REVIEWING NUTRIENT DELIVERY FROM BIRTH TO WEANING

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TAKE HOME MESSAGES

1. The pre-weaning period is a period of life where the calf is undergoing significant developmental changes and this development is directly linked to future productivity in the first and subsequent lactations.

2. Pre-weaning growth rate and primarily protein accretion appears to be a key factor in signaling the tissue or communication process that enhances lifetime milk yield.

3. Anything that detracts from feed intake and subsequent pre-weaning growth rate reduces the opportunity for enhanced milk yield as an adult.

4. Nutrient supply, both energy and protein, are important and protein quality and digestibility are essential.

5. There are no substitutes for liquid feed prior to weaning that will enhance the effect on long-term productivity.

6. Factors other than immunoglobulins in colostrum modify feed intake, feed efficiency and growth of calves and can enhance the effect of early life nutrient status.

7. As an industry and as nutritionists we need to talk about metabolizable energy and protein intake and status relative to maintenance and stop talking about liters, kilograms and grams of dry matter, milk, milk replacer, etc. The calf has discrete nutrient requirements not related to dry matter and liquid volume measurements.

8. The effect of nurture is many times greater than nature and the pre-weaning period is a phase of development where the productivity of the calf can be modified to enhance the animal's genetic potential.

INTRODUCTION

In the last ten years, the concept of “intensified feeding” or “accelerated growth” has become a topic of interest among calf raisers and researchers and is being applied on farms in various management systems. The various management approaches involve differences to best manage and deliver nutrition and nutrient intake for the pre-weaned calf within the specific farm management capability. There are teleological arguments for providing a greater supply of nutrients from milk or milk replacer, (e.g. what would the dam provide) and there are also arguments for improving the welfare status of calves by following that concept (Jasper and Weary, 2002; de Paula Vieira et al., 2008). Further, data generated over the last ten years has documented positive responses in productivity of calves as adult cattle when fed greater nutrient intake from milk or milk replacer.
replacer prior to weaning. How a calf receives nutrients and how nutrients or non-nutritional components of various dietary factors impact growth, development and productivity is still a very active area of management and research and will be discussed.

**EARLY DEVELOPMENT AND PRODUCTIVITY**

Lactocrine Hypothesis

It has been well recognized that the level of milk yield of an individual is affected by both genetic composition as well as environment. The environment contains multiple external signals that affect the development and expression of the genetic composition of an animal. While in the womb, the mother controls the environment in which the fetus is developing, influencing in this way the expression of the genetic material. The effect and extent of maternal influence in the offspring’s development does not end at parturition, but continues throughout the first weeks of life through the effect of milk-born factors, including colostrum in this definition, which have an impact in the physiological development of tissues and functions in the offspring. This concept has been recently described as the “lactocrine hypothesis” (Bartol et al., 2008). Conceptually, this topic is not new but the terminology is useful and the ability of several groups to make a direct connection from a factor in milk to a developmental function at the tissue or behavior level is significant (Nusser and Frawley, 1997; Hinde and Capitanio, 2010). Data relating to this topic has been described and discussed by others in neonatal pigs (Donovan and Odle, 1994; Burrin et al., 1997) and calves (Baumrucker and Blum, 1993; Blum and Hammon, 2000; Rauprich et al. 2000). The implication of this hypothesis and these observations is that the neonate can be programmed maternally and post-natally to enhance development or alter development of a particular process.

Colostrum’s role as a nutrient supply and as a lactocrine vehicle

*Nutrient role*

To maximize calf survival and growth, plasma immunoglobulin (Ig) status and thus colostrum management is of utmost importance. This is obviously not a new concept and there are hundreds of papers describing the management and biology surrounding colostrum quality, yield and Ig absorption by the calf although some recent research in colostrum handling and management suggest we can still make improvements (Godden, 2008). Until recently, the primary reason colostrum has been of interest in neonatal ruminants is due to the importance of supplying Ig’s to calves born without any and lacking a mature immune system (Weaver et al., 2000). Thus, without sufficient levels of Ig’s, morbidity and mortality rates are increased. While Ig’s are important, colostrum provides the newborn calf with much more than Ig’s. There is an abundance of literature describing some of these other factors in colostrum and the role these compounds can have in the development of the calf. Given that calves over time can produce their own Ig’s through exposure to bacteria and viruses, maternal antibodies from colostrum are transient and an argument could be made that they are not
absolutely necessary. Minimizing the bacterial load of colostrum is probably one of the major management concerns with many farms and is usually a factor not considered or analyzed for. Data demonstrate that the presence of bacteria in the gut prior to colostrum ingestion or in the colostrum reduces the uptake of Ig, thus increasing the incidence of failure of passive transfer (James et al. 1981, Godden, 2008). Thus excellent udder health and proper post-harvest colostrum handling is as important, or even more important than vaccination programs to minimize neonatal and post weaned calf diseases and death loss.

Further, standardization or evaluation of colostrum with a refractometer to ensure the appropriate solids or protein content is also important. Using a calibrated Brix refractometer, a minimum of 22% Brix provides good sensitivity and specificity for Ig levels for fresh and frozen colostrum above 50 mg/mL (Bielmann et al., 2010). Thus, anything above 22% is adequate for the first feeding for calves and anything below 22% should be reserved for later feedings. Finally, to determine total solids with a Brix refractometer, the Brix value needs to be converted. An equation from Moore et al. (2009) can be used to do this effectively, and the equation is: percent total solids = 0.9984 x (Brix%) + 2.077. Given the regression coefficients, a quick calculation is Brix% + 2 units. An evaluation of the use of a Brix refractometer was recently published by Quigley et al. (2012) and they suggested a cut point of 21% was appropriate for their data.

Colostrum is the first meal and accordingly is very important in establishing the nutrient supply needed to maintain the calf over the first day of life. The amount of colostrum is always focused on the idea we are delivering a specific amount of immunoglobulins (Ig’s) to the calf, and many times we underestimate the nutrient contribution of colostrum. Further, many times of year, we tend to underestimate the nutrient requirements of the calf, especially for maintenance. For example, a newborn Holstein calf at 85 lbs birth weight has a maintenance requirement of approximately 1.55 Mcals ME at 72 °F. Colostrum contains approximately 2.51 Mcals metabolizable energy (ME)/lb, and a standard feeding rate of 2 quarts of colostrum from a bottle contains about 1.5 Mcals ME. Thus, at thermoneutral conditions, the calf is fed just at or slightly below maintenance requirements at its first feeding. For comparison, if the ambient temperature is 32 °F the ME requirement for maintenance is 2.4 Mcals, which can only be met if the calf is fed approximately 1 lb of DM or about 3.5 quarts of colostrum. This simple example illustrates one of the recurring issues with diagnosing growth and health problems with calves and that is the use of volume measurements to describe intake instead of discussing energy and nutrient values. Two quarts of colostrum sounds good because that is what the bottle might hold, but it has little to do with the nutrient requirements of the calf.

Managing the calf for greater intake over the first 24 hours of life is important if we want to ensure positive energy balance and provide adequate Ig’s and other components from colostrum for proper development. For the first day, at least 3 Mcals ME (approximately 4 quarts of colostrum) would be necessary to meet the maintenance requirements and also provide some nutrients for growth. On many dairies this is done
via an esophageal feeder and the amount dictated by the desire to get adequate passive transfer. Those dairies not tube feeding should be encouraging up to 4 quarts by 10 to 12 hours and might be undersupplying Ig’s to the calf. Thus, the first step in supplying a “model” diet to a calf is to ensure colostrum is fed not only to meet the Ig needs of the calf, but also to ensure that the nutrient requirements are met for the first day of life.

Lactocrine role

Colostrum, in comparison with milk, is known to be rich in Ig’s (60x cow), as well as hormones and growth factors such as relaxin (>19x pig), prolactin (18x cow), insulin (65x cow), IGF-1 (155x cow), IGF-2 (7x cow), and leptin (90x humans) (Odle et al., 1996; Blum and Hammon, 2000; Wolinski et al., 2005; Bartol et al., 2008) among many other factors that have biological activity in the neonate. For a long period of time, colostrum has been known to have a major effect on the development of the gastrointestinal tract, but the exact mechanisms are still not well understood. During the first few days of life in neonatal piglets, a notable increase in the length, mass, DNA content, and enzymatic activities of certain enzymes (lactase) occurs in the small intestine for neonates fed colostrum/milk versus a control of water (Widdowson et al., 1976, Burrin et al., 1994). This was originally thought to be mediated by differences in nutrient intake between milk and water (Burrin et al. 1992). However, other studies have demonstrated differences between animals fed colostrum that is rich in growth factors, versus milk with comparable energy values (Burrin et al., 1995).

Of interest are the studies that have described decreased growth rate and increased morbidity of calves with low serum immunoglobulin status (Nocek, et al., 1984; Robinson et al., 1988) and some have even indicated that milk yield during first lactation can be affected (DeNise et al., 1989). Robinson et al. (1988) demonstrated that calves with higher Ig status were able to inactivate pathogens prior to mounting a full immune response which allows them to maintain energy and nutrient utilization for growth, whereas calves with low Ig status must mount an immune response which causes nutrients to be diverted to defense mechanisms. How severe is this difference or for how long does it persist? The data of DeNise et al., (1989) demonstrated that for each unit of serum IgG concentration, measured at 24 to 48 hr after colostrum feeding, above 12 mg/mL, there was an 8.5 kg increase in mature equivalent milk. The implication was that calves with lower IgG concentration in serum were more susceptible to immune challenges which impacted long term performance.

Work from Faber et al. (2005) using Brown Swiss calves demonstrated that the amount of colostrum provided to calves at birth significantly influenced pre-pubertal growth rate by over 0.4 lb per day and the calves receiving greater colostrum showed a trend for an additional 2,260 lbs of milk throughout the second lactation. The growth rate observation was not unique to this study, but begs the question if the response was due to greater feed intake or better feed conversion efficiency, which was not measured in the study. Further, Jones et al. (2004) examined the differences between maternal colostrum and serum-derived colostrum replacement. In that study, two sets of calves were fed either maternal colostrum or serum-derived colostrum replacement with
nutritional components balanced. The serum-derived colostrum replacer was developed to provide essential IgG's to a neonatal calf; however the colostrum replacer does not generally contain the other bioactive factors native to colostrum. These two groups were then further separated into calves fed milk-replacer with or without animal plasma, yielding four different groups. The results demonstrated that calves fed maternal colostrum had significantly higher feed efficiency compared to calves fed serum-derived colostrum replacement. The IgG status of the calves on both treatments were nearly identical, suggesting that other factors in colostrum other than IgG's were important in contributing to the differences.

Some of the other components in colostrum, such as insulin, IGF-I, relaxin and other growth factors and hormones, might be important factors in developmental processes; likewise, a lack or shortage of them in early life might alter developmental functions, leading to a change in nutrient utilization and efficiency. To examine this concept, Soberon and Van Amburgh (2011) examined the effect of colostrum status on pre-weaning ADG and also examined the effects of varying milk replacer intake after colostrum ingestion. Calves were fed either high levels (4 liters) or low levels (2 liters) of colostrum, and then calves from these two groups were subdivided into two more groups being fed milk replacer at limited amounts or ad libitum. In this study, none of the calves exhibited failure of passive transfer. Comparing calves fed 4 liters of colostrum and ad libitum intake of milk replacer versus 2 liters of colostrum and ad libitum intake of milk replacer, calves fed the 4 liters of colostrum demonstrated an 8.5% increase in milk replacer intake, an 18% increase in pre-weaning ADG, a 12% increase in post-weaning feed intake, and a 25% increase in post-weaning ADG through 80 days of life, indicating that colostrum potentially affects appetite regulation, which enhances growth and possibly feed efficiency (Table 1). Therefore, it can be logically concluded that if colostrum induces changes in feed efficiency, then the first feeding can also potentially affect future milk production.

A model diet

Milk and milk replacer

Does a model diet exist? This question has an obvious answer but is a difficult question when diet management is part of the solution. Given a choice the dam would provide for the calf an ideal diet of milk and then would teach the calf to consume non-milk feed when the calf was physiologically ready to do so. Thus, the model diet for a calf would be whole milk consumed at the level appetite regulation and demand would dictate and the dam is willing to supply. The most important aspects of this are the energy and protein supply this approach would provide to the calf and the recognition that as an industry, we have to start applying nutritional principles to this group of cattle if we are going to truly start solving problems with growth and health. The industry has made significant changes in the last 10 years with respect to calf nutrition, health, and growth; however we are still often using volume measurements to describe intake and nutrient status instead of megacalories of energy and grams of protein. To ensure a more ideal diet is fed, the ability to discuss calf nutrition in terms of energy values and
developing a comfort level with that approach will enhance our problem solving opportunities and allow us to develop more standardized feeding levels relative to nutrient demand.

Table 1. Effect of high (4+2 L) or low (2L) colostrum and ad-lib (H) or restricted (L) milk replacer intake on feed efficiency and feed intake in pre and post-weaned calves (Soberon and Van Amburgh, 2011).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>HH</th>
<th>HL</th>
<th>LH</th>
<th>LL</th>
<th>Std dev</th>
</tr>
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<tbody>
<tr>
<td>N</td>
<td>34</td>
<td>38</td>
<td>26</td>
<td>27</td>
<td></td>
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<td>Birth wt, kg</td>
<td>44.0</td>
<td>43.4</td>
<td>41.8</td>
<td>43.3</td>
<td>0.95</td>
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<td>Birth hip height, cm</td>
<td>80.5</td>
<td>80.3</td>
<td>80.0</td>
<td>80.9</td>
<td>0.56</td>
</tr>
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<td>IgG concentration, mg/dl*</td>
<td>2,746&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2,480&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1,466&lt;sup&gt;c&lt;/sup&gt;</td>
<td>1,417&lt;sup&gt;c&lt;/sup&gt;</td>
<td>98</td>
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<tr>
<td>Weaning wt, kg</td>
<td>78.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>63.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>72.2&lt;sup&gt;c&lt;/sup&gt;</td>
<td>62.4&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.89</td>
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<tr>
<td>Weaning hip height, cm</td>
<td>93.0&lt;sup&gt;a&lt;/sup&gt;</td>
<td>88.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>91.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>89.6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.60</td>
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<td>ADG pre-weaning, kg</td>
<td>0.79&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.42&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.67&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.39&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.028</td>
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<td>Hip height gain, pre-weaning, cm/d</td>
<td>0.248&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.158&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.227&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.161&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.009</td>
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<td>ADG birth to 80 d, kg</td>
<td>0.78&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.59&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.66&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.53&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.034</td>
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<td>Hip height gain, birth to 80 d, cm/d</td>
<td>0.214&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.157&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.184&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.148&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.008</td>
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<td>Total milk replacer intake, kg DM</td>
<td>44.4&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.5&lt;sup&gt;b&lt;/sup&gt;</td>
<td>40.9&lt;sup&gt;c&lt;/sup&gt;</td>
<td>20.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.2</td>
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<td>Grain intake pre-weaning, kg</td>
<td>2.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.0&lt;sup&gt;b&lt;/sup&gt;</td>
<td>2.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.5</td>
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<td>ADG/DMI, pre-weaning</td>
<td>0.60</td>
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<td>0.67</td>
<td>0.61</td>
<td>0.042</td>
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<td>ADG post-weaning, kg</td>
<td>1.10&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.97&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>0.88&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.92&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.061</td>
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<td>DMI post-weaning, kg/d</td>
<td>2.89&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>2.89&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.58&lt;sup&gt;c&lt;/sup&gt;</td>
<td>2.66&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.104</td>
</tr>
<tr>
<td>ADG/DMI post-weaning</td>
<td>0.359</td>
<td>0.345</td>
<td>0.335</td>
<td>0.358</td>
<td>0.020</td>
</tr>
</tbody>
</table>

<sup>1</sup>HH = high colostrum, high feeding level, HL = High colostrum, low feeding level, LH = Low colostrum, high feeding level, LL = Low colostrum, low feeding level. Rows with different superscripts differ P < 0.05.

For example, whole milk is approximately 2.5 Mcals ME per pound of dry matter (DM) for the average Holstein and about 2.6 Mcals ME per pound DM for a Jersey. For comparison, a pound of 20% CP, 20% fat milk replacer contains 2.15 Mcals ME and a more contemporary milk replacer like a 28% CP, 20% fat would contain slightly more energy at 2.22 Mcals ME per pound DM.

A Holstein calf with a 100 lb BW at 68°F will have a maintenance requirement of 1.75 Mcals ME under good management conditions (dry, no wind, adequate previous level of nutrient intake). Therefore, to meet maintenance requirements, 0.8 lb DM of either milk replacer are needed to meet that requirement of 1.75 Mcals, and 0.7 lb DM of milk are need to cover the requirement. Ideally, the calf would be fed a liquid diet that is 12.5%
solids or DM, and to do this the total weight would be 6.4 pounds, composed of 0.8 pounds milk replacer DM and 5.6 pounds of water. Again, a refractometer should be employed to ensure that the concentration of the diet is consistent from day to day.

This is especially true when feeding waste milk. Recent visits to farms using waste milk as their primary liquid feed for pre-weaned calves found ranges in solids content of 8 to 13% with a significant portion below 11% solids. The liquid volume being fed on a couple of the farms was quite high, but due to the lower solids level, the calves were still not receiving the amount of megacalories the manager was targeting. To account for the difference, a milk replacer type product was employed to standardize the solids and nutrient content of the waste milk. Further, the nutrient content of waste milk should be evaluated on a regular basis to understand nutrient density and make adjustments when necessary.

The data from Soberon et al. (2012) and Soberon and Van Amburgh (2013) demonstrate that achieving adequate pre-weaning nutrient intake above maintenance to promote growth significantly enhances first and subsequent lactation milk yield. The linear equation from the meta-analyses of current studies indicates 1,500 lb of first lactation milk for every one pound of pre-weaning average daily gain. Thus, ensuring adequate and consistent nutrients above maintenance requirements enhances long-term productivity.

The nutrient requirements for growth of pre-weaned calves were described in the 2001 Dairy NRC (NRC, 2001) and redefined by Van Amburgh and Drackley (2005). The amount of megacalories required to achieve specific growth targets are described in Table 2. The first step is to calculate the value of the maintenance requirement and then provide additional nutrients above that requirement for growth. For example, a 120 lb calf under conditions of some cold stress (20 °F) will require 3.4 Mcals ME to meet the maintenance requirement. To achieve 1.5 lb/d of body weight gain, the calf would need to consume 5.8 Mcals of ME which results in 2.4 Mcals available for gain. The protein requirements would be about 240 g/d of CP to meet the energy allowable growth. To achieve this gain, if feeding standardized waste milk, the calf would need to consume about 2.5 gallons per day. This can be a management challenge for the manager and the calf, especially in twice day feeding systems due to the volume required. However it is important to focus on the energy requirement for the given conditions and work to ensure the energy values are met and targets are established for growth during all environmental conditions. Without targets and pro-active decision making along with monitoring, there is little ability to evaluate performance and make the appropriate changes. It is also important to begin to recognize and appreciate the energy values required to achieve the growth targets and objectives that fit our current understanding of calves' growth potential along with the implications for long-term productivity.
Role of calf starter

There is no debate about the role of calf starter in promoting rumen development and growth of calves. It is essential that the calf learn to consume starter and develop a functional rumen by the time the weaning process is completed. Basic requirements for starter intake prior to complete weaning would suggest that calves be consuming at least 2 pounds of starter by the time liquid feed is removed. Recent work has investigated the role of hay prior to weaning (Kahn et al., 2011; Castells et al., 2012), and the type of starter, textured or pelleted, that enhances feed intake and calf growth and development without compromising rumen health and digestibility (Bach, 2013; Kertz, 2013).

There are several factors at play when evaluating these studies and their implications. Behavior is most likely the primary factor affecting a majority of the studies that have evaluated calf starter intake and preferences. A calf under natural conditions would learn to consume feed from the dam and be encouraged and taught to do so as it developed and became physiologically ready for that type of diet. Several studies have been conducted on feeding behavior of grazing animals and it is clear that the dam teaches the calf what to eat and how to eat under those management conditions (Howery, L. D., et al. 1998; Provenza, 2005). Under most of the conditions we offer calves starter grain, there are barriers to learning that affect the how the calf views and accepts the starter grain as a food source. Our way of managing that learning has been to limit the nutrients from milk or milk replacer in an effort to enhance hunger so they are encouraged to consume nutrients from other sources. Having calves of somewhat varying ages in group housed conditions helps with the learning process because the older calves provide lessons in eating behavior for the calves not yet experienced enough to understand where and what the starter grain might be. Creating an environment that allows calves to teach each other about starter grain intake is essential to enhance nutrient delivery and weaning efficiency in dairy calves and help avoid any post-weaning energy balance problems. Adding flavors and odors to starter grain helps this process, especially for calves fed grain in situations where they receive no visual feedback about what other calves are doing.

The chemical composition of the starter is also important. The debate about textured versus pelleted is helpful in sorting out other factors that impact intake and rumen health. The research on addition of forage to the diet prior to weaning also provides food for thought, but outside of research conditions, this is very difficult to manage on a large scale calf ranch. One opportunity is to evaluate some of the byproducts used in the development of the starter and consider those byproducts or ingredients that supply carbohydrates high in soluble fiber, such as citrus, beet pulp or almond hulls. These feeds are relatively high in NDF, and contain a reasonably high level of soluble fiber (pectins) that are rapidly fermentable, have high water holding capacity (swells), have cation exchange capacity (will absorb hydrogen ions) to help buffer the rumen and are generally palatable. Those ingredients are not very good for pelleting, but are compatible with starter grain production and would provide a controlled amount of NDF and fermentable carbohydrate and would more easily take the place of the chopped or
processed hay and be more manageable in many of our feeding systems. The data from Castells et al. (2012) and Montoro et al. (2013) suggest that chopped dry hay is helpful for rumen health, feed intake and overall calf performance. An equivalent amount of NDF from one of the above byproducts should provide similar benefits and be easier to manage. Previous work with Agway indicated that inclusion of 7 to 15% citrus or beet pulp along with soluble fiber levels of approximately 7% to 8% were useful in enhancing feed intake and feed efficiency. Soyhulls are not a substitute and will cause diarrhea if the inclusion level is too high.

**SUMMARY**

Early life events appear to have long-term effects on the performance of the calf. Our management approaches and systems need to recognize these effects and capitalize on them. Improving the nutrition and management of calves appears to improve the sustainability of the animal through increased productivity throughout life and this has implications for welfare and the environment along with profitability. We have much to learn about the consistency of the response and the mechanisms that are being affected. Given the amount of variation accounted for in first and subsequent lactation milk yield, there are opportunities to enhance the response once we understand those factors. The bottom line is there appears to be a positive economic outcome as adults by improving the management of our calf and heifer programs starting at birth.

**REFERENCES**


