F:C of 50:50. Starch in the diets increased (27.7, 30.3, and 34.8) and NDF decreased 32.2, 31.0 and 28.3 with increasing concentrate. TMR and grain was fed at the same times (0800 and 1500 hr) each day. Forage was offered one hr after concentrate in SI. Cows fed SI actually consumed a ration of 43% forage and 57% concentrate indicating that cows did not eat all the forages offered. Milk fat percent was greater ($P < 0.05$) for cows fed the 60:40 F:C ration but all other milk production measures were not different.

The diurnal pattern of rumen pH is shown for the four diets in Figure 3. Rumen pH was lowest throughout the day for cows fed the SI ration. The 40:60 F:C had lowest pH for the TMR fed cows throughout the day. None of the measures of pH were different between rations over the 24 hour period. Note, however, that rumen pH of cows fed the 40:60 F:C and SI rations started at different points in the afternoon feeding compared to first feeding of the day. Close inspection of Figure 2 shows that average pH for cows fed SI was less than or equal to 5.8 from about 1100 hrs to 0300 hrs of the next morning. Likewise, rumen pH of cows fed the 40:60 ration was less than or equal to 5.8 most of the same time-frame as SI cows. In this case, the short interval between feedings may have placed cows fed the 40:60 and SI rations at greater risk for SARA even though intake was likely 3.0% or less of body weight in this study.

Thus, the challenge for nutritionists is to design rations that provide sufficient NDF to control rumen pH and passage rate, yet, not have a negative effect on feed intake. Absolute values for NDF of feeds are strictly a chemical measure of the slowly digestible carbohydrate fraction. Lignin is a component of NDF and the degree of lignifications in large part determines digestibility of NDF. The physical properties of feeds, e.g. particle size, density, etc., determine the effectiveness of the NDF source in maintaining rumen function such as stimulation of saliva secretion, rumination, fill, mat formation, digestibility, rate of passage and pH (Allen 2000) . Grinding reduces the physical property (size) of forage particles but can increase digestibility through reduction its particle size (Mertens, 1997).

Mertens (1997) defined physical effective NDF (peNDF) as ***"the physical characteristics of fiber (primarily particle size) that influence chewing activity and the biphasic nature of ruminal contents (floating mat of large particles on a pool of liquid and small particles)."*** Although not a nutrient, peNDF is a dietary critical ration requirement for defining the minimum F:C for a ration and for sustaining health and productivity of ruminants. The peNDF of a feed measures the ability of the NDF source to stimulate chewing and, is the product of the NDF concentration multiplied by physical effective factor (pef). The range of pef is 0 to 1.

The dietary requirement for peNDF is determined by forage source, source of starch, processing of starch source (Zebeli et al., 2012). There is still much to understand about peNDF requirements for a particular starch source. Some computer models currently consider pef for estimating the physical nature of the diet (Foster; Tylutki; personal communication). Research in the future will better define the requirement for peNDF based on selected inputs such forage type and processing. starch source and processing, feeding management and more using widely different but related end-points, e.g. rumen microbial growth and animal well-being.

Efficiency: The definition of efficiency is simply the ratio of output over input, i.e.

Output/Input

This simple ratio is used most sectors of commerce to measure or compare the effectiveness and sustainability of an operation or process. In the equation, all of the variance of the operation or process resides in the denominator. If efficiency is to be improved, controlling variance must be the focus of attention (HTTP://en.wikipedia.org/wiki/W_EDWARDS_DEMMING). Dairy cow efficiency in this discussion highlighted sources of variation associated with the ration that contribute to SARA. Other sources that must be considered include grouping strategies, facilities and the art of husbandry of the cow.

Lifetime Productivity:

Lifetime productivity is a key indicator of the sustainability of a dairy operation. Average number of lactations per cow is approximately 2.8 in the United States dairy herd (Hare et al., 2006). Each day in the life of a cow from birth to removal from the herd requires input costs, e.g. feed, labor, facilities and capitol. These costs accumulate from birth to calving at which time the cow begins producing two streams of income - milk and off-spring. The cow also has a one-time salvage value when sold. Milk is the most important source of income generated by the cow to recover lifetime input costs. Milk per day of life of the dairy cow becomes the most important measure of measure of lifetime productivity and profitability (Cady and Smith, 1996)

The Animal Improvement Productive Laboratory (AIPL) within the United States Department of Agriculture is responsible for producing sire summaries for the dairy industry. In 1994, the AIPL introduced productive life (PL) and somatic cell score as the first non production yield traits in sire evaluation (Shook, 2004). Many other countries soon followed with similar selective indices. Geneticists defined PL as milk yield from first calving through four lactations with a maximum of 10 months of lactation. Additional non yield traits including feet and legs and body size were added in 2000. These non yield traits have added greatly to the progress in selection indices. Today, selection for non yield traits affect the physical character of the cow, e.g. udder score and feet and legs and, can be used to select cows with reduced risk to important causes of economic loss (mastitis and lameness).

The University of Minnesota in the United States began a breeding experiment in 1966 with 60 cows. Half of the cows and their progeny were dedicated to produce a large body size line and half of the cows and progeny were bred to sires to produce a small body size line of cows strictly by breeding. Other than sires, all cows were managed identically. The objective was based on selection for large and small body size. Summaries of the study reported that the small line of cows had higher feed efficiency (Yerex et al., 1988) and fewer digestive disorders (Mahoney et al., 1986). Over the course of the study, removal of cows in body line differed in three reasons: udder conformation (less for large line), problems with foot and legs (less for small line), and miscellaneous reasons, primarily infections (less for small line). Productive life measured for a for a maximum of six years of age was 87.7 days longer for cows in the small line (Hansen et al., 1999). These results show a strong relationship of animal size as an important risk factor for the two most costly diseases in dairy cattle.

Vallimont et al (2013) evaluated measures of feed efficiency on PL in 11 Pennsylvania dairy herds maintained in tie-stalls. Genetic correlation between 305 day feed efficiency and PL was 0.66. Correlation of PL and body weight was -0.22 and of PL and body condition score was -0.48. Bicalho et al (2009) found a greater prevalence of lameness (locomotion score ≥ 3) with parity greater than 1 (48.2%) as compared to first lactation (19.8%). Maekawa et al., (2002b) reported that salivation rate was not affected by parity of the cow. They suggested that multiparous cows may be at greater risk for SARA than primiparous cows fed the same ration because salivary secretion of multiparous cows cannot compensate for the increase in fermentation acids produced as the result of higher feed intake.

Bicalho (2012) investigated the relationship of lameness (claw horn disruption lesions (CHDL) which include sole ulcers and white line disease) and body condition score (BCS) at dry-off on fate of cows in the ensuing lactation. Cows were assigned to groups (G): BSG1- BCS < 3; BCSG2 – BCS= 3; and BCSG3- BCS>3. Cows without CHDL at dry-off were 1.4 times more likely to become pregnant and conceived earlier (119 vs 163 DIM) than cows with CHDL. Similarly, cows in BCSG2 were 1.35 and 1.02 times more likely to become pregnant than BCSG1 and BCSG3, respectively. Cows in BCSG1 produced less milk and exited from the herd earlier in lactation than cows in BCSG2 and BSG3. It is clear that a cow’s physical status relative to lameness and BCS at dry-off is an indicator of success in the ensuing lactation.

Relationships of cow factors, parity, size, body condition score and genetics suggest associations with risk of disease, PL and/or lifetime productive efficiency. For example, large body size places of cows at greater risk for SARA and its consequences than small body size due to greater feed intake, lower saliva secretion per unit of feed intake, and the potential stress to feet and legs.

Lameness in dairy cattle is the most important welfare issue affecting public opinion (van Keyserlingk et al., 2009) and accounts for significant economic loss (Hutjens, 2006). Its root cause lies with SARA. However, reduction on of the impact of lameness to the cow requires a holistic systems approach that deals with factors ranging from sire selection to size and design of animal housing facilities.

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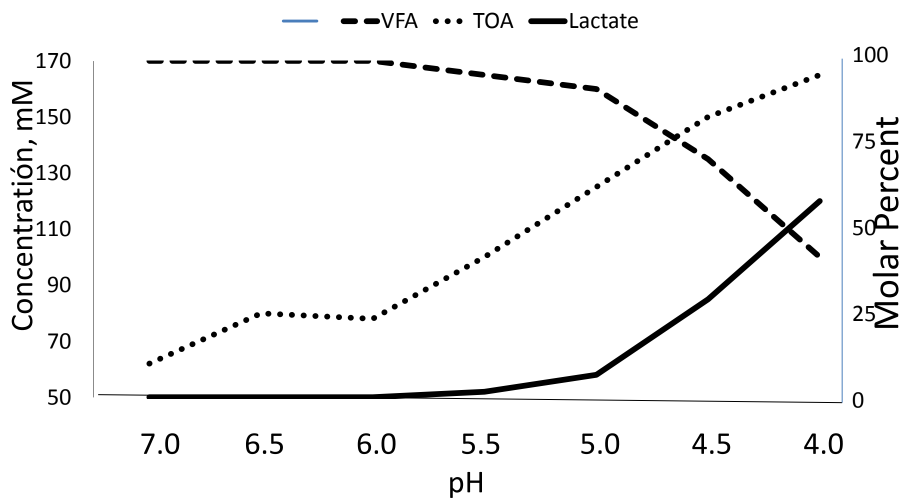
Table 1. Effects of Acute and Sub Acute Acidosis in Cattle

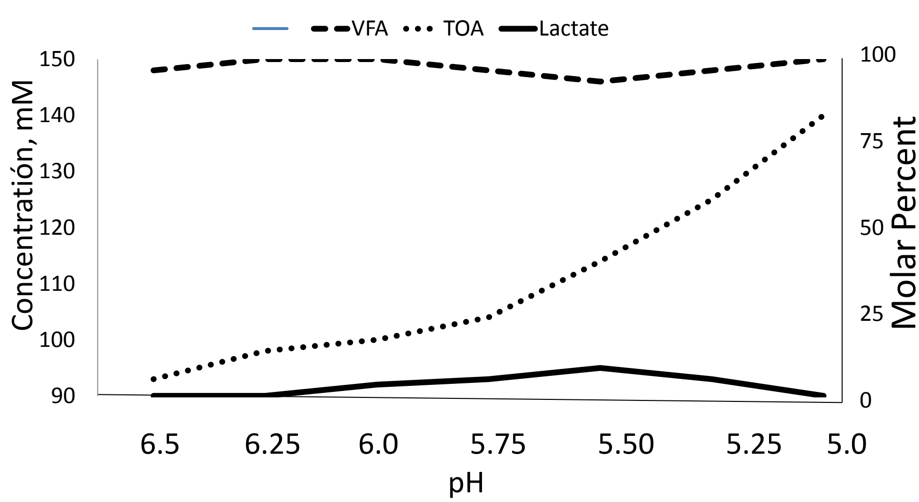
Acute	**Subacute**
Bloat	Erratic intake
Founder	Reduced intake
Enterotoxemia	Lower milk yield
Polioencephalomalacia	Milk fat/milk protein ≤ 1.0
Rumenitis	Lower fertility
Liver abscess	Lameness
Death	Removal from the herd

Figure 1. Total Organic Acids, Volatile Fatty Acids and Lactic Acid during Acidosis



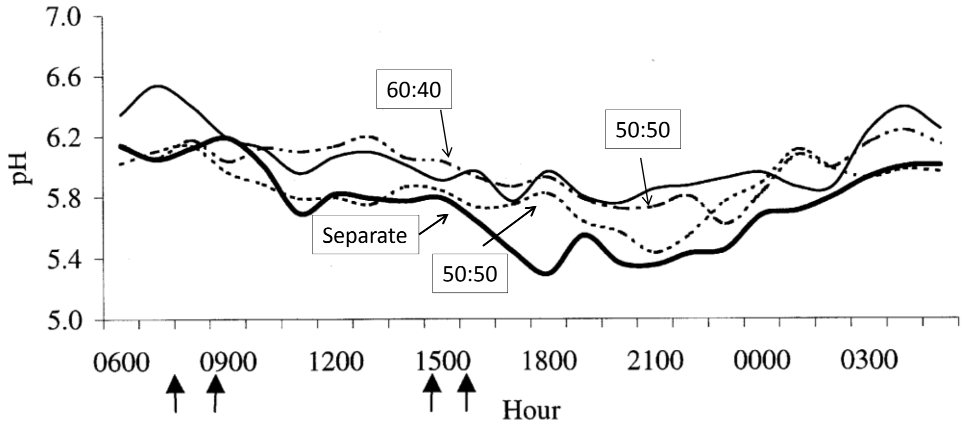
Nagaraja and Titgemeyer. J. Dairy Sci. 90: E17-E38. 2007

Figure 2. Total Organic Acids, Volatile Fatty Acids and Lactic Acid during Subacute Acidosis



Nagaraja and Titgemeyer. J. Dairy Sci. 90: E17-E38. 2007

Figure 3. Effect of F:C in Total Mixed Rations and Feeding Forage[1] and Concentrate Separately on 24 Hour Rumen pH



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1. Forage fed one hour after concentrate