Nutrition for Dairy Calves During the Milk-Feeding Period: Update on Enhanced Early Nutrition Programs

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SUMMARY

Interest in intensified or enhanced early nutrition programs for dairy calves continues to grow. These programs are based on greater than "conventional" rates of liquid feeding, approximately twice the dry solids intakes. In turn, rates of body weight gain and stature change are greater. Possible advantages of such programs include better early health, shortened time to first calving, and enhanced future production ability. Disadvantages include greater cost during the young calf period and challenges in transitioning to solid feed intake. While goals of the programs are consistent with normal biological growth when milk is not limited, long-term outcome data needed to evaluate overall profitability are not yet available.

INTRODUCTION

Healthy newborn calves provide the foundation for profitable dairy or heifer rearing enterprises. Unfortunately, neonatal mortality in dairy calves remains a significant problem in the US. The USDA National Animal Health Monitoring System's Dairy 2002 survey reported mortality of 10.8% of heifer calves born alive (National Animal Health Monitoring System, 2003). While the importance of early intakes of an appropriate amount (3 - 4 quarts) of high-quality colostrum are unequivocal (see Davis and Drackley, 1998, for review), the role of nutrition during the early milk-feeding period has been controversial. During the first 2 to 3 weeks of life, the calf's digestive system is immature and is designed to digest milk-based nutrients efficiently. Consequently, in calves as in all mammals, milk or milk replacer must be the major feed for some time after birth.

Interest in so-called "accelerated growth" or "intensified nutrition" programs remains high. These programs are outgrowths from research by the laboratory of Dr. Mike Van Amburgh at Cornell University (Diaz et al., 2001). In those experiments, calves were fed much larger amounts of a specially designed, high-protein milk replacer to gain over 2 lb/d during the first few weeks of life. It is well documented that greater intakes of milk solids decrease intake of calf starter (Hodgson, 1971; Huber et al., 1984), which places this type of program in direct opposition to very-early weaning systems. Interest in field application of these preliminary results soon outstripped available research, leaving many unanswered questions concerning health, economics, and effects on long-term

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profitability. The objective of this paper is to evaluate the current status of intensified or enhanced early nutrition programs.

ORIGIN OF CURRENT PRACTICES

As the US dairy industry developed in the last century, economics and sanitary considerations led to calves being raised without suckling the cow. From an economic perspective, the incentive has been to wean calves as quickly as possible (without sacrificing health) from more expensive milk or milk replacer to less expensive concentrate-based feeds (starter) and forages. Health of calves consistently was shown to improve once calves were weaned from milk, which likely is a factor of the extensive detoxifying ability of the rumen, the bulking effect of solid feeds in the intestine, and improvements in energy balance. Requirements for labor per calf also decrease considerably when calves no longer have to be fed liquid diets individually and can be housed in groups.

Before the development of the first milk replacer in 1951, it was common for producers to feed considerably more milk than used today, often as much 4 quarts (8 quarts/day). An extensive body of scientific literature exists in which different amounts and frequencies of liquid feedings were compared with respect to calf growth, weaning age, and health. Results of these experiments have been summarized elsewhere (Appleman and Owen, 1975). From these early studies came the general recommendation to limit-feed calves. Natural extensions of this philosophy were early-weaning programs (e.g., Kertz et al., 1979).

Another factor in development of current convention for feeding milk replacer was the poor quality of early milk replacers. In particular, milk proteins were often isolated and dried improperly, leading to heat damage and poor calf performance (Davis and Drackley, 1998). Fat sources were not efficiently emulsified, leading to poor digestibility. Consequently, these early milk replacers often could not be fed at rates much greater than 1 lb of powder per day without causing calves to scour. Reputable manufacturers of milk replacers today use high-quality, highly digestible ingredients and improved manufacturing processes that result in highly digestible products that can be fed at higher rates if desired.

At higher rates of milk or milk replacer feeding, intake of starter clearly is decreased (e.g., Hodgson, 1971; Huber et al., 1984). Lower starter intake slows the rate of rumen development, which in turn may contribute to calves “stalling out” when weaned from milk. However, the greatest stimulus for increases of dry feed intake even in early weaning systems is removal of the liquid portion of the diet (Appleman and Owen, 1975), which causes feed intake to nearly double in the first day (Luchini et al., 1993). Establishment of a mature, functional population of microorganisms capable of fermenting both starchy and fibrous carbohydrates occurs gradually during the first 6 to 8 wk of life (Anderson et al., 1987). Quigley et al. (1985) showed that production of microbial protein in the rumen increased progressively with age in young calves. Because of the immaturity of rumen digestion at this point, a major factor contributing to the "stall-out" that may occur at weaning is that calves fed more liquid diet simply cannot eat and digest enough dry feed quickly enough to keep them growing at the higher rate after they are weaned from milk.

The current convention of raising calves in North America has worked reasonably well and allows producers to wean healthy calves at less than 5 wk of age and at minimal cost. However, the US dairy industry has become accustomed to unreasonably high rates of heifer calf mortality (10.8%; National Animal Health Monitoring System, 2003). Excellent managers have much lower death losses; what is the role of adequate early nutrition in this regard?

"INTENSIFIED FEEDING" FOR CALVES: BIOLOGY VERSUS MANAGEMENT

The current focus on "accelerated growth" or "intensified nutrition" for calves involves rates of milk replacer feeding (2 to 2.5 lb of powder) approximately twice those of conventional recommendations (1 to 1.25 lb of powder). The milk replacer is formulated with higher crude protein (CP) content (similar to that of whole milk solids) to meet amino acid requirements of the rapidly growing bone and muscle. The aim of these programs is to capitalize on the rapid early lean growth potential of young calves, and allow greater lean growth without fattening. Target rates of growth will be greater than current convention, and may reach 2 lb per day by the end of the second week, with weaning by 6 to 7 wk. Under exceptional management, calves on conventional early weaning systems might reach or approach that growth rate by the third or fourth week as starter intake increases.

Calves allowed to suckle their mothers typically consume 6 to 10 meals per day, and may consume 16 to 24% of their body weight as milk after 3 to 4 wk of age (Hafez and Lineweaver, 1968). Canadian Holstein calves left with their dams for 14 d after birth were almost 29 lb heavier at 14 d of age than calves removed from the dam on d 1 and limit-fed milk whole milk at 10% of their body weight daily (Flower and Weary, 2001). In a subsequent study by the same group (Jasper and Weary, 2002), calves allowed ad libitum consumption of milk from an artificial teat drank 89% more milk than calves limit-fed to 10% of body weight, and gained 63% more weight than conventionally fed calves. Studies with twice-daily hand feeding of milk also show that ad libitum intakes of milk are in excess of 18% of body weight. For example, Khouri and Pickering (1968) fed whole milk to calves during the first 6 wk of life at rates of 11.3%, 13.9%, 15.9%, or 19.4% (ad libitum) of body weight. Daily gains during weeks 2 to 6 of life were 0.90, 1.10, 1.37, and 2.07 lb/d, respectively. Feed efficiencies (lb milk DM per lb body weight gain) were 1.58, 1.48, 1.34, and 1.23, respectively. The latter values compare favorably with feed efficiencies for young pigs and lambs. Consequently, what is referred to currently as "accelerated growth" is, in fact, **biologically normal growth**. It is a *management decision* to feed smaller amounts of milk or milk replacer twice daily to encourage dry feed intake. In light of this concept, I prefer to use the term "enhanced early nutrition" rather than "accelerated growth".

An examination of the nutrient requirements for calves is instructive in understanding the goals of enhanced early nutrition. The overall feeding rate determines energy intake and sets limits on the growth possible, as illustrated in Table 1. Note that as average daily gain increases, the required metabolizable energy (**ME**) intake also increases and more milk replacer powder must be fed to provide that energy. In our own studies at the University of Illinois, male Holstein calves were fed a 26% CP milk replacer (12.5% solids) at 10%, 14%, or 18% of BW, adjusted weekly as calves grew (Bartlett, 2001). Calves were started on treatments at about 3 wk of age and remained on experiment for 5 wk. Intake of milk replacer powder and average daily gain increased linearly as more milk replacer was fed (0.79, 1.55, 2.26 lb/d).

The amount of protein required by calves is largely driven by the rate of growth, because maintenance requirements are small and in theory could be met with only 8.3% CP in milk replacer (Table 1). The National Research Council (2001) states that 187.5 grams of CP are needed per kilogram of average daily gain. Consequently, the amount of CP required by the calf increases as it is fed more energy and rates of gain increase (Table 1). Note in Table 1 that the content of CP needed in milk replacer approaches a maximum in the range of 28% CP.

The concept of enhanced early nutrition is, in itself, not a new idea. Numerous studies have examined increased rates of feeding milk or milk replacer (e.g., Hodgson, 1971; Huber et al., 1984; Khouri and Pickering, 1968). Other studies have examined ad libitum intakes of acidified milk replacer (e.g., Nocek and Braund, 1986; Richard et al., 1988). Calves generally grew more rapidly during the liquid feeding period, but had lower starter intakes. Typically, the early growth advantage was not maintained as calves went into the heifer growing phases. Several differences between these early studies and current research must be noted, however. First, the milk replacers fed did not contain sufficient protein to support high rates of lean tissue growth. Second, in most cases calves were weaned to a starter feed or forages that may not have provided enough protein and digestible energy to maintain the rapid rates of growth. Finally, the emphasis on near ad libitum milk intake in those early studies probably resulted in excessive milk replacer intake for a practical system where calves could be weaned easily to dry feed at the desired time.

It is also important to distinguish between the goals of increased liquid feeding for heifer calves and goals in the production of veal calves. Obviously, near ad libitum feeding of whole milk for extended periods of time would lead to fattening, which is similar to production of veal calves. Increased growth in heifers should emphasize growth of skeleton and muscle so that increases in stature are attained. An important innovation in current research on enhanced early nutrition programs is the use of a high-protein milk replacer with moderate fat content. In the Cornell University experiments (Diaz et al., 2001), the original objective was to study the requirements of energy for tissue growth. Their milk replacer was formulated to ensure that protein would not be the limiting nutrient. Consequently, they achieved high rates of lean tissue deposition without fattening. In our own research, we have shown that body fat content is decreased as protein content increases in milk replacers with similar energy content (Bartlett et al., 2001b; Blome et al., 2003). Thus, these recent results have shown that it is possible through dietary manipulation to produce high rates of lean growth without fattening as occurs in veal production.

Furthermore, not only the protein content and energy intake impact growth, but also the source of energy (fat versus lactose). We recently demonstrated that a standard commercial milk replacer (22% protein, 19% fat) promoted more rapid growth of calves than whole milk or a high-fat milk replacer of similar composition to whole milk, when feeds were fed in amounts to supply equivalent energy and protein intakes (Bartlett et al., 2001a). Similar experiments at Cornell University (Tikofsky et al., 2001) demonstrated that, when calves consumed similar quantities of protein and total ME, fat contents in the milk replacer greater than 15% showed no advantage in lean growth, but only led to greater fat deposition. Higher fat contents of the liquid diet also clearly suppress intake of calf starter (Kuehn et al., 1994).

Although most of the body composition data available were obtained using bull calves, there is little difference in body composition between male and female calves up to about 200 lb of body weight (National Research Council, 1978). Bull and heifer calves also grow at similar rates and with similar hormonal profiles up to at least 200 lb of body weight (Smith et al., 2000). Comparative studies between calves fed on enhanced early nutrition programs and conventional early weaning programs where both groups are also receiving calf starter are needed urgently.

We have recently completed two experiments comparing enhanced early nutrition programs to conventional early weaning programs for Holstein heifer calves (Pollard et al., 2003). In trial 1, calves fed an enhanced early nutrition program gained an average of 46 lb of body weight from birth to 4 wk, whereas conventionally raised calves gained 19 lb. In trial 2, weight gains to 4 wk were 42 and 30 lb for enhanced and conventional calves, respectively. Consumption of starter through 8 wk of age was 49 and 110 lb for enhanced and conventional calves in trial 1, and 56 and 119 lb for enhanced and conventional calves in trial 2. Total gain:feed was increased from less than 0.5 for conventional controls to greater than 0.6 for the enhanced groups in both trials.

POTENTIAL ADVANTAGES AND DISADVANTAGES OF RAPID EARLY GROWTH SYSTEMS

Research has clearly established that it is possible through increased milk replacer feeding to attain higher rates of lean growth during the first 2 to 3 weeks than what is observed in conventional early weaning systems. Preliminary data indicate that it is possible to design systems to allow calves to wean easily and maintain growth advantages at least through puberty. Plane of nutrition before 3 mo has been shown clearly to have no effect on mammary development (Sejrsen et al., 1998, 2000). However, the key issue is whether normalizing early growth provides any long-term advantages to the calf or to subsequent productive longevity in the dairy herd relative to conventional early weaning systems. Research in these areas has not been completed, although some experiments are currently in progress.

What might be the **potential advantages** of enhanced early growth?

1. *Decreased time to breeding size and first calving* Increased rates of growth during the early life period may be able decrease the time to target breeding age. The greatest difference in growth rates will occur during the pre-weaning period, especially the first 2 wk of life before starter intake increases appreciably in conventionally raised calves. Available research data suggest that the growth advantage is maintained, and perhaps even increases, after weaning for calves on the enhanced early nutrition. This may occur by activating the normal growth hormone–insulin-like growth factor (**IGF**)-I system for controlling growth at an earlier age (Smith et al., 2002). In our experiments, IGF-I in plasma was increased by greater feeding rates and by greater protein content in milk replacer (Bartlett, 2001). These results clearly show a functional IGF-I system in young calves that is responsive to early nutritional status. This is similar to the situation with bST action in lactating cows. If nutrition is inadequate, cows do not respond to bST with increased milk production. If nutrition is inadequate for calves, the growth hormone system will not be active to stimulate growth.

   Individual calf raisers would need to determine achievable growth rates and their impact on economics specific to their operation. As a reasonable scenario, if higher liquid diet feeding resulted in net advantages in gain of 1 lb/d during the first 3 wk, and 0.25 lb/d for the next 9 wk, heifers would reach a target breeding weight (750 lb) about 20 d sooner, assuming growth rates of 1.8 lb/d from 3 mo to breeding. It must be remembered that differences in *average daily gain* to 200 lb may not be large between calves in conventional rearing systems and calves on an accelerated program. However, growth is achieved on the accelerated program by enhancing lean tissue deposition; consequently stature and the degree of body fatness will be different between the schemes if done correctly. Those results would be consistent with the goal of producing heifers with sufficient frame size and without fattening at an earlier calving age.

2. *Increased efficiency of body size gain.* It is a well-established concept in growth of animals or poultry that up to some point, efficiencies of converting feed to body gain increase as growth rates increase. This is attributable to increased gain per unit of maintenance. This "dilution of maintenance" concept is similar to the efficiencies gained by genetic improvement of milk production or by use of bST for lactating cows; more milk is produced for a given "overhead charge" of maintaining the cow's body. In the Cornell University studies (Diaz et al., 2001), gain to feed ratios were improved 20% by increasing the rate of gain to 143 lb from 1.15 lb/d to 2.05 lb/d. In our own research (Bartlett, 2001), increasing the rate of feeding a reconstituted milk replacer (26% protein) from 10% of body weight to 14% to 18% resulted in increased growth rates (0.79, 1.55, 2.26 lb/d) and increased gain to feed ratios (0.55, 0.71, 0.81).

Enhanced early nutrition schemes would capitalize on the rapid early growth potential of young calves. Proportional rates of increase in wither height and body weight are highest during the first 2 mo of life (Kertz et al., 1998). Furthermore, the feed cost per increase in wither height is lowest during the first 2 mo (Kertz et al., 1998). Efficiency of dietary protein use for body protein gain is highest in young calves and decreases with body size (Gerrits et al., 1996).

3. *Improved health*. Enhanced early nutrition programs may offer the possibility of leading to improved health through enhanced function of the immune system. Evidence in the scientific literature to support this idea is limited, but suggestive of possible benefit (Williams et al., 1981; Griebel et al., 1987; Pollock et al., 1993, 1994; Nonnecke et al., 2000; Foote et al., 2003). One way in which improved nutritional status might be expected to benefit the immune system is via growth hormone and the IGF. These hormones play a direct role in integrating the growth, maintenance, repair, and function of the immune system (Clark, 1997). Consequently, increased concentrations of IGF-I resulting from improved nutrition might be expected to enhance immune function in calves.

   Whether these effects will translate into actual improvements in health has not been documented. Anecdotal evidence from producers implementing enhanced early nutrition programs suggests that those calves may be more resistant to early-life scours and respiratory disease, and that calves that do become sick are able to recover more quickly without major impacts on growth rate during illness. However, controlled research should be conducted.

4. *Enhanced milk production ability.* Obviously, improvements in first-lactation milk production would be the ultimate payback for a greater investment in early calf nutrition. Data to evaluate this potential are not yet available. At least three studies have provided evidence that something related to improved early nutrition results in greater first lactation milk yield (Foldager and Krohn, 1994; Bar-Peled et al., 1997; Foldager et al., 1997). While several complicating factors were present in these cited results, and it is difficult to extrapolate the results to enhanced early nutrition programs in the US, it would seem likely that, at the least, there will be no negative impact on subsequent milk yield.

What might be the **potential disadvantages** of accelerated early growth?

1. *Increased costs during the milk feeding period.* The goals of an enhanced early nutrition program program cannot be met by simply feeding more of a conventional milk replacer. The milk replacer must contain higher amounts of high-quality milk proteins, and lower concentrations of many vitamins and minerals. The formulation of the milk replacer should be dictated by animal requirements (see earlier discussion). Consequently, feeding more milk replacer of higher protein content will be more expensive than conventional programs. Increasing the protein content from 22% to 28-30% will increase the ingredient cost of a 50-lb bag of milk replacer by $5 to $6. If milk replacer is fed for the same amount of time in both systems, then

doubling the feeding rate with a more expensive milk replacer would more than double the total milk replacer cost. Furthermore, to maintain the growth advantages obtained with increased liquid feeding, a reformulated starter with higher protein content often is advocated (although not documented by research). This could increase the cost of the starter program as well. An example and discussion of potential economics of enhanced nutrition schemes is in the next section. Given the greater cost, biological advantages in health, decreased age at first calving, or subsequent milk production will have to be demonstrated to re-pay the investment.

2. *Delayed rumen development and weaning.* As discussed earlier, starter intake is important for rumen development, and increased liquid feeding rates suppress starter development. However, a careful reading of the early literature on rumen development and weaning (summarized by Warner, 1991) indicates that calves that are healthy, have good appetites, and are growing generally consume enough dry feed to allow rumen development to continue, in support of that growth. Furthermore, it appears that rumen development requires about 3 wk, regardless of when the process is initiated. On-going field studies in several parts of the country (personal observations) and our own studies at the University of Illinois (Pollard et al., 2003 and in progress) show that target liquid feeding rates do impact voluntary starter intake, but that at appropriate liquid feeding rates calves consume sufficient amounts of starter by 4-6 wk of age to prevent a marked growth slump at weaning. Gaining benefit from enhanced early nutrition requires integration with the entire heifer rearing scheme.

3. *Intensity of management required for success with the program.* This item is the one most likely to limit adoption of enhanced early nutrition programs, even if clear-cut benefits are demonstrated. However, like many practices, intensive management requirements represent a negative only if perceived that way. Like many advanced or high-performance technologies, management must be excellent at all phases of implementation, including colostrum and disease management at birth, sanitation, water availability, the ability to cut back liquid feeding during the weak before weaning, observation to detect illness, appropriate nutrition during the post-weaning and grower phases, and a good reproductive program to get heifers bred at the target weight instead of by age.

What areas appear to be **non-issues** with enhanced early growth?

1. *Increased scouring and unthriftiness of calves.* A common argument in favor of restricted liquid feeding and early weaning has been that scouring is decreased. Fecal consistency becomes less fluid as dry feed is consumed, primarily from the bulking effect of dietary fiber. However, merely feeding more milk or more of a high-quality milk replacer does not cause scouring (Mylrea, 1966; Huber et al., 1984; Nocek and Braund, 1986). The occurrence of calf scours, unless a poor-quality milk replacer containing damaged ingredients is fed, depends more on the load of pathogenic microorganisms in the calf's environment (Roy, 1980) and the degree of environmental stress on calves (Bagley, 2001).

Calves fed on enhanced early nutrition programs will have softer feces, and that requires a shift of mindset by producers. Our own experiences with calves fed milk replacer at up to 18% of BW indicates that average fecal scores are not significantly different but that days with elevated fecal score (softer feces) are increased (Bartlett, 2001). Feeding milk replacer results in softer feces than feeding similar amounts of whole milk, regardless of the composition of the milk replacer (Bartlett, 2001).

Although there are few definitive research data in direct support, ingredient quality and the manufacturing process used to produce milk replacers appears to be critical in responses of calves. Milk replacers containing low-cost non-milk proteins are in general less well-digested by young calves (Davis and Drackley, 1998). Less reputable suppliers may substitute down-graded or inferior quality milk products in their formulas, which may result in poor performance by calves even when feeding an "all-milk" formula milk replacer in an early-weaning system. It is logical, then, that use of poor-quality ingredients in an accelerated program would produce even worse results.

2. *Negative effects on mammary development and subsequent milk production, or on reproductive development.* Overfeeding energy during the period of 3 mo to puberty may negatively impact mammary development and milk production. Concern has been raised that accelerated early growth also may impact mammary development. As state earlier, however, Danish researchers have recently found no evidence for effects of high growth rate during the first 2 mo on mammary development (Sejrsen et al., 1998, 2000). Indeed, if growth rates of 2 lb/d on starter are considered healthy and not a problem for subsequent milk production, there is no reason to expect that growth rates of that magnitude on milk replacer should be different! Recent research from Michigan State University has shown that improved early nutrition actually stimulated mammary tissue development (Brown et al., 2002). Data from controlled research on effects of rapid early lean growth on puberty and reproductive function will be useful.

ECONOMICS OF ENHANCED EARLY NUTRITION PROGRAMS

As mentioned earlier, the lack of data documenting milk production responses to current enhanced early nutrition programs prevents a complete economic assessment at this point. However, a framework for evaluation of the program can be provided using current pricing and data from actual growth trials. Data used for the following example are from an ongoing research project at the University of Illinois, in which a conventional early-weaning program is being compared with a modified version of a widely available commercial program for enhanced (intensified) early nutrition in Holstein heifer calves.

Assumptions used in this example are shown in Table 2. Calves are fed colostrum for the first two days of life. In the conventional early wean program, calves are fed an all-milk protein milk replacer (22% CP, 20% fat) at a fixed rate of 10% of birth weight (reconstituted to 12.5% solids) through 28 d of age, with starter (18% CP) and water available ad libitum. During d 29-35 of age, the afternoon feeding of milk replacer is eliminated, so that calves receive only half of the milk replacer powder daily. Calves are weaned abruptly on d 35, regardless of starter intake. Second, for the enhanced program, calves are fed a commercial intensified milk replacer (28% CP, 20% fat) reconstituted to 17% solids. During the week 1 of life, milk replacer is fed at a rate of 2% (powder) of BW. At d 8, the amount of powder is increased to 2.5% of BW, with that amount kept constant through d 35. During d 36-42, the afternoon feeding is eliminated, and calves are weaned abruptly on d 42. Starter (22% CP) and water are available at all times. Calves are housed in individual hutches through d 56, and then are moved into groups in super-hutches through 12 wk of age. Control calves continue to receive the 18% CP starter free choice, and have good–quality hay available as well. Calves on the enhanced program are fed only the 22% CP starter.

Feed consumption data and economic comparisons associated with the gains depicted in Table 2 are in Table 3. Note that even though total feed cost to weaning is substantially greater for the enhanced nutrition program, the difference in total feed cost to a given body weight (here set at 200 lb) is not as large ($100.47 - $69.45 = $31.02 in this example). This is attributable to the greater feed efficiency obtained with the enhanced nutrition program. If one assumes that, as in these data, 13 d less are required to reach first calving, the cost of rearing the heifer is decreased by $20.80 (assuming a value of $1.60 per day of life to first calving). Consequently, the net increased cost per heifer reared would be $10.22 under these conditions. Dairy producers will need to accept the greater cost as a minimal investment in proposed benefits of the program, such as improved early health and increased milk production. Obviously many factors and scenarios will change the relative outcome of these calculations. As more research data are accumulated, more rigorous economic evaluations can be performed. Producers will need to perform their own calculations to determine whether an enhanced nutrition system will be economical in their situation. However, the net additional cost will be small when implemented properly.

CONCLUSIONS

As is evident from the preceding discussion, an abundance of research remains to be conducted on both "biological" and "management" issues associated with enhanced early nutrition programs for heifer calves. These issues include the proper composition of milk replacers and starters to achieve and maintain early growth advantages, feeding strategies for liquid and starter feeds to allow easy weaning, effects on milk production, effects on health and immune function, and a host of other questions.

The lack of definitive research in all areas of the biology and management associated with enhanced early nutrition programs still precludes a complete assessment of its economic impact. Consequently, heifer growers and dairy producers with interest in such programs will in effect be conducting their own "field trials". It is important to understand that the biological responses associated with enhanced early growth programs may be different than the management objectives or capabilities. In the author's opinion, there are strong biological advantages already demonstrated by increasing the rate of milk replacer feeding during early life of the calf. Demonstration of benefits to the end-user (the dairy farmer) likely will be required before it can be determined that costs from an investment in intensified early nutrition can be recovered.

REFERENCES

Anderson, K. L., T. G. Nagaraja, J. L. Morrill, T. B. Avery, S. J. Galitzer, and J. E. Boyer. 1987. Ruminal microbial development in conventionally or early weaned calves. J. Anim. Sci. 64:1215-1226.

Appleman, R. D., and F. G. Owen. 1975. Breeding, housing, and feeding management. J. Dairy Sci. 58:447-464.

Bagley, C. V. 2001. Influence of nutrition and management on calf scours (bovine neonatal diarrhea). Pages 27-37 in Proc. Intermountain Nutr. Conf., Utah State Univ., Logan.

Bar-Peled, U., B. Robinzon, E. Maltz, H. Tagari, Y. Folman, I. Bruckental, H. Voet, H. Gacitua, and A. R. Lehrer. 1997. Increased weight gain and effects on production parameters of Holstein heifer calves that were allowed to suckle from birth to six weeks of age. J. Dairy Sci. 80:2523-2528.

Bartlett, K. S. 2001. Interactions of protein and energy supply from milk replacers on growth and body composition of dairy calves. M.S. Thesis, University of Illinois, Urbana.

Bartlett, K. S., F. K. McKeith, and J. K. Drackley. 2001a. Effects of energy sources in milk replacers on growth and body composition of Holstein calves. J. Dairy Sci. 84:1560. (Abstr.)

Bartlett, K. S., F. K. McKeith, and J. K. Drackley. 2001b. Effects of feeding rate and protein concentration in milk replacers on growth and body composition of Holstein calves. J. Dairy Sci. 84:1560. (Abstr.)

Blome, R. M., J. K. Drackley, F. K. McKeith, M. F. Hutjens, and G. C. McCoy. 2003. Growth, nutrient utilization, and body composition of dairy calves fed milk replacers containing different amounts of protein. J. Anim. Sci. 81:1641-1655.

Bork, A. L., J. M. Smith, M. R. Foote, and M. E. Van Amburgh. 2000. The somatotropic axis of young calves can be modulated by nutrition and bST. J. Dairy Sci. 83(Suppl. 1):143. (Abstr.)

Brown, E. G., M. J. VandeHaar, K. M. Daniels, J. S. Liesman, L. T. Chapin, and M. S. Weber Nielsen. 2002. J. Dairy Sci. 85(Suppl. 1):80. (Abstr.)

Clark, R. 1997. The somatogenic hormones and insulin-like growth factor-1: Stimulators of lymphopoiesis and immune function. Endocrine Rev. 18:157-179.

Davis, C. L., and J. K. Drackley. 1998. The Development, Nutrition, and Management of the Young Calf. Iowa State University Press, Ames, IA.

Diaz, M. C., M. E. Van Amburgh, J. M. Smith, J. M. Kelsey, and E. L. Hutten. 2001. Composition of growth of Holstein calves fed milk replacer from birth to 105-kilogram body weight. J. Dairy Sci. 84:830-842.

Drackley, J. K. 2001. Milk feeding strategies for calves: Does "accelerated growth" make sense? Pages 27-36 in Proc. 5th Annu. Professional Dairy Heifer Growers Assoc. National Conf., Seattle, WA. PDHGA, Savoy, IL.

Dritz, S. S., K. Q. Owen, R. D. Goodband, J. L. Nelssen, M. D. Tokach, M. M. Chengappa, and F. Blecha. 1996. Influence of lipopolysaccharide-induced immune challenge and diet complexity on growth performance and acute-phase protein production in segregated early-weaned pigs. J. Anim. Sci. 74:1620-1628.

Flower, F. C., and D. M. Weary. 2001. Effects of early separation on the dairy cow and calf: 2. Separation at 1 day and 2 weeks after birth. Appl. Anim. Behav. Sci. 70:275-284.

Foldager, J., and C. C. Krohn. 1994. Heifer calves reared on very high or normal levels of whole milk from birth to 6-8 weeks of age and their subsequent milk production. Proc. Soc. Nutr. Physiol., 3. (Abstr.)

Foldager, J., C. C. Krohn, and L. Mogensen. 1997. Level of milk for female calves affects their milk production in first lactation. In Proc. 48th Annu. Mtng. European Assoc. Anim. Prod.

Foote, M. R., B. J. Nonnecke, W. R. Waters, M. A. Fowler, B. L. Miller, and D. C. Beitz. 2003. Effects of plane of nutrition on proliferation of lymphocyte subsets from neonatal calves vaccinated with M. bovis bacillus Calmette-Guerin (BCG). FASEB J. 17:A1124. (Abstr.)

Gerrits, W.J.J., G. H. Tolman, J. W. Schrama, S. Tamminga, M.W. Bosch, and M.W.A. Verstegen. 1996. Effect of protein and protein-free energy intake on protein and fat deposition rates in preruminant calves of 80 to 240 kg live weight. J. Anim. Sci. 74:2129-2139.

Griebel, P. J., M. Schoonderwoerd, and L. A. Babiuk. 1987. Ontogeny of the immune response: effect of protein energy malnutrition in neonatal calves. Can. J. Vet. Res. 51:428-435.

Hafez, E.S.E., and L. A. Lineweaver. 1968. Suckling behaviour in natural and artificially fed neonate calves. Z. Tierpsychol. 25:187-198.

Hodgson, J. 1971. The development of solid food intake in calves. 5. The relationship between liquid and solid food intake. Anim. Prod. 13:593-597.

Huber, J. T., A. G. Silva, O. F. Campos, and C. M. Mathieu. 1984. Influence of feeding different amounts of milk on performance, health, and absorption capability of baby calves. J. Dairy Sci. 67:2957-2963.

Jasper, J., and D. M. Weary. 2002. Effects of ad libitum milk intake on dairy calves. J. Dairy Sci. 85:3054-3058.

Kertz, A. F., B. A. Barton, and L. R. Reutzel. 1998. Relative efficiencies of wither height and body weight increase from birth until first calving in Holstein cattle. J. Dairy Sci. 81:1479-1482.

Kertz, A. F., L. R. Prewitt, and J. P. Everett, Jr. 1979. An early weaning calf program: summarization and review. J. Dairy Sci. 62:1835-1843.

Khouri, R. H., and F. S. Pickering. 1968. Nutrition of the milk-fed calf I. Performance of calves fed on different levels of whole milk relative to body weight. N.Z. J. Agric. Res. 11:227-236.

Kuehn, C. S., D. E. Otterby, J. G. Linn, W. G. Olson, H. Chester-Jones, G. D. Marx, and J. A. Barmore. 1994. The effect of dietary energy concentration on calf performance. J. Dairy Sci. 77:2621-2629.

Luchini, N. D., S. F. Lane, and D. K. Combs. 1993. Preweaning intake and postweaning dietary energy effects on intake and metabolism of calves weaned at 26 days of age. J. Dairy Sci. 76:255-266.

Mylrea, P. J. 1966. Digestion in young calves fed whole milk ad lib. and its relationship to calf scours. Res. Vet. Sci. 7:407-416.

National Animal Health Monitoring System. 2003. Dairy 2002. Part II: Changes in the United States Dairy Industry, 1991-2002. USDA-APHIS Veterinary Services, Ft. Collins, CO.

National Research Council. 1978. Nutrient Requirements of Dairy Cattle. 5th rev. ed. National Academy of Sciences, Washington, DC.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle. 7th rev. ed. National Academy Press, Washington, DC.

Nocek, J. E., and D. G. Braund. 1986. Performance, health, and postweaning growth on calves fed cold, acidified milk replacer ad libitum. J. Dairy Sci. 69:1871-1883.

Nonnecke, B. J., M. E. Van Amburgh, M. R. Foote, J. M. Smith, and T. H. Elsasser. 2000. Effects of dietary energy and protein on the immunological performance of milk replacer-fed Holstein bull calves. J. Dairy Sci. 83(Suppl. 1):135. (Abstr.)

Pollard, B. C., H. M. Dann, and J. K. Drackley. 2003. Evaluation of intensified liquid feeding programs for dairy calves. J. Dairy Sci. 86(Suppl. 1):174. (Abstr.)

Pollock, J. M., T. G. Rowan, J.B. Dixon, S. D. Carter, D. Spiller, and H. Warenius. 1993. Alteration of cellular immune responses by nutrition and weaning in calves. Res. Vet. Sci. 55:298-306.

Pollock, J. M., T. G. Rowan, J.B. Dixon, and S. D. Carter. 1994. Level of nutrition and age at weaning: effects on humoral immunity in young calves. Br. J. Nutr. 71:239-248.

Quigley, III, J. D., C. G. Schwab, and W. E. Hylton. 1985. Development of rumen function in calves: nature of protein reaching the abomasum. J. Dairy Sci. 68:694-702.

Richard, A. L., L. D. Muller, and A. J. Heinrichs. 1988. Ad libitum or twice daily feeding of acidified milk replacer to calves housed individually in warm and cold environments. J. Dairy Sci. 71:2193-2202.

Roy, J.H.B. 1980. Factors affecting susceptibility of calves to disease. J. Dairy Sci. 63:650-664.

Sejrsen, K., S. Purup, H. Martinussen, and M. Vestergaard. 1998. Effect of feeding level on mammary growth in calves and prepubertal heifers. J. Dairy Sci. 81(Suppl. 1):377. (Abstr.)

Sejrsen, K., S. Purup, M. Vestergaard, and J. Foldager. 2000. High body weight gain and reduced bovine mammary growth: physiological basis and implications for milk yield potential. Domest. Anim. Endocrinol. 19:93-104.

Smith, J. M., M. E. Van Amburgh, M. C. Diaz, M. C. Lucy, and D. E. Bauman. 2002. Effect of nutrient intake on the development of the somatotropic axis and its responsiveness to GH in Holstein bull calves. J. Anim. Sci. 80:1528-1537.

Tikofsky, J. N., M. E. Van Amburgh, and D. A. Ross. 2001. Effect of varying carbohydrate and fat content of milk replacer on body composition of Holstein bull calves. J. Anim. Sci. 79:2260-2267.

Warner, R. G. 1991. Nutritional factors affecting the development of a functional ruminant – A historical perspective. Pages 1-12 in Proc. Cornell Nutr. Conf., Cornell Univ., Ithaca, NY.

Williams, N. H., T. S. Stahly, and D. R. Zimmerman. 1997. Effect of level of chronic immune system activation on the growth and dietary lysine needs of pigs fed from 6 to 112 kg. J. Anim. Sci. 75:2481-2496.

Williams, P.E.V., D. Day, A. M. Raven, and J. A. McLean. 1981. The effect of climatic housing and level of nutrition on the performance of calves. Anim. Prod. 32:133-141.

Table 1. Effect of rate of BW gain with constant initial BW (100 lb) on protein requirements of pre-weaned dairy calves (adapted from Davis and Drackley, 1998, and subsequently from National Research Council, 2001).

Rate of gain (lb/d)	ME (kcal/d)	ADP (g/d)	Required DMI[1] (lb/d)	CP Required (% of DM)
0	1748	28	0.84	8.3
0.50	2296	82	1.11	18.1
1.00	3008	136	1.45	22.9
1.50	3798	189	1.83	25.3
2.00	4643	243	2.24	26.6
2.50	5532	297	2.67	27.2

[1] Amount of milk replacer dry matter (DM) containing 2075 kcal ME/lb DM needed to meet ME requirements.

Table 2. Assumptions and data used in economic evaluation.

Item	Control	Enhanced
Calf birth weight (lb)	84	84
Age at weaning (days)	35	42
Body weight (BW) at weaning (lb)	115	155
BW gain to weaning (lb)	31	71
Average daily gain to weaning (lb)	0.86	1.69
Days required to reach 200 lb BW	75	62
BW gain post-wean to 200 lb (lb)	85	45
Average daily gain wean to 200 lb (lb)	2.12	2.25
Cost of milk replacer ($/lb)	$0.94	$1.05
Cost of starter ($/lb)	$0.17	$0.19
Cost of hay ($/lb)	$0.08	---

Table 3. Feeds consumed and cost of gain comparisons.

Item	Control	Enhanced
Total milk replacer fed (lb)	31.9	79.4
Total starter fed to weaning (lb)	19.4	10.0
Milk replacer cost ($)	$29.99	$83.37
Starter cost to weaning ($)	$3.30	$1.90
Total feed cost to weaning ($)	$33.29	$85.27
Feed cost / lb BW gain ($)	$1.07	$1.20
Starter intake post-wean to 200 lb BW (lb)	208	80
Hay intake post-wean to 200 lb BW (lb)	10	0
Starter cost post-wean to 200 lb BW ($)	$35.36	$15.20
Hay cost post-wean to 200 lb BW ($)	$0.80	0
Total feed cost post-wean to 200 lb BW ($)	$36.16	$15.20
Feed cost / lb BW gain post-wean to 200 lb ($)	$0.43	$0.34
Total feed cost to 200 lb ($)	$69.45	$100.47
Feed cost per lb BW gain to 200 lb BW ($)	$0.60	$0.87
Feed cost per day of life to 200 lb BW ($)	$0.93	$1.62
Net difference in total feed costs ($)		$31.02
Value of 13 d less to first calving (@$1.60/d)		$20.80
Marginal net difference in total costs (USD)		$10.22