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Feeding for Accelerated Growth in Dairy Calves

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Summary

Interest in "accelerated" growth programs for dairy calves, more properly called intensified or enhanced early nutrition programs, continues to increase. 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 to 4 quarts) of high-quality colostrum is undisputed (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

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unanswered questions concerning health, economics, and effects on long-term profitability. The objective of this paper is to evaluate the current status of intensified or enhanced early nutrition programs. A discussion of the origin of current "conventional" feeding practices and some basic principles of early growth are included in order to properly frame the ideas behind intensified early nutrition.

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 substantial improvements in energy balance. Labor requirements per calf also decrease considerably when calves no longer have to be fed milk individually and can be housed in groups.

Before the development of the first milk replacer in 1951, it was common for farmers to feed considerably more milk than used today, often as much 4 quarts per feeding (8 quarts/day). An extensive amount 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 (e.g., 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) that were applied with reasonable success in the field.

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 (e.g., Luchini et al., 1993). Establishment of a mature, functional population of rumen 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 higher amounts of milk or milk replacer 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 might be 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 must contain greater amounts of crude protein (CP), similar to the amount in 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 and efficient early lean growth potential of young calves, and allow greater frame 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 (BW) 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 BW 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 BW, and gained 63% more weight than conventionally fed calves. Studies with twice-daily hand feeding of milk replacer also show that ad libitum intakes of milk are in excess of 18% of BW. 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 BW. Daily BW 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 BW 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 in an attempt 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 may help to understand 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. Third, 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. Finally, only BW and perhaps stature measurements were used to define success; favorable changes in body composition, early endocrine system development, immune system development and function, and subsequent mik production were not evaluated.

It is also important to realize that the goals of increased milk feeding for heifer calves are different from the goals of veal production. Obviously, near ad libitum feeding of whole milk for extended periods of time would lead to fattening, 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). Together, then, 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 either whole milk or a high-fat milk replacer of similar composition to whole milk, when calves 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 (Kertz et al., 19979; 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 BW (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 BW (Smith et al., 2000). Comparisons between calves fed on enhanced early nutrition programs and conventional early weaning programs where both groups are also receiving calf starter are needed urgently. Such studies currently are in progress at Cornell University.

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 and field trials indicate that it is possible to design systems to allow calves to wean relatively 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 shortor 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. *Improved health.* Enhanced early nutrition programs may offer the possibility of improved health through enhanced development or function of the immune system, decreased early life stress response (cortisol or other stress hormones) to marginal nutrition, or through several other hypothesized mechanisms. 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 growth and nutritional status might be linked to an enhanced immune system is via growth hormone and the insulin-like growth factors (IGF). In addition to stimulating growth in young animals, 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 as well.

Whether these effects will translate into actual improvements in health has not been documented through controlled research. Anecdotal evidence from producers that have implemented 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 on all aspects of immune development and calf health still is needed.

2. *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 to 3 wk of life before starter intake increases appreciably in conventionally raised calves. Available research data suggest that the growth advantage can be maintained, and perhaps even increases, after weaning for calves on enhanced early nutrition programs. This may occur by activating the normal growth hormone–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 responds 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 able to stimulate growth.

Individual calf raisers 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 0.75 to 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 15 to 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.

3. *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 case of calves, more growth is obtained for the same amount of maintenance cost. Studies at Cornell University (Diaz et al., 2001) showed that gain to feed ratios were improved 20% by increasing the rate of gain to 143 lb BW 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 BW 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 BW 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).

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. Improved early health could be one factor that leads to better future performance.

What might be the **potential disadvantages** of enhanced 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 the necessity has not been documented by research). This could increase the cost of the starter program as well.

Our initial estimates are that feed cost to weaning could be more than doubled, although differences in feed costs per pound of BW gain were not nearly as large ($1.07 vs. $1.20 for control and enhanced, respectively). Our estimates of total greater feed cost for a replacement heifer are in the range of $30 to $35. If implemented into a well-managed heifer rearing program, where heifers are bred based on body size rather than age, then the net increase in overall cost per heifer freshened will be less than the increased feed cost. For example, if intensified early nutrition leads to reaching a given BW 10 d earlier (with no changes in the post-weaning program), and heifers are bred and freshened 10 d earlier, this is a savings of at least $16.00 in rearing costs (at $1.60/d). Total net increased cost per heifer freshened in this scenario is then in the range of $15 to $20. The payback for this slightly greater cost would need to be found in biological advantages in health, decreased age at first calving, or subsequent milk production.

2. *Delayed rumen development and weaning.* As discussed earlier, starter intake is important for rumen development, and increased liquid feeding rates slow down the intake of starter. The early scientific 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), research at Cornell University (M. E. Van Amburgh, personal communication), and our own studies at the University of Illinois (Pollard et al., 2003 and in progress) show that increased liquid feeding rates do impact voluntary starter intake. Our studies (discussed below) indicate that starter intake curves are similar to those of early-weaning controls, but are delayed by about 2 wk. Cornell University research and feedback from dairy producers indicate that calves consume sufficient amounts of starter by 4-6 wk of age to prevent a marked growth check at weaning. Appropriate formulation and management of starter to increase intakes and prevent growth slumps at weaning seem to remain important unresolved obstacles to universal success with enhanced early nutrition programs. Gaining benefit from enhanced early nutrition also requires integration with the entire heifer rearing program.

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 or height 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 limit-feeding milk 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 stated

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 any different! Recent research from Michigan State University has shown that improved early nutrition actually stimulated mammary tissue development (Brown et al., 2002).

Intensified Early Nutrition: Current Illinois Studies

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 both trials, calves were housed in individual hutches and were fed colostrum and transition milk for the first 3 d of life. In both trials, control calves were fed a commercial milk replacer (22% CP, 20% fat) at a fixed rate of 1.25% of birth weight (dry powder weight) reconstituted to 12.5% solids for 4 wk. During wk 5, the afternoon feeding of milk replacer was stopped and calves were weaned at the end of wk 5. A commercial texturized calf starter (18% CP as fed) and water were available for ad libitum consumption from wk 1 throughout the trial. Calves on the enhanced early nutrition program in both trials received a commercially available intensified milk replacer (28% CP, 20% fat). The enhanced nutrition milk replacer was reconstituted to 17% solids. In trial 1, calves on the enhanced early nutrition program were fed at a rate of 2% of BW (dry powder) during wk 1, and then at 2.5% of BW during wk 2 to 5, with the amount being adjusted weekly as calves grew. In trial 2, enhanced calves were fed at a rate of 2% of BW during wk 1 and then a fixed amount of 2.5% of wk 2 BW during wk 2 to 5. In both trials, enhanced calves had the afternoon feeding dropped during wk 6 and were weaned at the end of wk 6.

In trial 1, control calves gained an average of 46 lb of BW 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. Consumption of starter was delayed by about 2 wk for the enhanced calves in both trials 1 and 2. Because of the markedly lower starter intake during and after weaning for the enhanced calves, total DM intake and average daily gains fell drastically during wk 7 (after weaning). By 8 wk of age the difference in BW had narrowed in both trial 1 (154 and 167 lb for control and enhanced calves, respectively) and trial 2 (165 and 178 lb, respectively).

On the basis of our results there appears to be no clear advantage to either approach in enhanced liquid feeding, i.e., stepping up the amount fed weekly vs. holding the larger amount fed constant. Although post-weaning differences in BW had diminished, it is important to remember again that BW alone is not an adequate evaluation of early nutrition programs for young calves. Effects on body composition, early health, and developmental events must be considered but are difficult to determine experimentally. Based on data from other species and field experiences with intensified early nutrition systems to date, such advantages still seem likely and deserve additional investigation.

In an ongoing experiment, we have preliminary data to indicate that the transition to dry feed may be improved in calves fed a lower-fat formula for accelerated growth. Such findings would be consistent with other data showing that higher-fat milk replacers decrease early starter intake (Kuehn et al., 1994).

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 subsequent 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 prevents a complete assessment of its economic impact. Consequently, the best recommendation at this point is that heifer growers and dairy producers with interest in such programs should try some of their calves on the program. In doing so, producers should actually measure or weigh calves so that they can fully identify differences in size at a particular age, and also observe impacts on health and weaning. It is critical to use products specifically designed for these programs and to work closely with a knowledgeable nutritionist. 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 economic benefits (improved health, decreased days to first calving, improved milk yield) to the end-user (the dairy farmer) are required before a complete economic analysis can be provided.

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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.