Calf Growth and Development: New Requirements and Implications for Future Performance

Mike Van Amburgh,
Departments of Animal Science
Cornell University

Abstract

Since the inception of milk replacer and our understanding of rumen development, calf nutrition programs have been developed to minimize liquid feeding in an effort to reduce cost and decrease the time to weaning. This approach has been widely adopted over the last 50 years, however it does not represent the systematic approach we as an industry have developed and adopted with every other class of growing cattle. A re-evaluation of our calf programs suggest that new nutritional management guidelines should be developed in an effort to improve calf growth and survivability. New tools are available to help us make more systematic decision about calf nutrition and data are available that suggest what we do in the first few weeks of life will have long-term impacts on animal productivity.

Introduction

From the perspective of a nutritionist, one of the most over-looked groups of animals on a dairy farm has been the milk-fed and transitional calf. There are several reasons for the lack of a mechanistic approach to "ration formulation" for the young calf, primary of which has been the unavailability of tools for calculating nutrient requirements and supply. With the release of the 2001 National Research Council Nutrient Requirements of Dairy Cattle, a more useful approach to feeding calves has been developed. The new Dairy NRC (National Research Council, 2001) employs a more mechanistic approach to calf growth and development than previously utilized in the United States, and with adoption of the system the industry will be encouraged to re-evaluate the one-size fits all approach to calf feeding that currently exists.

The objectives of this paper will be 1) to review current feeding recommendations published by manufacturers of milk replacers and evaluated by the new 2001 Dairy NRC, 2) to describe new body composition research and implications for that research, 3) discuss data that indicates that calf management in the first few weeks of life is beneficial for long-term productivity and 4) share some preliminary data that describes our experience with both a more intensified calf feeding system and the adoption of the target growth system.

Milk replacer formulation and feeding guidelines have been developing on a widespread, commercial basis since the 1950s. Roy (1964) examined the origins of commercial milk replacer and clarified the context in which developments like fat concentration, ingredient choices, and feeding practices were made. It is clear from the review of Davis and Drackley (1998) that considerable research has been completed over the last 50 years to elucidate the specific nutrient requirements of the young calf, as well as the potential benefits (or risks) of various feeding practices. It is therefore logical to assume that the advances in this nutrition technology would be subsequently reflected in the feeding instructions used to tag calf milk replacer products developed for and by the dairy industry.

However, the results of our investigation of milk replacer products currently on the market illustrate that technological advances of the last 50 years are not well represented by current industry recommendations. Our field observations, as well as the market research results of large milk replacer manufacturers, indicate that calf raisers are unaware of the disconnect in the research and development of a system because while adhering to the old paradigms of minimized liquid feed intake they continue to complain about animal performance, including growth and health.

Likewise, dairy calf raisers should be encouraged to adapt their feeding practices to allow for significant changes in management so that implementation of a more systematic approach may yield economically beneficial results. An assessment of economic feasibility should be based not only on the investment in heifer rearing, but also on the return on that investment. It has been recognized that replacement heifer management decisions interact with the biological aspects of growth, thereby influencing the future profitability of the heifer (Mourits, M. 2000; Quigley et al., 1996). It is intuitive that the biologically correct growth system is the best method for the rearing of an animal of any species. If "biologically correct" does not equate to "economically optimal", then we would argue that there is a bottleneck in the management system.

Evaluation of Current Feeding Practices

The following examples are used to demonstrate labeled feeding rates for a group of randomly selected commercially available milk replacers. For this exercise we fed an example calf with the 2001 Dairy NRC Model (National Research Council, 2001) according the feeding instructions provided by the milk replacer manufacturer on the product tag. For this exercise calves were characterized in the following way:

1) Twelve to fourteen days of age **-** It is reasonable to believe that by this stage of development a calf is more than capable of the dry matter intake specified by label recommendations, but she is not likely be consuming a quantity of starter grain sufficient to contribute to an appreciable amount of metabolizable energy.

2) One hundred pounds body weight **-** average Holstein calf birth weights are between 86 and 95 lb (Diaz et al., 2001, Tikofsky et al., 2001), and calves generally do not gain a significant amount of weight in the first two weeks of life due to a variety of challenges including health, environmental change, and nutrient intake.

All of the milk replacers were made from all milk protein sources. The 2001 Dairy NRC uses metabolizable energy (ME) and apparently digestible protein (ADP) as the respective energy and protein "currencies" which is a welcome departure from previous approaches. Based on the energy and protein allowable gains presented in Table 1, the goal as described by the feeding instructions of these samples of standard milk replacers (A, B, C, and D) is some production level between a near-maintenance gain of 0.22 lb/d and 0.88 lb/d assuming a thermo-neutral environment. These expected gains are consistent with research observations (Diaz et al., 2001, Bartlett, 2001). Evaluations of milk replacers E and F demonstrate energy and protein allowable gains between 1.65 and 2.00 lb/d, and an acceptable balance between the energy and protein allowable gain, unlike the previous milk replacers.
From a systematic perspective, setting manageable targets for both weaning weight and feed efficiency would indicate that milk replacers E and F are more appropriately labeled and formulated for meeting those goals.

The requirement for protein is energy driven, subsequently any increase in energy intake will increase the demand for protein and a given product might not provide the best balance of nutrients. This is illuminated in Table 2 by the data summarized by Davis and Drackley (1998) and described by Drackley (2000). The data summarized by Drackley (2000) demonstrate that the protein requirement is a function of the energy allowable gain. As the energy intake increases the protein required to meet the energy allowable gain increases, thus there is no single protein value that meets the nutrient requirement of the calf.

The feeding examples described in Table 1 were according to the labeled feeding rates on the product tag. Many question whether feeding more of a 20% CP, 20% fat milk replacer would allow calves to achieve the same performance as calves fed a higher protein milk replacer. Comparisons of "off-label" feeding rates are found in Table 3. From the data found in Table 3, it is apparent that traditional milk replacer formulations were designed to be fed at close to labeled rates. Exceeding that level of intake in all cases except for milk replacers E and F demonstrates a deficiency in protein allowable gain, which will lead to an accumulation of fat and a reduction in protein deposition and feed efficiency (Bartlett, 2001, Diaz et al., 2001). All of the slaughter work conducted in the last few years (Bartlett, 2001, Diaz, et al., 2001, Tikofsky et al., 2001) supports the predictions of the 2001 NRC calf model. Within the equations employed in the 2001 NRC calf model there are areas of debate concerning energy partitioning and efficiency of use for protein, but the prediction of energy allowable gain is reasonable within the limits that most of the industry would apply.

All of the examples in Tables 1 and 3 assume thermo-neutral conditions. Due to their body weight to surface area ratio, calves become cold stressed at moderate temperatures. Again the 2001 Dairy NRC calf model was employed to evaluate feeding recommendations. The model has an environmental component that allows the user to evaluate the affect of temperature on maintenance requirements. Two milk replacers were used, a 20:20 CP:fat and a 28:20 CP:fat inputted at labeled feeding rates and temperatures were decreased from 68°F to 50°F and to 32°F for a 100 lb calf (Table 4). From this exercise it becomes apparent that a calf will be cold stressed at a relatively moderate temperature of 50°F (Table 4). Most 100 lb calves have not begun to develop a rumen and dry matter intakes aside from milk replacer or milk, are usually very limited. The calf fed a traditional amount of the 20:20 CP:fat milk replacer will be very close to negative energy balance at 50°F and will definitely be mobilizing adipose tissue at 32°F. When a calf reaches this point, immune status can be easily compromised and the calf becomes susceptible to factors other than cold. The empty body fat content of 100 lb calves is 3.5 to 4%, (3.5 to 4 lb) of which approximately half can be mobilized to support heat production. The calf fed the 28:20 CP:fat milk replacer will receive enough nutrients to maintain adequate growth through the cold stress conditions and we could expect more immune competence from this calf, assuming an adequate dry cow vaccination and colostrum program was in place. Some milk replacer feeding instructions suggest feeding a supplemental fat during periods of cold stress. Most of those products are 7% CP and 60% fat. Adding 0.25 lb/d of a 7:60 fat source to supplement the intake of the calf fed 1.0 lb of the 20:20 CP:fat milk replacer at a temperature of 32°F increases the energy allowable gain to 0.22 lb/d, just slightly above maintenance. Feeding more of an appropriately balanced diet to meet the requirements for both energy and protein allowable gain would appear to be the most systematic solution to this cold-stress challenge. Incidentally, it is during periods of cold stress that many producers will indicate they notice greater acceptability and intake of starter grain compared to warmer periods – this is most likely in response to a tremendous need for energy to maintain body temperature and survival.

Growth Studies

In the first study (Diaz et al., 2001; Smith et al., 2002), 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 = 1.1, TRT 2 = 2.1 and TRT 3 = 3.1 lb/d). The milk replacer (MR) (Milk Specialties Co., Dundee, IL) was formulated to contain 30% CP and 20% fat (DM basis) and was an all-milk protein formulation. This dietary CP content was selected based upon previous studies (Donnelly and Hutton, 1976a,b) 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. Calves were assigned to treatment and slaughter at predetermined body weights (Table 5).

On the same set of calves we simultaneously investigated the relationship between DM intake, growth rate and the development of the somatotropic axis. We were interested in determining how early in life the ST axis is expressed and functional. To test functionality we administered exogenous somatotropin (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:

3 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.

4 Feed efficiencies were relatively high (0.6 to 0.78 gain to feed) compared to traditional on farm efficiencies (~0.3 to 0.4), 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.

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. Composition of gain is also different than that predicted by the current calf model (National Research Council, 2001), however the prediction of average daily gain is reasonable.

6 Increased MR feeding did not result in any observable negative health consequences, which suggests our management was adequate and that the milk replacer 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.

6.3 The somatotropic 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 with conventional nutrient densities in our industry standard MR are adequate to allow full expression of the somatotropic axis.

A subsequent study by Tikofsky et al., (2001), 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., 2001). Previous work was confounded by varying fat and or protein levels and allowing intakes to remain similar, thus creating diets 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.

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 8). 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 designed to create isocaloric and isonitrogenous dietary intake conditions. Free choice water was offered at all times. Dry feed was not offered.

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 9. 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 10.

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.

Significant results from the study of Tikofsky et al. (2001):

7 Treatments remained iso-caloric and iso-nitrogenous throughout the course of the study, thus providing us with better interpretive data than previous studies.

8 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 (60% lactose is the critical level for increasing the likelihood of carbohydrate induced scours).

9 Although diet composition was dramatically different, when fed under iso-caloric and iso-nitrogenous conditions, daily growth rate was not different.

10 Increasing dietary fat intake increased body fat deposition and did not affect protein retention or "you are what you eat."

11 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.

A study conducted by Bartlett (2001) evaluated the effects of isocaloric diets at four protein levels and two levels of intake (Table 11). A set of baseline calves were slaughtered and the remaining calves were fed treatment diets for 35 days and then slaughtered. The protein content of the milk replacers was 14, 18, 22 and 26% and the protein source was all milk protein. Intakes were set at 10% and 14% of body weight on an as fed basis and milk replacer was reconstituted to 12.5% solids. It is apparent from the data that growth rate is primarily energy driven, however protein level can have a reasonable impact on the growth rate of calves (Table 11).

Significant results from the study of Bartlett (2001):

12 Data indicate that energy intake drives the requirement for protein, thus the protein required will be a function of the desired growth rate.

13 If the desired outcome is a leaner calf, growth rate alone is misleading since growth rate did not significantly change in calves at the 14% bodyweight intake level when the diet was increased from 22% to 26% protein, however body composition was significantly altered by the change in protein concentration and thus intake level.

14 Coupled with the data of Diaz et al. (2001), this data suggests that to optimize protein deposition in calves fed a milk based protein diet, the dry matter content of protein would need to be ~ 28% CP which is similar to the crude protein content of whole milk. Equations generated from this data indicate that to meet the energy allowable protein requirement when calves are gaining in excess of 1.5 lb/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). Higher protein content would be necessary to achieve high rates of gain without increased fat depositon.

Early Development and Productivity

A consistent question surrounding this research and that potential application of this research is what is the long-term impact of increased feeding rates of milk fed calves? Several studies exist in the literature, which serve to address that question. Brown et al., 2002 conducted a study to determine if feeding increased amounts of milk replacer decreased mammary development in milk fed calves. The study was conducted in two phases, two to eight weeks and then eight to fourteen weeks. Calves were assigned to a either a high or low rate of gain prior to weaning and then maintained on that level or switched an alternate rate of gain post-weaning (Table 12). The heifer calves were then slaughtered and mammary development determined. During the prior to weaning the high calves were fed a 28.5% CP, 15% fat milk replacer whereas the low calves were fed a 20%CP, 20% fat milk replacer. Mammary parenchyma growth was enhanced by 32% during the high milk feeding phase and mammary DNA and RNA was enhanced by 47% during the high milk feeding phase. This increase in mammary development was not observed once the calves were weaned, indicating the calf is more sensitive to level of nutrition prior to weaning and that the enhancement mammary development cannot be "recovered" once we wean the animal.

Sejrsen et al., (2000) also reported data supporting this observation and that once the calves were weaned mammary development was decreased by increased nutrient intake. It should be noted that this author does not believe that this difference in mammary development is directly linked to the potential for increased milk yield. Rather, this effect is an "indicator response" for enhanced whole animal development whether it be immune function, satellite cell incorporation or some other currently undocumented developmental process.

Further, there are three studies that have investigated either the effect of suckling versus controlled intakes or ad-libitum feeding of calves from birth to 42 or 56 days of life (Bar-Peled et al, 1997; Foldager and Krohn, 1994; Foldager et al, 1997). In each of these studies, increased nutrient intake prior to 56 days of life resulted in increased milk yield during the first lactation that ranged from 1,000 to 3,000 additional pounds compared to more restricted fed calves during the same period. This data further suggests there is factors not well defined that allow the calf to be more productive throughout her life. Similar responses have been observed in baby pigs that indicate enhanced early nutrition has long-term positive effects on health and productivity. Research is underway in our laboratory to further define these factors.

Cornell Lactation Data. The following data was generated from the Cornell University Dairy Herd. In 1997 all of our herd heifers were moved to an "intensified" feeding management system. The following study data is controlled, therefore it allows us to make a comparison within herd of the first lactation milk yield compared to the mature cattle in the herd that were never on an intensified system of rearing. The study described here was a pre-pubertal fatty acid feeding study and all heifers were fed the intensified system (Smith and Van Amburgh, 2002). Heifers were assigned in a restricted randomization to accommodate pen-feeding conditions at the Cornell Teaching and Research Center Dairy Unit. Calves were fed a 30% CP, 20% fat milk replacer at 2% BW DM intake and were provided a starter grain that was 25.7% CP (DM basis) and contained 1.18 Mcals NEm and 0.47 Mcals NEg per lb. Calves were weaned by eight weeks and were then group fed one of four diets: Control – no fatty acid supplementation; Sunflower oil – sunflower oil added to equal the fat level of the CLA diet; Ener GII – Ener GII added to equal the fat level of the CLA diet; and a calcium salt of conjugated linoleic acid (CLA) – mixed isomers. Heifers were fed treatment diets until they were 630 lb on average and averaged 182 days on treatment. Diets were balanced to be similar in metabolizable energy (ME) and protein (MP) allowable gain (~ 1.0 kg/d ME and MP allowable gain) using the CNCPS (Fox et al., 2000) and the gains were designed to allow for 22 mo age at first calving. Heifers entered the breeding window when they weighed approximately 750 lb BW. The target breeding system described by Fox et al., (1999) and the 2001 Dairy NRC (National Research Council, 2001) was utilized. Based on an average mature weight of 1,476 lb, heifers were targeted to be pregnant by approximately 812 lb (55% of mature weight) independent of age and to weigh 1,210 lb (82% of mature weight) post-calving at first calving. A common post-treatment diet was fed to all heifers after they were removed from treatment and was designed to achieve the target post-calving body weight. During lactation, the heifers were fed a common diet, housed as a group, milked three times per day and given bST per label. Breeding was based on a voluntary weight period of approximately 45 days.

There was no significant difference in 3.5% fat corrected milk among the fatty acid treatments (Table 13) therefore the heifers were re-stratified independent of the original treatments. The heifers were stratified by age at first calving independent of the original study. Heifers were categorized by those calving less than 21 mo, 22-23 mo. and 24 mo and greater (Table 14). Although there was no heifers fed less to serve as controls for rate of gain effects on lactation performance, the production of the heifers in the first lactation compared with the mature cattle production levels is above average. First lactation heifers should produce at 80% or better of the lactation milk yield of the mature cattle in the herd (82 to 85% is excellent). The third lactation cattle at the Cornell Dairy Unit are currently producing ~ 28,522 lb milk per lactation. Thus, the first lactation heifers are producing at 88% of the mature cattle in the herd. The heifers that calved in early (20 mo) are most likely the smaller mature size cattle within the herd and achieved puberty at an earlier age, whereas the larger mature size cattle (24 mo) achieved puberty at a slightly heavier weight, which lead to a greater AFC. Note however there is no difference in milk yield among heifers calving at an average age of 20 mo, compared with the older animals.

This data demonstrates that a systematic approach to calf and heifer management from birth coupled with an appropriate rearing strategy and adherence to a target growth approach will allow heifers to achieve lower ages at first calving without a milk loss or at least reduce the variation in milk yield associated with age at calving. Whether this increase in performance relative to the mature cattle in the herd is due to the more intensive calf rearing system is unknown, and a study to determine this directly is underway.

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Table 1. Energy (ME) allowable gain (lb/d) and apparently digestible protein (ADP) allowable gain (lb/d) of example calf fed variety of milk replacer formulations according to labeled instructions as evaluated by the 2001 Nutrient Requirements of Dairy Cattle (National Research Council, 2001).

Milk replacer	Formulation[a] (CP%:fat%)	Gross energy (Mcal/lb)[b]	DMI (lb/day)	Dilution (%)	Energy allowable gain (lb/d)	Protein allowable gain (lb/d)
A	22 : 12	2.14	0.93	10.4	0.22	0.55
B	22 : 20	2.34	1.00	10.4	0.48	0.62
C	18 : 21	2.33	1.25	11.6	0.88	0.64
D	20 : 20	2.32	1.25	11.6	0.79	0.73
E	28 : 20	2.31	1.98	15.3	1.65	1.86
F	28 : 15	2.27	2.25	17.4	2.00	2.20

[a]All milk replacers manufactured with all milk protein sources. The fat source was mostly lard or choice white grease. [b]Calculated value, assuming gross energy values (kcal/g) for lactose, protein, and fat common to milk replacers are 3.95, 5.86 and 9.21, respectively (Davis and Drackley, 1998). Assuming ash content of all milk replacer is 7% and lactose is calculated by difference (100 – ash – fat – protein).

Table 2. Effect of rate of body weight gain with constant initial body weight (100 lb) on protein requirements of pre-weaned dairy calves (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	1.75	28	0.84	8.3
0.50	2.30	82	1.11	18.1
1.00	3.01	136	1.45	22.9
1.50	3.80	189	1.83	25.3
2.00	4.64	243	2.24	26.6
2.50	5.53	297	2.67	27.2
3.00	6.46	350	3.12	27.6

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

Table 3. Nutrient balance as calculated by the 2001 Nutrient Requirements of Dairy Cattle (National Research Council, 2001) based on off-label increased feeding rates of milk replacers.

Milk replacer	Formulation[a] (CP%:fat%)	Gross energy (Mcal/lb)	DMI (kg/day)	Dilution (%)	Energy allowable gain (lb/d)	Protein allowable gain (lb/d)
A	22 : 12	2.14	2.20	10.4	1.85	1.63
B	22 : 20	2.34	2.20	10.4	2.07	1.63
C	18 : 21	2.33	2.20	11.6	2.05	1.28
D	20 : 20	2.32	2.20	11.6	2.07	1.45
E	28 : 20	2.31	3.30	15.3	3.30	3.35
F	28 : 15	2.27	3.30	17.4	3.15	3.35

[a]Same milk replacers as in Table 1.

Table 4. Effect of cold stress on predicted calf growth using the 2001 Dairy NRC calf model (National Research Council, 2001). A 100 lb calf was used as the model calf.

Temperature, degrees F	Milk replacer formulation and intake, lb/d	Energy allowable gain, lb/d	Protein allowable gain, lb/d
	20:20		
68	1.0	0.46	0.53
50	1.0	0.05	0.53
32	1.0	0.00	0.53
	28:20		
68	2.0	1.96	1.96

50	2.0	1.67	1.96
32	2.0	1.41	1.96

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. 2001.

	Treatment 1			Treatment 2			Treatment 3				*P*
										SE[1]	TRT[2]
N	6	6	6	6	6	6	6	6	6		
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	0.9
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	0.9
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	0.02
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	0.04
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	0.04
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	0.001
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	0.001
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	0.003
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	0.4

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

Table 6. Comparison of observed energy and protein retained from the study of Diaz et al. with prediction equations used in the 1989 Dairy (National Research Council, 1989), 1996 Beef NRC (National Research Council, 1996) and the 2001 Dairy calf model (National Research Council, 2001).

	Retained Energy, Mcal/d				Retained Protein, g/d			
Treatment	Observed	Predicted 1989 Dairy	Predicted 1996 Beef	Predicted 2001 Dairy	Observed	Predicted 1989 Dairy	Predicted 1996 Beef	Predicted 2001 Dairy
1	1.17	1.17	0.92	1.40	137	99	130	103
2	2.48	2.12	1.72	3.00	199	161	213	199
3	2.82	2.45	2.01	3.52	244	183	244	227

Table 7. Calf plasma insulin-like growth factor-I concentrations expressed in ng/ml from the study of Smith et al (2002). 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)

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

Table 8. Milk replacer diet specifications on a dry matter basis for calves fed on the study of Tikofsky et al., 2000.

	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
Magnesium, % DM	0.14	0.15	0.15
Potassium, % DM	1.72	1.78	1.78
Sodium, % DM	0.77	0.84	0.89
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.

Table 9. 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., 2000.

	Low fat	Medium fat	High fat	SEM	P
n	8	8	8		
Days on treatment	54.6	56.1	55.1	2.7	0.90
Initial body weight, lb	105	104	102	2.2	0.83
Final body weight, lb	190	188	188	1.3	0.91
Average daily gain, lb	1.6	1.5	1.6	0.03	0.66
Dry matter intake, lb	122[x]	116.4[xy]	103[y]	2.49	0.02
GE intake, Mcals	257.6	268.8	270.3	12.83	0.63
Protein intake, lb	28.7	28.8	27.8	0.62	0.79
Fat intake, lb	18[x]	25[y]	31.6[z]	0.60	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 10. 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.

Table 11. The daily protein (g/d) and energy intake (kcal/d), average daily gain of calves assigned to one of four treatment diets that varied in crude protein level under isocaloric intake conditions at two levels of dietary intake, 10% and 14% og body weight. The tissue deposition is from the 14% bodyweight intake treatment calves(Bartlett, 2001).

	Formulated CP%			
Intake	14%	18%	22%	26%
CP, g/d				
10% Bodyweight	89	119	150	162
14% Bodyweight	138	175	214	245
ME, kcal/d				
10% Bodyweight	2837	2934	3079	2980
14% Bodyweight	4394	4312	4399	4516
Average daily gain, lb/d				
10% Bodyweight	0.55	0.67	0.9	0.79
14% Bodyweight	1.12	1.24	1.52	1.54
Tissue deposition for the 14% bodyweight intake treatment over 35 days, lb				
Protein	4.61	5.75	7.91	8.73
Fat	8.13	7.32	6.57	6.17

Table 12. Effect of two levels of nutrient intake from 2 to 8 weeks and 9 to 14 wks of age on mammary development in Holstein heifer calves. Data indicates that mammary development was enhanced by liquid feed intake prior to weaning, but the effect was not observed once weaning occurred. (Brown et al., 2002)

	Low-Low	Low-High	High-Low	High-High
Daily gain 2 to 8 wk, lb/d	0.84	0.84	1.47	1.47
Daily gain 9 to 14 wk, lb/d	0.97	2.41	0.97	2.41
Final bodyweight, lb	176	234	192	267
Total mammary wt., g/100 kg bodyweight	253	391	266	512
Parenchymal wt., g/100 kg bodyweight	16	15	22	23
Parenchymal DNA, mg/100kg bodyweight	45	42	79	86
Parenchymal RNA, mg/100kg BW	140	132	194	219

Table 13 . Management and production characteristics of Holstein heifers fed a control diet or diets supplemented with either sunflower oil, a commercially available calcium salt of primarily palm oil (Ener GII), or a calcium salt of conjugated linoleic acid during the prepubertal period. Data are preliminary and are presented as least square means. (Smith and Van Amburgh, 2002)

	Control	Sunflower oil	Ener GII	Ca CLA	Std. Dev.
n	16	16	17	16	
Pre-pubertal daily gain, lb	1.90	1.92	1.96	1.87	0.15
Age first calving, mo	21.8	21.6	22.3	22.3	1.5
Days in milk	299	294	294	290	10
Body weight at calving, lb	1,228	1,199	1,240	1,267	75
Milk yield, 3.5% FCM, lb	25,057	24,599	25,538	25,344	2,451

Table 14. A post-hoc analysis of the management and production characteristics of Holstein heifers ranked by age at first calving, independent of dietary treatment. Data are preliminary and are presented as least square means. (Smith and Van Amburgh, 2002)

Age first calving rank, mo	<21	21 - 23	>23	Std. Dev.	P
n	19	27	19		
Pre-pubertal daily gain, lb	2.16[a]	2.03	1.96[b]	0.2	0.05
Age first calving, mo	20.2[a]	21.8	24.2[b]	0.6	0.001
Days in milk	298	299	285	14.0	0.7
Post -calving weight, lb	1,177[a]	1,218	1,314[b]	42.0	0.001
Milk yield , 3.5% FCM, lb	24,817	25,485	24,976	2,405	0.6

[abc]Values with superscripts within row differ $P < 0.05$.