Accelerated Growth Programs for Milk-Fed Calves

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INTRODUCTION

The most recent USDA National Animal Health Monitoring System survey reported that preweaning mortality of heifers alive at 48 hr of age was 7.9 % (USDA, 2007). Although slightly lower than previous survey results, industry-average morbidity and mortality of preweaned dairy calves remains unacceptably high in the USA. Disease agents and environmental stressors interact with nutrition to determine disease susceptibility (Davis and Drackley, 1998). Labor for care and individual feeding of calves before weaning is the major cost of calf production, but nutritional inputs are also more costly during this period. Therefore, nutrition of young calves remains of paramount importance for calf health and profitability of dairy operations.

Conventional calf-rearing systems historically have restricted the amount of milk or milk replacer fed during the first few weeks of life in an effort to encourage solid feed intake and allow early weaning. Over the last several years, demonstrations of the remarkable improvements in growth and feed efficiency that are obtained by feeding greater quantities of milk (Flower and Weary, 2001; Jasper and Weary, 2002; Khan et al., 2007a,b) or milk replacer (Bartlett, 2001; Diaz et al., 2001; Tikofsky et al., 2001; Blome et al., 2003; Brown et al., 2005; Bartlett et al., 2006) have stimulated renewed interest in early calf nutrition. Such systems have been called by various names, including *accelerated early nutrition, accelerated growth, enhanced nutrition*, *intensified nutrition*, and *biologically appropriate growth*. While interest in these systems has been high, a major limitation in adoption has been the unknown economic benefits of improved early nutrition. To develop a full economic model of the effect of such systems on dairy enterprise profitability, necessary inputs include effects on:

- Growth rates and cost per unit height or weight increase,
- Subsequent growth after weaning,
- Health, and
- Subsequent milk production.

While data continue to accumulate in each of these areas, it is not yet possible to prepare a complete economic assessment. The objective of this paper is to provide an overview of the current state of knowledge on accelerated early nutrition programs and data that show negative or positive biological effects.

NUTRIENT REQUIREMENTS

The rationale for so-called accelerated feeding is simple to appreciate if one considers nutrient requirements for growth in young calves. Like other animals, calves require nutrients for maintenance and for growth. Moreover, like other animals, amounts of nutrients required are not fixed but vary with bodyweight (**BW**) and average daily gain (**ADG**) of BW. The National Research Council (**NRC**) in its most recent publication of nutrient requirements for dairy cattle (NRC, 2001) established energy requirements for young calves in terms of metabolizable energy (**ME**). Recent growth

Table 1. Nutrient requirements and estimated gain:feed for a 110-lb (50-kg) calf under thermoneutral conditions, using the Cornell-Illinois modifications of NRC (2001) equations (Van Amburgh and Drackley, 2005).

Rate of gain, lb/d (kg/d)	Dry matter intake, % BW	ME, Mcal/d	CP, g/d	CP, % of diet DM	Estimated gain:feed
0.44 (0.2)	1.05	2.34	94	18.0	0.38
0.88 (0.4)	1.30	2.89	150	22.4	0.63
1.32 (0.6)	1.57	3.49	207	26.6	0.77
1.76 (0.8)	1.84	4.40	253	27.4	0.86
2.2 (1.0)	2.30	4.80	318	28.6	0.87

experiments at the University of Illinois and Cornell University have provided data to develop modified NRC equations that better predict growth performance by dairy heifer and bull calves under typical US rearing conditions (Table 1).

Several important principles can be demonstrated from data in Table 1. First, the amount of milk solids required to meet maintenance ME requirements is not small. The ME requirements for maintenance under thermoneutral conditions are approximately 1.75 Mcal/d for a 100-lb (45 kg) calf. Whole milk contains about 5.37 Mcal ME/kg of solids, which means that a 100-lb (45-kg) calf requires about 0.71 lb (325 g) of milk solids, or 5.7 lb (2.6 kg) of whole milk (about 2.5 L) just for maintenance. Because most milk replacers are lower in fat content than whole milk, they have less ME per unit of solids (4.6 – 4.7 Mcal/kg). Consequently, a 100-lb (45-kg) calf requires about 0.84 lb (380 g) of milk replacer (about 3.0 L as fed) for maintenance. Amounts of milk solids consumed above maintenance can be used for growth.

Second, for calves to grow faster, they need to be fed more milk or milk replacer, or, in older calves, they must consume more starter. Calves clearly respond to greater intake of milk or milk replacer with greater BW gains (Huber et al., 1984; Richard et al., 1988; Diaz et al., 2001; Jasper and Weary, 2002; Brown et al., 2005; Bartlett et al., 2006; Khan et al., 2007a,b). Third, the amount of crude protein (**CP**) required in the calf's diet as a percentage of dry matter (**DM**) is very low for maintenance, but increases as rate of gain increases. Fourth, CP content of the diet appears to approach a plateau at about 28 % of the DM, which is not unlike the CP content of whole milk solids (about 26 % on a DM basis).

Finally, these relationships highlight the importance of matching dietary protein and energy intakes with the expected growth performance of the calf. For example, feeding twice as much of a conventional milk replacer with 20 % CP will not provide enough protein for lean tissue growth, and the surplus energy will be converted to fat. Conversely, feeding a high-protein milk replacer (e.g., 28 % CP) designed for *accelerated growth* at conventional feeding rates of 1 to 1.25 lb/d (454 to 568 g/d) provides excess protein to the calves, which cannot be used for additional growth because energy is limiting. In this case the excess protein will be degraded and the nitrogen excreted in urine.

Requirements discussed to this point assume that calves are in thermoneutral conditions, which means that they do not need to expend energy to maintain body temperature. The thermoneutral zone for calves less than 21 d of age is 59 to 77 °F (15 to 25 °C; NRC, 2001). Consequently, calves in the High Plains region spend a considerable portion of their time outside of the thermoneutral zone. Above or below this range, calves must expend more energy to maintain body temperature; in hotter temperatures they will pant and sweat, while in colder temperatures they will shiver and use other means to increase heat production. This increase in energy expended becomes part of the maintenance energy requirement. For calves older than 21 d, the lower critical temperature falls to about 41 °F, which means they are more able to withstand colder temperatures because of increases in body fat content and hair coat. The increased maintenance energy requirement in cold temperatures is built into the NRC model (NRC, 2001). As environmental temperature decreases, maintenance requirements for ME increase. A 100-lb (45-kg) calf at 4 °F (-20 °C) requires about 1.24 lb/d (563 g/d) of milk replacer powder just to meet maintenance requirements and maintain body temperature, compared with about 0.84 lb/d (382 g/d) of powder under thermoneutral conditions. If calves are fed the same amount of milk or milk replacer as in thermoneutral conditions, less energy will be available to fuel growth.

Heat stress also increases the maintenance energy requirements of calves, although the exact amount needed for cooling has not been as well quantified as the effects of cold stress. Estimates based on data for older growing cattle (NRC, 2001) would indicate increased maintenance requirements of 20 to 30 % (about 0.15 to 0.25 lb more milk replacer powder) during heat stress. Free choice water availability and shade are critical to maintain body temperature in young calves. Sand bedding also helps calves dissipate heat better than straw or wood shavings.

Based on data from an Israeli study (Arieli et al., 1995), an additional maintenance requirement may be needed by young calves undergoing transport. On average, this amount is about 0.22 lb (100 g) of powder for calves weighing 95-110 lb (43-50 kg). Calves should be fed this increased amount (in addition to any needed for temperature allowance) for 14 d following transport (Van Amburgh and Drackley, 2005).

CONVENTIONAL VS. ACCELERATED FEEDING SYSTEMS

Traditionally, calves have been fed limited amounts of milk or milk replacer (typically 8 to 10 % of birth BW) with starter offered for ad libitum consumption from the first week of life. This amount of liquid feed is much lower than ad libitum intakes, which are in the range of 16 to 20 % of BW or 2 to 2.5 % of BW as dry solids (Hafez and Lineweaver, 1968). The restricted liquid feeding approach arose in an attempt to stimulate early intake of starter and to minimize input costs of higher-value feed. In addition, early milk replacers were of poor quality and were not well utilized by calves at higher feeding rates (Davis and Drackley, 1998). Restricted feeding allows only for maintenance requirements and up to about 0.5 lb/d ADG under thermoneutral conditions (Table 1). As starter intake increases, typically doubling every week, enough nutrients are consumed to allow calves to begin to grow rapidly (Kertz et al., 1979).

A contrasting approach is the accelerated feeding system, which allows calves much greater intakes of liquid feed during early life, closer to *natural* conditions in which calves would have ad libitum access to milk. Milk feeding rates are approximately twice those of conventional systems. An easy thumbrule is to provide 1.5 % of BW as milk solids during the first week of life, then 2 % of BW from the second week of life until the week before weaning, when one feeding is dropped (Stamey et al., 2005). Intake of starter will lag behind calves fed on conventional systems, but increases at approximately the same rate once the amount of liquid is cut back (Stamey et al., 2005; Hill et al., 2006, 2007). To avoid or minimize growth slumps around weaning, calves should not be weaned until they are consistently eating 2 lb of starter daily. As shown in Figure 1, the major difference in growth rate is in the first 2-3 wk of life, and after that growth rates generally are parallel. Accelerated feeding programs using whole milk also can be successful, particularly when implemented with step-down (Khan et al., 2007a,b) or gradual weaning programs (Jasper and Weary, 2002).

Feeding programs have been developed that are intermediate in nature to accelerated and conventional programs. These moderately aggressive programs call for liquid intakes between those in conventional and accelerated programs (Stamey et al., 2006; Hill et al., 2006). These programs are reported to result in less slump in growth around weaning and fewer digestive upsets in calves than more aggressive liquid feeding programs (Hill et al., 2006), while

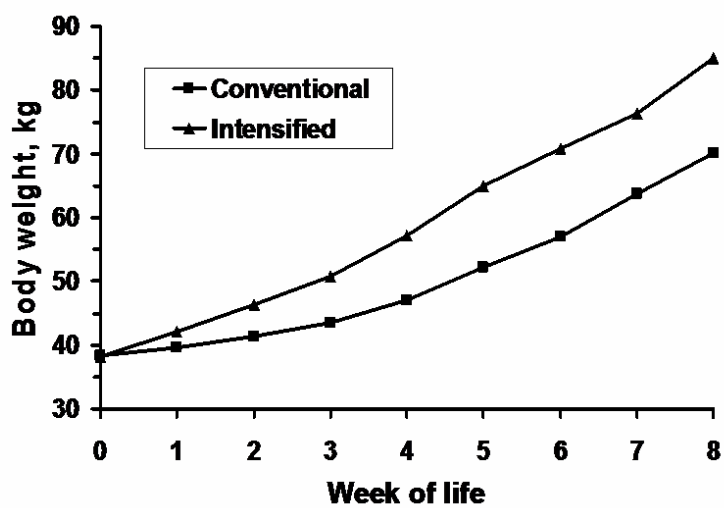

Figure 1. Example of differences in early growth between calves fed on a conventional limit-feeding program (milk replacer powder fed at 1.25 % of birth BW; calves weaned at 35 d) or on an accelerated (intensified) program where milk replacer was fed at 2 % of birth BW for wk 1, then 2.5 % of BW during wk 2-5. Calves had access to water and starter from wk 1 of life and were weaned at d 42. (B.C. Pollard and J.K. Drackley, unpublished data, 2002)

still providing improved nutritional status during the critical first 2-3 wk (Stamey et al., 2006). Milk replacers designed for use in intermediate programs usually contain 24 to 26 % CP and are fed at 1.5 to 1.75 % of BW. While easier to implement, they do not fully capitalize on the early growth potential. These programs may be more easily implemented with transported or colostrum-deprived calves than are more aggressive accelerated programs (Hill et al., 2006).

BENEFITS OF ACCELERATED EARLY NUTRITION

Benefits of improved nutritional status in the first 2-3 wk may include reaching breeding age (and thus calving age) sooner, an improved ability to withstand infectious challenges, and increased subsequent milk production (Drackley, 2005).

Increased Growth and Earlier First Calving

The increased early growth of heifers easily translates into 2 wk earlier calving age provided typical BW or height differences at weaning are maintained. If heifers continue to grow more rapidly the advantage may increase to more than 1 mo. Of course, to realize this decrease in calving age, heifers must be bred according to body size rather than age. It is important to note that calves must have adequate early colostrum intake to be able to efficiently utilize additional nutrients from milk intake. In addition, calves undergoing adaptation to stressors, such as transport, also may be less able to utilize high amounts of milk solids intake in early life (Hill et al., 2006; Quigley et al., 2006).

Improved Health

Poor health during early life is believed to have long-lasting effects on milk production and herd life. Epidemiological studies relating specific neonatal illnesses to later productivity generally have not found strong relationships between any specific illness or condition and subsequent survivability or productivity, although respiratory disease in calves increased the age at first calving (Correa et al., 1988). Early-life *dullness* in calves was a significant risk factor for shorter herd life. Calves that were characterized as having dullness before 90 d of age (defined as dull appearance, listlessness, droopy ears, and off-feed) were 4.3 times more likely to die after 90 d of age (Curtis et al., 1989) and 1.3 times more likely to leave the milking herd than herdmates (Warnick et al., 1997). The authors speculated that this condition might reflect the combined effects of poor health and suboptimal nutrition.

Considerable evidence points to inadequate nutrition during early life as a major factor in decreased resistance to disease and compromised health and well being. Williams et al. (1981) compared calves fed 2 amounts of milk replacer solids (600 g/d and either 300 or 400 g/d) with either ad libitum or restricted access to calf starter. Calves fed the higher amount of milk replacer with ad libitum access to starter had the greatest ADG and least mortality. More recently, Khan et al. (2007b) showed a reduction in fecal scores for calves fed at an accelerated rate with whole milk.

The available evidence suggests that improvements in health seen with calves fed greater amounts of milk or milk replacer likely are due to improved overall nutritional status rather than to any specific alterations in immune system characteristics or function. Studies that have examined functional aspects of components of the immune system generally have found small differences between calves fed conventionally or on accelerated programs (Griebel et al. 1987; Pollock et al., 1993, 1994; Nonnecke et al., 2003; Foote et al., 2005, 2007). Unfortunately, studies are not available in which calves have been grown on different planes of nutrition and then were challenged with a disease organism to assess the impact of plane of nutrition on the ability to prevent disease or recover more quickly from disease.

The health status of young calves is impacted by interactions of early nutrition and the environment. Nutritional insufficiency may be especially problematic for immune function during cold or heat stress, when maintenance requirements for temperature regulation are increased. For example, we conducted an experiment to determine the value of supplementing milk replacer with energy sources for Jersey calves raised in hutches during winter (Drackley et al., 1996). To do so required establishment of an appropriate baseline feeding regimen. Jersey heifer calves fed a conventional milk replacer at 8 % of BW did not maintain BW and had a high incidence of health problems. Calves fed the same milk replacer at 10 % of BW gained small amounts of BW, but still were unhealthy. Only when calves were fed at a rate of 12 % of BW were they able to maintain health and modest rates of BW gain.

A study conducted in Minnesota (Godden et al., 2005) compared equal volumes of pasteurized non-saleable milk and a conventional milk replacer. Because whole milk contains about 17 % more energy than milk replacer at equal amounts, indirectly these authors were comparing 2 planes of nutrition. Calves fed the pasteurized non-saleable milk had greater ADG than those fed milk replacer. In summer, mortality of calves did not differ between those fed milk (2.2 %) or milk replacer (2.7 %). However, for calves born in the winter, mortality was much greater for calves fed milk replacer (21.0 %) than for those fed milk (2.8 %). Much of this difference is likely attributable to the marginal nutrient status of the calves fed milk replacer, because of the greater maintenance energy requirements during cold stress.

Greater Subsequent Milk Production

One of the most exciting current areas of research concerning accelerated feeding is to document long-term effects of early nutrition on subsequent productivity. As more and more lactation data become available for calves fed differently after birth it is becoming clear that improved growth rates and early nutrition translate into greater milk production. Several earlier studies suggested improvements in subsequent milk production when calves were fed greater amounts of milk (Foldager and Krohn, 1994; Foldager et al., 1997; Bar-Peled et al., 1997). Average improvements in first-lactation milk yield are in the range of 1,000 to 2,000 lb milk.

We compared an accelerated milk replacer feeding system with a conventional limit-feeding system for calves born in spring and summer over 2 subsequent years (Pollard et al., 2003). The same milk replacers were fed in each year but the feeding rate of the accelerated program varied slightly in the two years; consequently each year represents a separate trial. Calves fed the acclerated treatments had greater ADG during the milk feeding period (Table 2), but stalled markedly around weaning. By 12 wk of age, differences in BW and stature had narrowed between groups. First-lactation 305-d actual milk yields (Drackley et al., 2007) are shown in Table 2. Early life enhanced feeding resulted in greater milk production during the first lactation, although the tendency for the diet by trial interaction indicates that the difference was greater for Trial 1 than Trial 2. *Accelerated* heifers from Trial 1 calved about 1 mo later on average, were slightly larger, and had greater milk yields. Heifers from both diets in Trial 2 calved at the same average age and BW, and milk yields differed less. Regardless of diet, heifers from Trial 2 did not perform as well as those from Trial 1. This points out the importance of variation from year to year, which complicates on-farm determination of effects of management changes. Correlation analysis revealed that ADG was correlated negatively with subsequent milk production within the conventional treatment, but was correlated positively with milk production in the accelerated treatment (M. E. Van Amburgh and J. K. Drackley, unpublished).

We currently are completing analysis of a large experiment with heifer and bull calves born on the University of Illinois dairy farm (Stamey et al., 2005, and unpublished). The experiment compared a traditional restricted-feeding program of a 20 % CP, 20 % fat milk replacer with an intensified step-up feeding program using a 28 % CP, 15 % fat milk replacer. Both groups of calves had starter and water available free choice and were weaned at 6 wk of age. The ADG through 8 wk of age were 20% greater (777 g/d vs. 648 g/d) for the intensified calves. Of greater importance is that gains of wither heights were also about 24 % greater for the intensified calves. We have followed these heifers through subsequent growth and first lactation, and the data should allow a complete economic evaluation of the program.

Table 2. Growth and first-lactation data for heifers fed either conventional or intensified milk replacer programs as calves in 2 trials (Drackley et al., 2007).

Variable	Conventional	Accelerated
ADG to weaning (lb)		
Trial 1	1.14	1.65
Trial 2	1.23	1.56
Age at calving[a] (mo)		
Trial 1	25.4	26.5
Trial 2	24.0	24.3
Calving BW (lb)		
Trial 1	1,238	1,284
Trial 2	1,243	1,238
305-d milk[abc] (lb)		
Trial 1	20,340	23,269
Trial 2	19,351	20,104

[a] Trial, $P < 0.01$.
[b] Diet, $P < 0.01$.
[c] Diet × trial, $P = 0.13$.

CONCLUSIONS

The concept of *accelerated feeding* for young milk-fed calves is now well-accepted as an alternative to traditional restricted feeding. Research and field experience have highlighted many important aspects that are required for successful implementation. Calves must be fed a properly formulated milk replacer or whole milk at approximately twice the conventional rate. A step-down or gradual weaning process facilitates a smoother transition to dry feed. Colostrum-deprived calves or calves that are undergoing transport stress will not respond as well to increased amounts of milk and may in fact be impacted negatively. Benefits to accelerated milk-feeding programs include: decreased age at first calving, improvements in health, and increased milk production. Ongoing research will provide the necessary input variables to model the overall economic impact of accelerated milk feeding programs.

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