The Advantages of “Accelerated Growth” in Heifer Rearing

Mike Van Amburgh and Jeff Tikofsky

Department of Animal Science, Cornell University, 272 Morrison Hall, Ithaca, NY 14853.
Email: mev1@cornell.edu.

▪ Take Home Message

Profitability of the heifer enterprise is an integration of our understanding of the biology of heifer growth and the management necessary to accomplish appropriate growth in the most timely and cost effective manner. The concept of accelerated growth has been receiving additional attention. Our definition of the concept involves a systematic approach to redefining nutrient requirements from birth and setting specific targets and goals from the day of birth that appear to more closely resemble “normal growth”. In addition our definition includes an evaluation of the management and environment of the farm to ensure that all of the factors responsible for the success of the rearing system, through the end of the first lactation, are accounted for and managed accordingly.

▪ What is “Accelerated Growth”?

Before any discussion of the advantages or disadvantages of “accelerated growth” can be made, a definition of accelerated growth must be determined. The term “accelerated growth” must be used in the context of a specific management or production milestone and in the case of dairy replacement heifers, that milestone is age at first calving (AFC). This implies there is a management goal such as a target weight and age at which a group of heifers is to be confirmed pregnant which then dictates when the AFC will occur. A definition of “accelerated growth” gains further complexity because the evaluation of the weight and AFC is not complete without first lactation milk yield. The desire to evaluate all first lactation production outcomes based primarily on AFC has made the benchmark a dumping ground for a series of other management factors that may have also affected first lactation milk yield but are harder to quantify (Table 1). This discussion might seem over-simplistic but it is necessary since the term “accelerated growth” has taken on connotations that are not appropriate due to individual interpretations.

Table 1. A partial list of factors that affect the heifer performance benchmark age at first calving. The term age at first calving is traditionally not evaluated until after first lactation production has been measured, therefore any factors affecting first lactation production must be included.

Birth weight Weaning weight Prepubertal growth rate Disease – through first lactation Accurate nutrient supply Growth rate during pregnancy	Maintenance requirements Heat detection Breeding weight Conception rate Calving weight Body condition
Lactation feeding, management, grouping strategy	

For over 30 years our industry target or goal for AFC has been 24 months with a post-calving bodyweight (BW) of approximately 565 kg. In order to achieve that AFC goal, Holstein heifers must be confirmed pregnant by 15 months of age at a weight of at least 340 kg. Given those goals, is it then implied any growth rate and associated management practices in excess of that required to meet the AFC goal of 24 months constitutes “accelerated growth”? We would suggest that this is not the case and in fact the term “accelerated growth” is a misnomer and open to mis-interpretation since it involves only the growth rate aspect of the rearing of dairy replacement heifers. We would further suggest that the concept of accelerated growth is a management decision, not simply a growth rate, and that the outcome of an “accelerated program” will be herd specific. Furthermore, the decision to adopt an “accelerated program” should be based on the management inputs available to allow the animals to express their potential to grow, develop and produce milk. Producers and growers must be aware that the end of the heifer growth stage is not signaled by the onset of first lactation. In actuality, heifers are ideally 85% of mature BW at first calving, and growth continues through the first and second lactation. Therefore, the rearing of heifers demands a systematic approach from birth to at least the end of the first lactation and should involve all of the nutrition, management and environmental factors associated with this lengthy phase of the animal’s life.

Economics, Growth Management, and Within Herd Evaluation

Economics.

Most data indicates that the cost of rearing replacements constitutes 15 to 20% of the total costs on dairy farms. Age at first calving is the single most important variable influencing costs associated with raising heifers (Cady and Smith, 1996). Age at first calving could also be considered total days on feed and is a function of the rate at which breeding weight and conception is achieved. Once the animal is pregnant, total days on feed is fixed. Costs associated with total days on feed include feed, labor, housing, and machinery, interest on investment, breeding and health, bedding and death loss. Thus if we are to reduce the costs associated with heifer rearing, we have two alternatives: decrease the age to first calving or, since feed constitutes 60% of the costs, find alternative low cost feeds that still meet the requirements of the animal. Since there is not a significant supply of low cost feeds universally available, we will focus on the reduction in AFC.

Commercial heifer raisers in New York are currently charging from $1.65 to $2.00 per day to raise replacement heifers. We are assuming they have built some profit margin in to those charges, and those profits could be available to individual producers if they reared heifers with the same management inputs. Using an average of those costs ($1.80 per day), lowering the AFC one month reduces rearing costs by $50 to $60 per heifer. In addition, the average net farm income (NFI) per lactating animal in NY State in 1999 was $452 (NY Dairy Farm Business Summary, 1999). So, under the current economic conditions a decrease of one month in the AFC in effect increases the NFI per heifer by approximately 12%.

Growth Management.

From our perspective if we are to use the term “accelerated growth”, it includes several factors primary of which is the development of a system that from day of birth sets targets or goals through the end of the first lactation so there are no breaks in the management that detract from a previous phase of development where all targets were met. The management targets for growth should reflect what we understand about the biology of growth of the heifer. Kertz et al. (1998) demonstrated that 58 to 60% of linear growth (height) occurs during the first 12 months of life and concluded that “increases in relative BW and wither height are most rapid and cost efficient during the first 6 months of life.”

Puberty is a function of BW not age and in Holsteins can occur by 280 kg and reflects physiological maturity. At the time puberty occurs, the rate of lean tissue (muscle and bone) deposition decreases while the rate of fat deposition increases. An understanding and application of this biology indicates that delaying breeding due to age related decisions could be detrimental to proper calving weight and body composition assuming a constant growth rate. For example, a manager might decide to invest extra feed and labor in the calves during the milk feeding and weaning phase with the desire to establish a growth rate capable of achieving puberty and breeding weight by 10 months of age. However, if the breeding weight is then ignored or not properly identified, the system breaks down because the extra 3 to 5 mo. of growth at the end of the gestation period will be predominantly fat deposition. What was gained early in life might actually be detrimental in the end due to an over-accumulation of fat in the heavier, older heifers that didn't become pregnant based on their physiological maturity. This accumulation of added fat or increased condition score might then negatively impact first lactation milk production (Hoffman et al, 1996; Radcliff et al., 2000).

Within Herd Evaluation.

Another potential break in the system could come from calving in heifers of a younger age and potentially lighter post-calving BW than what was traditionally done in a particular management system. In this scenario, the lighter, younger heifers require a nutrition and management "package" that is tailored to their ability to consume DM and the requirements for both growth and lactation, since requirements for growth have a priority over lactation in this animal. This scenario is illustrated in Table 2 (Corwin Holtz-personal communication).

Table 2. A four-year, retrospective within-herd evaluation of the effects of age at first calving on the number of lactations and lifetime milk production of heifers within the herd. Notice that heifers calving at greater than 25 months of age produced similar amounts of milk to those calving at less than 23 months of age. (Data courtesy of Corwin Holtz).

Number heifers	Age at calving, mo	Lifetime lactations	Lifetime milk, kg
51	21	2.4	21,506
146	22	3.1	31,488
156	23	3.7	38,662
48	24	3.2	36,454
38	25	3.2	32,350
39	26	2.3	21,642
22	27	2.1	20,125

The data in Table 2 represent a historical perspective of production responses of heifers in one NY dairy herd of approximately 800 lactating cows relative to the AFC of the heifers. The data was taken from the on-farm record keeping system Dairy Comp 305, but could be generated from any Dairy Herd Improvement data set. It is important to note this is a within-herd evaluation which implies the same type and level of management was applied to all of the animals regardless of AFC. Heifers that calved at less than 23 mo. of age did not perform as well as those that were 23 to 25 mo. of age. Surprisingly, heifers that calved at ages greater than 25 mo. did no better than heifers calving at less than 23 mo. and demonstrated that within this herd, there was no advantage to calving older, heavier heifers. From an economic perspective there is an obvious and distinct advantage to calving the heifers at an earlier age. Production aside, within this herd, if we evaluate the cost savings of decreasing the AFC of the heifers from 26.5 to 21.5 mo. (average value at the extremes), the five mo. decrease in AFC is worth $275 per heifer in reduced rearing costs. If we take a weighted average of the milk yield of the animals calving at less than 23 mo. and greater than 25 mo., the heifers calving early produced approximately 8,000 kg more lifetime milk. The financial advantage becomes very obvious because there was a double financial penalty for calving heifers at the ages greater than 25 mo.; there was the extra cost to rear them and a decreased lifetime production.

Ideally the farm advisor or herd owner should do an analysis of this type to identify those factors that contribute to the success of the animals calving at 23 to 24 mo. of age. In the above situation, the farm was expanding and was approximately 30% overcrowded with no grouping strategy other than “high cows” and “low cows”. In this herd the younger animals were lighter and less able to compete with the more mature cattle. The diet that was available did not meet their requirements for nutrient density and thus they could not consume enough dry matter and nutrients to meet the requirements for growth and lactation. This doesn’t mean that the heifers calving at less than 23 mo. couldn’t, under any circumstances, make similar amounts of milk and survive in the herd; they just couldn’t do it under those management and environmental conditions. To make the younger heifers more profitable in this situation, a separate group and ration strategy exclusive to first lactation animals would be necessary. However, the tendency when confronted with this stopgap management necessity is to just blame the animal response on the fact that they calved in at a young age and not that the management was not appropriate for the animal.

The heifers that calved at 25 to 27 mo. tended to be the heifers that were either unhealthy as calves or were bred numerous times in an effort to achieve pregnancy and were of a higher body condition score at calving. Assuming a 21-day reproductive cycle and 100% heat detection efficiency, three additional services would increase the AFC by at least 63 days. Thus, putting an upper limit on how many services were acceptable, relative to investment costs and milk production, was imperative to this herd and the paradigm that every heifer was worth keeping was altered.

Is this situation typical of all herds? We don't know, however, we do know that the relationship is not the same for all herds and that different management decisions and inputs will affect the production responses. To make an accurate assessment, the evaluation should be done on a within herd basis so you can evaluate the effect within your own management and environment conditions. Standard recommendations concerning the appropriate AFC may not be appropriate for all farms. Hopefully this discussion illuminates the idea that "accelerated growth" is not just growth rate and nutrition and that the **management of the system** has to accommodate all of the changes that are required to make the heifer program more profitable.

▪ Mammary Development, Applied Growth Biology and Nutrient Requirements

Mammary Development.

Previous work suggests that the primary effect of accelerated growth was reduced mammary development (Sejrsen et al., 1982; Sejrsen et al., 2000) and the inference has been made that heifers with reduced mammary development couldn't synthesize similar amounts of milk. Recent studies utilizing Holsteins of high genetic merit for milk that evaluated the effects of "accelerated growth" on first lactation milk yield have demonstrated a 5 to 8% reduction in first lactation milk yield (Hoffman et al., 1996; Lammers et al., 1999; Radcliff et al., 2000; Van Amburgh et al., 1998).

The Capuco et al. (1995) data set suggests that reduced mammary development is not the only significant factor affecting first lactation milk yield (Table 3). Their data are the only published data with cohort animals that were slaughtered at a particular stage of puberty while the rest went on to lactation. There was an approximately 50% reduction in mammary development in one of the treatment groups of slaughtered heifers, but no significant difference in first lactation milk yield in animals that continued on and completed a lactation from the same group. This suggests that mammary development per se is not an issue, but that accumulated fat in general and the composition of the body at calving might play a larger role in first lactation milk yield than does mammary development. If we slaughter animals at puberty, the best we can do is draw inference to what we believe the outcome would be during lactation. Based on the data of Hoffman et al. (1996), Radcliff et al., (2000) and Van Amburgh et al., (1998), we can make reasonable inference that the composition of the heifer at calving is as important a factor as mammary development has historically been. Under normal management conditions, if heifers accumulate fat at any point in their growth phase, that fat is most likely not mobilized until lactation is initiated. An exception might be pasture fed animals that experience fluctuations in forage availability through the growing season. Without good slaughter data through the entire phase of growth, this is difficult to quantify.

Table 3. Effect of prepubertal growth rate in Holstein heifers fed diets consisting of alfalfa or corn silage for two rates of daily live weight gain on mammary development and first lactation milk yield.

	Alfalfa diets		Corn Silage diets	
Level of intake	**Low**	**High**	**Low**	**High**
Body wt at slaughter, kg	335	338	329	331
Average daily gain, kg/d	0.77	0.97	0.79	1.01
Average treatment diet CP, % DM	22.5	22.5	14.6	14.9
Mammary DNA, mg/100 kg BW	566	530	613	317[a]
Mammary RNA, mg/100 kg BW	363	325	401	206[a]
4% Fat corrected milk yield, kg/d	22.8	21.4	24.0	22.6

[a]Values significantly different ($P < 0.05$).

Applied Growth Biology and Nutrient Requirements

Consistent with the concept that lowering the AFC is the most significant means of reducing the cost of raising heifer replacements, our group made several observations in 1996 that precipitated a series of ongoing experiments that will be discussed in the remainder of this paper. Without significant referencing, those observations were:

- Studies that had investigated pre-pubertal “accelerated growth”, in an effort to lower the AFC, started treatments well into the ruminant phase of growth and as late as 8 months of age. Thus, a significant amount of time and opportunity might have been lost with regard to lowering the AFC. Additionally, early postnatal growth is the most efficient time to deposit protein and develop skeletal growth.
- Recent evaluations of nutrient requirements for Holstein heifers suggested that our current system of equations did not adequately represent the composition of gain and thereby underestimated the energy and protein requirements for growth during the pre-pubertal phase of life. Further, this inability to meet the “true” requirements might have confounded our expectations and interpretation of accelerated growth studies.
- On-farm management of calf rearing typically followed nutrition programs developed for early weaning and thus restricted liquid feeding levels in an effort to encourage dry feed intake. Consideration of this practice, in light

of the 1996 National Animal Health Monitoring Service (NAHMS) data indicating that neonatal calf mortality was greater than 10%, led us to think about calf raising from a different perspective. The paradigm shift revolved around the following questions: 1) do standard calf nutrition programs contribute to the observed morbidity and mortality and 2) is the practice of restricting liquid feed intake the most biologically sound approach to achieving calf growth and health?

- We know of no other neonatal system that is successful at enhancing future productivity by restricting milk intake in an effort to force weaning, humans included.

Based on these observations we proposed and have conducted several studies to more clearly elucidate the energy and protein requirements for tissue growth from birth to approximately 105 kg of body weight (BW). In addition we have explored the relationship between amount and type of nutrient intake and the functioning of the somatotropic (ST) axis. Finally, we have begun to evaluate the role of nutrition in the development of the immune system in order to determine what role specific nutrient supply has on immune competency.

▪ Growth Studies

In the first study (Diaz et al., 2001; Smith et al., 1998), sixty calves were assigned randomly among three treatments (TRT) after a three to five day period of adjustment. Treatments were designed to achieve three targeted daily rates of LWG (TRT 1 = 500, TRT 2 = 950 and TRT 3 = 1400 g) (Table 4). There is an interpretation here that is important to understand. In order to conduct a study of this nature there must be a range in slaughter weights and growth rates to have enough animals and variation represented to develop mathematical equations that can be used with other populations across a range in growth rates and BW. This should not be interpreted as a study focusing on “accelerated growth.” However, the study did reveal the growth potential of calves under good management conditions. This might then be applied as a program which challenges producers to set new goals for their calf rearing programs.

The milk replacer (MR) (Milk Specialties Co., Dundee, IL) was formulated to contain 30% CP and 20% fat (DM basis) (Table 4). The MR was an all-milk protein formulation. This dietary CP content was selected based upon previous studies (Donnelly and Hutton, 1976a,b; Gerrits et al., 1996) that indicated a plateau in daily protein accretion might be achieved at near maximal DMI with a CP concentration of 30%. The goal of the diet formulation was to ensure that protein would not be the most limiting nutrient. The initial estimated energy requirements were derived from the available data (Donnelly and Hutton, 1976a,b; Gerrits et al., 1996; NRC, 1989; NRC, 1996). The vitamin and mineral contents of the MR were formulated based upon the expected amount of DMI, thus their concentrations were decreased in TRT 2 and 3 to prevent excessive intake.

Table 4. Chemical composition of milk replacer fed to calves at three levels of intake in the study of Diaz et al.[1].

Component	Treatment 1	Treatment 2	Treatment 3
DM, %	96.20	95.80	96.00
Protein, % of DM	31.20	29.48	30.56
Fat, % of DM	19.97	20.96	20.18
Lactose, % of DM	42.90	43.40	42.96
Ash, % of DM	5.90	6.10	6.30
Calcium, % of DM	1.10	1.03	1.24
Phosphorus, % of DM	0.71	0.70	0.77
Gross energy, kcal/g	4.97	5.19	4.92
Vitamin A[2], KIU/kg	60.00	30.00	15.00
Vitamin D_3[2], KIU/kg	20.00	15.00	10.00
Vitamin E[2], IU/kg	200.00	150.00	100.00

[1] Each treatment represents a separate batch of milk replacer.

[2] Vitamin levels were the formulated levels and were based on the expected level of DMI (1, 3 and 4% of BW per day for treatment 1, 2 and 3, respectively) necessary to achieve the target growth rates.

The calves assigned to TRT 1 and 2 were fed their respective MR reconstituted to 15% DM; TRT 3 calves received MR reconstituted to 18% DM. Calves were fed individually in buckets three times per d (0700, 1400 and 2100 h) and water was offered for ad libitum intake throughout the study. No dry feed was offered. Indices of calf health were monitored and recorded several times per day. Since all calves remained generally healthy and there were no differences among treatments, no health data will be presented.

On the same set of calves we simultaneously investigated the relationship between DMI, growth rate and the development of the ST axis. We were interested in determining how early in life the ST axis is expressed and functional. To test functionality we administered exogenous somatotropin (bST) (120 μg/kg BW) for 3 days prior to slaughter and then sampled plasma and various tissues for analyses of IGF-I and messenger RNA for IGF-I and the ST receptor.

Significant findings from these studies were:

- Growth rates of calves fed a milk replacer that more closely meets their requirements are difficult to control; calves have a tremendous capacity for growth.
- Calves fed a MR mixed at a lower dilution rate (18%) at less than 14 days of age have difficulty consuming adequate dry matter in order to meet specific growth targets (Table 5). Dilutions to 15% solids appear to be more acceptable at early ages.
- Feed efficiencies were relatively high compared to traditional on farm efficiencies, most likely a result of more adequate protein levels that allowed for greater protein deposition, levels of DM intake well above maintenance and no transition to dry feed during the course of study (Table 5).
- Composition of gain of calves on this study differed from that predicted by either the 1989 Dairy or 1996 Beef NRC equations (Table 6) and this has significant implications for proper growth and development of replacement heifers.

Table 6. Comparison of observed energy and protein retained, and composition of gain in calves in the study of Diaz et al. with prediction equations used in the 1989 Dairy (NRC,1989) and 1996 Beef NRC (NRC, 1996)[1].

	Retained Energy, (Mcal/d)			Retained Protein, (g/d)		
	Observed	**Predicted Dairy**	**Predicted Beef**	**Observed**	**Predicted Dairy**	**Predicted Beef**
Treatment 1	1.17	1.17	0.92	136.9	98.8	130.0
Treatment 2	2.48	2.12	1.72	199.4	160.6	213.1
Treatment 3	2.82	2.45	2.01	244.4	183.3	244.0

[1] The weight and weight gain units for the equations are kg. The prediction of retained protein utilized the actual energy value of the gain of the calves on study as determined by bomb calorimetry.

- Increased MR feeding did not result in any observable negative health consequences, which suggests our management was adequate and that the MR was formulated properly to allow for adequate digestibility. We believe data indicating that general health is decreased and scours are increased with increased liquid feed intake are related to lapses in management or are observations made from older data where milk replacer manufacturing methods were not as refined as they are today.

Table 5. Body weights, feed intake and growth performance of calves fed three levels of milk replacer and slaughtered at three different body weights in the study of Diaz et al.

	Treatment 1			Treatment 2			Treatment 3			
N	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**6**	**SE**^{1}
Target slaughter weight, kg	65	85	105	65	85	105	65	85	105	
Birth weight, kg	44.7	44.8	47.8	44.4	45.2	44.5	45.8	44.0	44.0	1.27
Actual slaughter weight, kg	65.5^{a}	85.0^{b}	105.5^{c}	68.0^{a}	86.0^{b}	102.5^{c}	68.0^{a}	84.0^{b}	104.0^{c}	1.26
Days on treatment	40.0^{a}	67.0^{b}	98.5^{c}	25.0^{a}	39.0^{b}	62.0^{c}	24.0^{a}	34.0^{b}	50.0^{c}	1.94
Total DMI, kg	32.0^{a}	59.6^{b}	88.9^{c}	30.0^{a}	57.8^{b}	95.0^{c}	27.0^{a}	50.3^{b}	84.5^{c}	3.54
Daily DMI, kg	0.80^{a}	0.89^{b}	0.90^{b}	1.20^{a}	1.48^{b}	1.53^{b}	1.13^{a}	1.48^{b}	1.69^{c}	0.01
DMI, % of BW	1.62^{a}	1.44^{b}	1.23^{c}	2.46^{a}	2.45^{a}	2.15^{b}	2.39^{a}	2.67^{b}	2.48^{c}	0.05
Gain to feed	0.65^{a}	0.65^{a}	0.42^{b}	0.57^{a}	0.60^{b}	0.62^{b}	0.78^{a}	0.76^{a}	0.70^{b}	0.03
ADG, g/d	0.52^{a}	0.60^{a}	0.59^{a}	0.94^{ab}	1.04^{b}	0.94^{a}	0.93^{a}	1.17^{b}	1.21^{b}	0.04
Plasma urea nitrogen^{8}**, mg/dl**	12.0^{a}	9.3^{b}	10.2^{c}	12.5^{a}	13.1^{b}	9.4^{c}	10.1^{a}	12.4^{b}	10.2^{a}	1.29

[1] SE = Standard error of the mean. [2] Treatment. [abc] Values with different superscripts differ ($P < 0.05$) by slaughter weight within treatment.

- The ST axis is functional as early as 21 days of age and is responsive to plane of nutrition (Table 7). This is significant in that it demonstrates normal regulation of endocrine and possibly paracrine signals of growth early in life. This raises the question of whether traditional feeding strategies on-farm applied with conventional nutrient densities in our industry standard MR are adequate to allow full expression of the ST axis.

Table 7. Calf plasma insulin-like growth factor-I concentrations expressed in ng/ml from the study of Smith et al., 1998. Pre-challenge samples were taken four days prior to slaughter. Pre-challenge samples were taken either 14- or 24-hr after the third daily bST injection.

		Target daily gain (g/d)		
Plasma IGF-I values (ng/ml) summarized over all slaughter weights (65, 85, 105 kg)		500	950	1,400
	Pre (baseline)	143	243	267
	Post 14-hour	293	500	527
	Post 24-hour	230	367	430

- Our data suggest that the protein requirement is not fixed and that the level of energy intake drives the requirement for protein. Equations generated from this data indicate that to meet the energy allowable protein requirement when calves are gaining in excess of 0.7 kg/d, the protein content of the diet must be at least 26 to 28% CP on a DM basis. This is in agreement with levels predicted in a summary of the literature (Drackley, 2000). Drackley’s review suggested that the minimum level of protein required to meet maintenance requirements and 0.25 kg/d gain is 18.1% on a DM basis (Table 8). Higher protein content would be necessary to achieve higher rates of gain without increased fat deposition.

Table 8. Effect of rate of body weight gain with constant initial body weight (100 lb) on protein requirements of pre-weaned dairy calves from literature data (adapted from Davis and Drackley, 1998) (From Drackley, 2000).

Rate of gain (lb/d)	ME, (Mcal/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
3.00	6457	350	3.12	27.6

[1] Amount of milk replacer DM containing 2075 kcal ME/lb DM need to meet ME requirements.

A subsequent study by Tikofsky et al., (2000) was conducted to determine the effect of varying levels of dietary fat and carbohydrate for dairy calves fed under isocaloric and isonitrogenous intake conditions. Furthermore, to assess this potential effect under conditions where calculated protein intakes as a function of the energy intake are not considered to be limiting growth (Davis and Drackley, 1998; Diaz, et al., accepted). Previous work was confounded by the variation of fat and or protein levels, without appropriate adjustments to DMI, which created dietary regimens that were not isocaloric or isonitrogenous. This lack of control confounds interpretation of the primary effect of fat or carbohydrate on the efficiency of use of the energy source on growth rate or body composition.

The receiving protocol was similar to the study of Diaz et al. Milk replacer formulations were manufactured according to protein and fat specifications determined by the investigators so that target DMI for each treatment would enable isocaloric and isonitrogenous intake conditions among treatments (Table 9). Treatment diets consisted of three specially formulated MR (Milk Specialties, Co., Dundee, Ill.). The protein content of all MR was derived from all-milk sources, and the fat content was primarily tallow. Fat and lactose content of all diets was formulated to deliver treatments that are defined as low fat, high lactose (LF); medium fat, medium lactose (MF); and high fat, low lactose (HF). Dry matter intake for calves on all treatments was calculated to deliver 0.24 Mcal/kg $BW^{0.75}$ for treatment d 1 through 14, and then increased to 0.28 Mcal/kg $BW^{0.75}$ from d 15 until final slaughter weight was reached. Targeted energy intakes for individual calves were adjusted every 7 d based on changes in animal weight. Dry matter intake targets were intended to create isocaloric and isonitrogenous dietary intake conditions. Free choice water was offered at all times. Dry feed was not offered.

Table 9. Milk replacer diet specifications on a dry matter basis for calves fed on the study of Tikofsky et al.

	Low fat	Medium fat	High fat
Dry matter	97.2	96.9	96.3
GE[a], Mcals/kg DM	4.62	5.09	5.77
Protein, % DM	23.54	24.80	27.00
Fat, % DM	14.79	21.62	30.62
Lactose[b], % DM	55.29	46.69	35.36
Ash, % DM	6.37	6.89	7.02
Ca, % DM	0.83	0.92	1.01
P, % DM	0.67	0.73	0.74
Vitamin A, KIU	16,500	18,117	20,060
Vitamin D, KIU	5,883	6,039	6,686
Vitamin E, IU	110	121	134

[a] Gross energy. [b] Lactose determined by difference.

Mean slaughter weights and days on treatment are shown in Table 10. Mean days on treatment were similar for calves among treatments (*P* = 0.9). Mean initial BW and mean final BW were similar among treatments (*P* = 0.83 and 0.91, respectively), and consequently average rate of BW gain was similar among treatments (*P* = 0.66). Gross energy and protein intakes of MR diets are shown in Table 3. No differences were detected for protein intake (*P* = 0.79), and GE intake (*P* = 0.63), thereby sustaining the desired effect of isocaloric and isonitrogenous intakes among treatments. There was a higher intake of fat as fat percentage in the diets increased from LF to HF (*P* = 0.001). Compositional results are shown in Table 11. Results expressed as a percentage of whole EB demonstrate the same pattern as weight results for all measured components. However, in this analysis it is apparent that water, as a percentage of whole EB, is different between the LF and HF treatments (*P* = 0.04). Therefore, means of dry EB composition among treatments were analyzed to determine if there was a tendency for a lower fat diet to promote the development of a leaner animal. On a water-free basis, protein and fat content of the dry EB composition were different between LF and MF, and LF and HF treatments (*P* = 0.006 and 0.003, respectively). Therefore, animals on LF deposited less fat resulting in the development of leaner animals.

Table 10. Days on treatment, initial and final full body weight, average daily gain for all treatments and calculated dry matter intake and measured intakes of GE[a], protein and fat for calves on the study of Tikofsky et al.

	Low fat	Medium fat	High fat	SEM	P
n	**8**	**8**	**8**		
Days on treatment	54.6	56.1	55.1	1.318	0.90
Initial body weight, kg	47.6	47.3	46.2	0.988	0.83
Final body weight, kg	86.0	85.5	85.4	0.587	0.91
Average daily gain, kg	0.71	0.68	0.71	0.014	0.66
Dry matter intake, kg	55.2^{x}	52.8^{xy}	46.8^{y}	1.13	0.02
GE intake, Mcals	257.6	268.8	270.3	5.82	0.63
Protein intake, kg	13.0	13.1	12.6	0.281	0.79
Fat intake, kg	8.16^{x}	11.41^{y}	14.33^{z}	0.270	0.001

[a] Gross energy.

^{x,y,z}Values with different superscripts are statistically different. Fisher's pairwise comparison used to determine differences between treatment means (individual error rate = 0.025). ANOVA used to calculate overall *P*-value from F-statistic.

Table 11. Whole empty body (EB) and dry EB composition

	Low fat	Medium fat	High fat	SEM	P
Whole EB composition					
EB protein, %	17.54	17.21	17.38	0.151	0.69
EB fat, %	8.48^{x}	9.91^{y}	11.0^{y}	0.253	0.002
EB ash, %	3.63	3.42	3.33	0.086	0.37
EB water, %	70.33^{x}	69.43^{xy}	68.25^{y}	0.307	0.04
Dry EB composition					
EB protein, %	59.18^{x}	56.42^{y}	54.85^{y}	0.498	0.006
EB fat, %	28.58^{x}	32.36^{y}	34.63^{y}	0.628	0.003
EB, ash %	12.24^{x}	11.23^{xy}	10.53^{y}	0.275	0.06

^{xy}Values with different superscripts are statistically different. Fisher's pairwise comparison used to determine differences between treatment means (individual error rate = 0.025). ANOVA used to calculate overall *P*-value from F-statistic.

Significant results from the study of Tikofsky et al. (2000):

- Treatments remained isocaloric and isonitrogenous throughout the course of the study, thus providing us with better interpretive data than previous studies.

- Increasing the level of carbohydrate (~55%) and lowering the fat (~15%) to levels within this experiment was not detrimental to digestive capacity and suggests that there is a critical upper level of carbohydrate intake that affects digestion and scours, which was not reached in this study.
- Although diet composition was dramatically different, when fed under iso-caloric and iso-nitrogenous conditions, daily growth rate was not different.
- Increasing dietary fat intake increased body fat deposition and did not affect protein retention.
- Under conditions of iso-caloric and iso-nitrogenous intake, body composition could be altered by diet composition, independent of growth rate; therefore rate of gain should not be a sole means of assessing the efficacy of a nutrition regimen for milk replacer-fed calves.

Based on the results of the study by Smith et al. (1998), a follow-up study was conducted to determine if calves fed and industry standard milk replacer (20% CP: 20% fat) at conventional rates (1.4% BW DM per day) developed an active ST axis compared to calves fed a higher protein (30% CP: 20% fat) milk replacer at 2.4% BW DM per day (Bork et al., 2000). Calves were fed twice daily and weighed twice weekly. Intake was adjusted weekly. No dry feed was offered. Additionally, blood was sampled weekly and sent to Dr. Brian Nonnecke at the National Animal Disease Center in Ames, Iowa for evaluation of immune competency. Separate blood samples were taken weekly for analyses of plasma urea nitrogen, IGF-I and other metabolites.

Growth rates were significantly different between treatments and were directly related to DM intake (Table 12). There was a 39 kg weight and 9.1 cm hip height advantage at the end of 63 days of treatment for calves fed at 2.4% BW DM. Calves fed under a more conventional system did not respond as well to a bST challenge at 5 weeks of life as those fed an accelerated amount of milk replacer. Basal circulating levels of IGF-I were 78 ng/ml for the conventionally fed calves (TRT 1) and 152 ng/ml for the “accelerated” fed calves. Post bST injection IGF-I levels were 109 ng/ml for the conventionally fed calves ($P < 0.06$) and 215 ng/ml for the “accelerated” fed calves ($P < 0.001$). A surprising observation was the 0.42 kg/d increase in growth rate observed on the TRT 2 calves the week following the bST challenge. There was no change in DMI during that period. The implication of this study is that current strategies for calf nutrition might not allow for normal expression of growth via the ST axis. In lactating dairy cattle this same condition would be considered very poor nutritional management. It is interesting to note that the plasma IGF-I levels correlated 0.97 with growth rate in the TRT 2 calves but the correlation in the TRT 1 calves was less than 0.7.

Table 12. Birth weight, final weight, average daily gain and dry matter intake of calves fed to achieve two levels of performance on the study of Bork et al. (2000).

	TRT 1 (conventional)	TRT 2 (accelerated)	S.E.	P value
Birth weight (kg)	46	46	1.3	0.9438
Final weight (kg)	74	113	3.9	0.0001
ADG (kg/day)	0.44	1.1	0.04	0.0001
DM intake (% BW)	1.4	2.4	*	*

Data on the effects on the immune system are still developing but suggest that higher levels of intake early in life have positive effects on the maturation of the immune system (Nonnecke, et al., 2000). Previous data have indicated that lower levels of intake can impair the responses of the immune system in neonatal calves (Williams, 1981; Pollack et al., 1993, 1994).

▪ Integration

Not surprisingly, one of our most relevant discoveries was the imperative link between the realization of the calf's biological potential and the systematic management of nutrient delivery. In other words, not only did we discover that the nutrient requirements used for current calf feeding systems are poorly described, but it became clear that calf management practices had adapted themselves to a set of practices far from what would be considered biologically normal. Dr. Jim Drackley (2000) and colleagues have been conducting similar research and have also discussed the contrast between that which is "normal and accepted" by current standards and what we understand to be normal by biological standards. Therefore, as we recommend the use of more accurately described nutrient requirements for growing calves; we must also recommend adjustments to current management protocols so that optimization of growth is a systematic integration of nutrients and nutrient delivery. Application of biological principles is not "plug-and-play" technology; more accurately described nutrient requirements of growing calves cannot be met by "conventional" calf management practices.

The data generated allows us to develop nutrition programs that can enhance not only growth rate but deliver what we consider to be more appropriate body composition early in life. With this increased understanding comes the ability to improve on-farm management of calf programs. Recent work has suggested that the mammary gland of replacement heifers is not affected by growth rates up to 100 kg BW (Sejrsen et al., 2000) so that issue should not be a concern for this early stage of growth. Based on the endocrine responses (i.e. increased responsiveness to bST challenge and higher basal circulating levels of IGF-I), more biologically normal growth appears to be in excess of our current industry practice for the first 6 to 8 weeks of life. We have developed weaning programs and diet formulations that enhance growth rates through this approach to feeding calves. Subsequently, further work is currently underway to determine if the application of this information will enhance lifetime profitability. It is apparent from all this research that a systematic approach to calf rearing is necessary to optimize the development of replacement animals so that the pitfalls of accelerated growth—or the uncoupling of applied growth biology from management—might be avoided.

▪ References

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. 83:143 (abstr.).

Cady, R.A. and T.R. Smith. 1996. Economics of heifer raising programs. Proceedings from the Calves, Heifers and Dairy Profitability National Conference. January 10-12, 1996.Harrisburg, PA. NRAES Publ. 74. Ithaca, NY.

Capuco, A.V., J.J. Smith, D.R. Waldo, and C.E. Rexroad. 1995. Influence of prepubertal dietary regimen on mammary growth of Holstein heifers. J. Dairy Sci. 78:2709.

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. In press.

Donnelly, P. E. 1983. Effects of dietary carbohydrate:fat ratio on growth and body compositionof milk-fed calves. N. Z. J. Agric. Res. 26:71-77.

Donnelly, P. E. and J. B. Hutton. 1976a. Effects of dietary protein and energy on the growth ofFriesian bull calves. I. Food intake, growth, and protein requirements. N. Z. J. Agric. Res. 19:289-297.

Donnelly, P. E. and J. B. Hutton. 1976b. Effects of dietary protein and energy on the growth of Friesian bull calves. II. Effects of level of feed intake and dietary protein content on body composition. N. Z. J. Agric. Res. 19:409-414.

Drackley, J. K. 2000. Calf nutrition related to heifer growth and longevity. Pp. 153-168. Proc. Minnesota Nutrition Conference. Department of Animal Science, University of Minnesota.

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

Hoffman, P.C. N. M. Brehm, S. G. Price, and A. Prill-Adams. 1996. Effect of accelerated postpubertal growth and early calving on lactation performance of primiparous Holstein heifers. J. Dairy Sci. 79:2024-2031.

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.

Lammers, B. P., A. J. Heinrichs, and R. S. Kensinger. 2000. The effects of accelerated growth rates and estrogen implants in prepubertal Holstein heifers on estimates of mammary development and subsequent reproduction and milk production. J. Dairy Sci. 82:1753-1764.

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. 83:135 (abstr.).

National Research Council. 1989. Nutrient Requirements of Dairy Cattle. Natl. Acad. Sci., Washington, D. C.

National Research Council. 1996. Nutrient Requirements of Beef Cattle. Natl. Acad. Sci., Washington, D. C.

Pollack, J.M., T.G. Rown, 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.

Pollack, 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.

Radcliff, R. P., M. J. Vandehaar, L. T. Chapin, T. E. Pilbeam, D. K. Beede, E. P. Stanisiewski, and H. A. Tucker. 2000. Effects of diet and injection of bovine somatotropin on prepubertal growth and first lactation milk yields of Holstein cows. J. Dairy Sci. 83:23-29.

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

Smith, J.M., M. C. Diaz, M. E. Van Amburgh, D. E. Bauman, and M. C. Lucy. 1998. Ontogeny of the somatotropic axis in milk-fed bull calves between birth and 105kg. Pp. 119-129. Proc. Cornell Nutr. Conf., Cornell University, Rochester, NY.

Tikofsky, J.N, and M. E. VanAmburgh. 2000. Effect of varying carbohydrate and fat levels on body composition of milk-fed calves. Pp. 239-250. Proc. Cornell Nutr. Conf., Rochester, NY.

VanAmburgh, M. E., D. M. Galton, D. E. Bauman, R. W. Everett, D. G. Fox, L. E. Chase, and H. N. Erb. 1998. Effects of three prepubertal body growth rates on performance of Holstein heifers during first lactation. J. Dairy Sci. 81:527-538.

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.

◆