Nutrient Requirements and Target Growth of Calves and Heifers – Making an Integrated System

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Growth is an essential component of the dairy enterprise, yet many of us that work in the dairy industry have had little training or background in applied aspects of animal growth. We are more comfortable with concepts involving milk yield and composition, primarily because that is where we generate income. However, in order to improve calf and heifer management, we must understand basic concepts of applied growth so that better recommendations can be developed.

From the perspective of a nutritionist, one of the most over-looked groups of animals on the 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 program 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 and evaluate the new 2001 Dairy NRC;
2) to describe new data that helps us refine our predictions of nutrient requirements for calves and heifers; and
3) to discuss a refinement for setting targets for pregnant and post-calving body weights and the weight gain and nutrients required to achieve those targets.

The Milk Fed Calf and Milk Replacer

Milk replacer formulation and feeding guidelines have been developing on a widespread, commercial basis since the 1950's. 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 adopted by the industry and used to tag calf milk replacer products.

However, the results of this 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. 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. This is compounded by environmental factors such as extreme cold. The concept of *intensified feeding* loses its foundation during periods of cold stress because the requirements of the calf simply to maintain core body temperature require feeding rates at least 50% greater than industry recommendations.

Evaluation of Current Feeding Approaches

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 to 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 to 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 feeding management.

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 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.

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.

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 overall predictions of the 2001 NRC calf model.

All of the examples in Tables 1 and 2 assume thermo-neutral conditions. Due to their body weight to surface area ratio, calves become cold stressed at moderate temperatures (< 50° F). 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. In this evaluation, the composition of the milk replacer is fixed; however most milk replacers contain similar amounts of energy, despite varying protein contents, thus the energy allowable daily gain predicted in Table 4 is transferable to most milk replacers. The effect of cold would be further exacerbated if Jersey calves were evaluated simply due to body size/surface area and heat loss.

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

Table 1. Energy (ME) allowable gain (lb/d) and apparently digestible protein (ADP) allowable gain (lb/d) of example calf fed a 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 tallow.
[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).

very limited. The calf fed a traditional amount of 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 Holstein 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 milk replacer at levels greater than 1.5 lb/d 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 a calf fed 1.0 lb of a 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.

Current Research and Application

Recently, several studies have been conducted to determine the effect of nutrition on body composition changes in milk fed calves (Bartlett, 2001; Blome et al., 2003; Diaz et al., 2001; Tikofsky et al., 2001). From this work we determined that under normal feeding conditions, maximum protein deposition in the calf would be achieved at a protein content of approximately 28% (Bartlett, 2001; Diaz et al., 2001). This data is consistent with the predictions of the Dairy NRC 2001, although some refinements can be made to the NRC equations with this new data. In addition, the level of fat in milk replacer was investigated (Bartlett, 2001; Tikofsky et al., 2001) and from the analyses of body composition data and the calf performance data, fat levels of 15% to 20% appeared adequate for normal growth and development in Holstein milk fed calves.

Work recently completed at Virginia Tech with Jersey calves indicates higher fat levels are required to meet their requirements for energy intake especially in cold weather (Bascom, 2003). Based on that work, the authors have recommended 25% fat content for milk replacers formulated for Jersey calves (Bascom and James, personal communication). Consistent with the data from Holsteins, the body composition data from the Jersey calves indicates that protein accretion would be maximized at 28% CP in the diet.

A consistent question surrounding this research and a 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 aspects of that

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 2.1 Mcal ME/lb DM needed to meet ME requirements.

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 to an alternate rate of gain post-weaning (Table 5). The heifer calves were then slaughtered and mammary development determined. During the prior to weaning phase, 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 in mammary development cannot be *recovered* once the animal is weaned.

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. 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 suggests there are factors not well defined that allow the calf to be more productive throughout her life based on early life nutritional status. Further work is required to quantify or elucidate those factors.

Target Growth

Age at first calving is a herd management decision and it should be a conscious decision based on a systematic approach to heifer rearing. First lactation performance is an integration of pre- and post-calving management, environment, genetic, and economic constraints and is heavily influenced by post-calving management. As heifer growth managers, the best evaluation we can make is to determine at what age/weight relationship do cattle generate the highest marginal profit and then manage to that target.

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). The energy content of most milk replacers is similar; therefore the energy allowable gains predicted are transferable.

	Temperature, degrees F				
100 lb calf weight	70	50	30	10	-10
Replacer intake, lb DM	Predicted growth rate, lb/d				
1.00	0.40	0	< 0	< 0	< 0
1.25	0.80	0.46	0	< 0	< 0
1.50	1.16	0.85	0.51	0	< 0
1.75	1.50	1.20	0.89	0.50	0.18
2.00	1.82	1.54	1.25	0.88	0.61
	Temperature, degrees F				
120 lb calf weight	70	50	30	10	-10
Replacer intake, lb DM	Predicted growth rate, lb/d				
1.00	0.17	0	< 0	< 0	< 0
1.25	0.58	0.17	0	< 0	< 0
1.50	0.94	0.59	0.17	< 0	< 0
1.75	1.27	0.94	0.59	0	0
2.00	1.58	1.27	0.94	0.52	0.18

By using standard *thumb rules* for Holsteins we have created a *one size fits all* approach to recommendations and that approach has the capability of introducing variation in body weight and composition at calving that is not appropriate for a particular herd, thus impacting first lactation milk production, independent of any other factors. We have realized that each dairy has it's own set of unique management and environmental conditions that make a universal age and weight at first calving an inappropriate goal. In order to improve first lactation performance, we need to reduce the variation in meeting targets for growth and body weight – and the herd owner/manager and nutritionist need to be working with the same numbers in order to have a successful outcome. The purpose of the remainder of this paper is to describe the target growth system and provide a basis for its use.

Table 5. 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 bodyweight	140	132	194	219

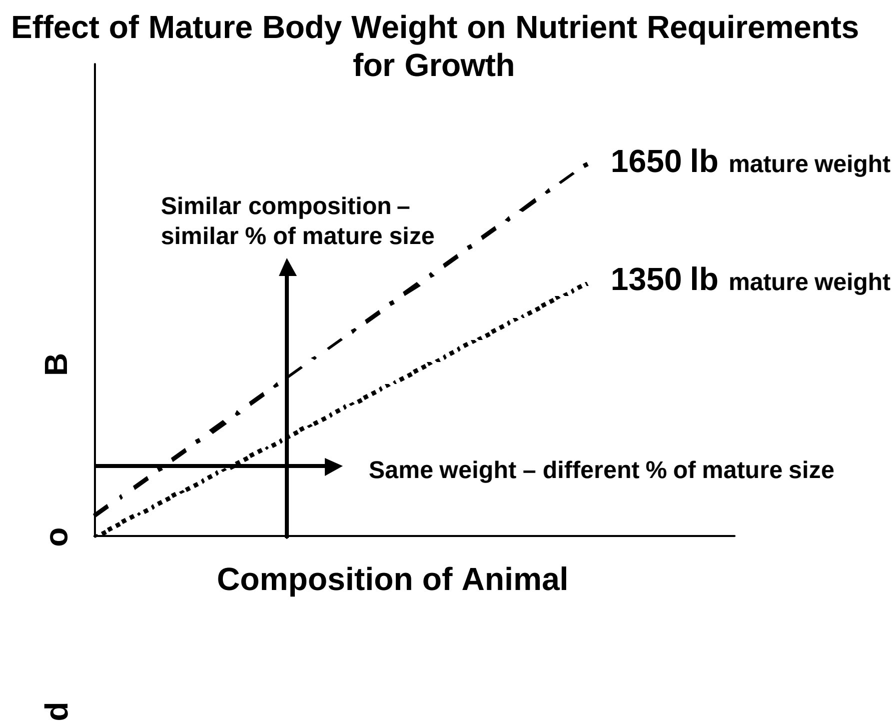

Figure 1. The diagram depicts the effect of varying mature body size on composition of the animal at similar stages of growth.

Integration of Body Composition and Mature Size

The weight at which cattle reach the same chemical composition differs depending on mature size and sex; hence, composition is different even when the weight is the same (National Research Council, 1996). All systems developed since the National Research Council 1984 Beef Cattle and 1989 Dairy Cattle Nutrient Requirements use some type of size-scaling approach to adjust for differences in weight at a given composition. The National Research Council (1996) adapted the size scaling equation developed by Fox et al. (1992) with refinements published by Tylutki et al. (1994) and by Fox et al. (1999) for dairy cattle; which is used to account for differences in mature size of cattle. As in the CSIRO (1990) and INRA (1989) systems, this growth model assumes that various types of growing cattle have a similar chemical composition of growth at the same degree of maturity. Similar to the CSIRO system, the size scaling equation in this model adjusts the body weights of cattle of various mature sizes to a weight at which they are equivalent in body composition to a standard reference animal. The committee that developed the 2001 Nutrient Requirements for Dairy Cattle (National Research Council, 2001) adopted the system for use in formulating heifer diets. The standard reference weight animal used in the system for dairy cattle is a 1,054 lb steer that contains 28% empty body fat.

The primary factor involved in the development of the target growth system was the need to combine the goals of heifer growth with the nutrient requirements of the animal. Although this sounds intuitive, the targets for dairy heifer growth and the subsequent requirements for a particular rate of gain were in practice generally exclusive of one another. The factors necessary for use of the system include:

1) the mature weight of the herd of cattle the system is being applied to,
2) the desired age at first calving,
3) the current weight,
4) the current age, and
5) the chemical composition and dry matter intake of the diet being fed.

All of these factors except for the mature weight of the animal are commonly used factors for formulating heifer diets. Once these factors are known, calculations for breeding weight and pre-calving or post-calving BW are predicted and compared to your targets.

If both heifers weigh 450 lb, then the heifer that will reach mature weight at 1,350 lb is 33.3% of it's mature size; whereas, the heifer that will grow to 1,650 lb is only 26.7% of it's mature size. Both of those heifers will contain approximately 28% fat in their empty body when they reach maturity. This might seem like a small difference, but the energy content of the tissue deposited will be quite different. The heifer with a mature weight of 1,350 lb will be depositing more fat per unit of gain at this stage because she is closer to her mature weight. Because there is additional fat in the gain, the energy required for gain (NEg) will be higher at the same rate of gain. Conversely, if the heifers are consuming the same amount of energy at the same body weight, the heifer with the larger mature size will be gaining weight at a slightly higher rate because she is depositing more protein per unit of gain (or has a higher requirement for protein deposition). There are approximately 3.6 units of water deposited with each unit of protein; therefore, protein deposition results in greater weight gain because the specific weight of water is greater than fat. However, on a whole body percentage basis, as fat accumulates in the body, fat will displace water. The application of this concept is found in Tables 6 and 7.

Table 6. Target growth example and diet for a Holstein heifer with a measured herd level mature body weight of 1,350 lb and a desired age at first calving of 22 months.

Growth characteristics	Target
Current weight, lb.	375
Current age, mo.	4
Target age at first calving, mo.	22
Target pregnant weight, lb.	745
Target pregnant age, mo.	13
Diet (DM basis)	
Corn silage, lb	3.00
Alfalfa silage, lb	3.00
Corn grain, rolled, lb	1.30
Soybean meal, roasted, lb	0.80
Soybean meal, solvent ext., lb	0.20
Minerals and vit. with carrier, lb	0.35

The diet as formulated for the 1,350 lb mature weight heifer is balanced for 1.80 lb/d liveweight gain on both an energy and protein allowable basis. If the same diet is applied to a group of heifers that are phenotypically larger, the heifers with a larger mature body weight are a smaller percent of the mature size, and at the same weight will contain less body fat and have a higher requirement for protein per unit of gain. Since the diet was not changed, the larger mature size heifer will be penalized because there is not enough metabolizable protein supply compared to the energy allowable gain. Thus the larger heifer will use the extra energy to deposit body fat and the expected weight gains will be a compromise between the energy and protein allowable gains. We have determined that this effect can occur as early as the milk-feeding phase and indicates that the effect could compound with increasing body weight.

Table 7. Effect of mature body weight on energy and protein allowable body weight gain. The diet was designed for the average heifer in Table 6, however the comparison is to a group of heifers from a herd with a larger mature body weight.

Mature weight, lb	1,350	1,650
Energy allowable gain, lb/d	1.80	2.10
Protein allowable gain, lb/d	1.80	1.80

From this example it becomes obvious that a one size fits all recommendation for first lactation post-calving body weight is most likely erroneous and will lead to situations where heifers are over-or-under fed nutrients in an effort to make them fit a target not suited to their genetic capabilities. To actualize this in the field, we suggest that the third and greater lactation cattle in the herd be weighed or taped and the weights be averaged. That weight will serve as a reasonable value for the mature size of the herd.

These target weights are used with current age and weight, age at first calving, and calving interval to compute daily gain required to reach the next target weight. For example, for heifers before first pregnancy, the target daily gain to target first pregnant weight is:

$$\frac{(\text{mature weight x .55}) - \text{current weight}}{(\text{days of age at first calving - 280}) - \text{current age}}$$

For first pregnant heifers, daily gain required is:

$$\frac{(\text{mature weight x .85}) - \text{current weight}}{280 - \text{days pregnant}}$$

Table 8. Target weights for dairy animals used in the 2001 NRC Nutrient Requirements for Dairy Cattle adopted from Fox et al., 1998.

	Mature weight of herd, lb		
	1,400	1,600	1,800
Pregnancy, 55% of mature wt., lb	770	880	990
	Post-calving weight		
1st calving, 85% of mature wt., lb	1,190	1,360	1,530
2nd calving, 92% of mature wt., lb	1,288	1,472	1,656
3rd calving, 96% of mature wt., lb	1,344	1,536	1,728

Conceptus daily gain is added to get measured weight gain required.

Daily gain required during the first lactation (including the dry period) is:

$$\frac{\text{(mature weight x .92)} - \text{current weight}}{\text{calving interval days} - \text{days since calving}}$$

Daily gain for the second and third lactations is computed the same way, using 0.96 or 1 to compute the next target weight for the second and third lactations, respectively.

The weight of the mature animals within a herd is used to set targets, making the recommendations specific to the management conditions observed in a herd. Under normal management conditions heifers will reach puberty at 45 to 50% of mature body weight. Recommendations are to achieve pregnancy by 55 to 60% of the herd mature body weight. First lactation post-calving body weight is set at 85% of the mature body weight. The mature weight is determined by weighing third lactation cattle during mid lactation and dividing the weights by 0.96 (third lactation cattle are 96% of mature weight) and measuring the body weight of all fourth lactation cattle (up to the last trimester of pregnancy). Observed ranges among herds in NY for mature size in Holstein cattle are 1,300 to 1,900 lbs.

If the mature weight of cattle is not known (expanding or populating a new herd) a default weight for Holsteins is 1,450 lb (subsequent pregnant weight of 798 lb and post calving body weight of 1,230 lb) and this value is in the middle range of the weight recommended by Pat Hoffman based on post calving body weights (Hoffman, 1997).

Data in Table 9 shows how the target growth system eliminates the *one size fits all* approach. Goals for AFC are identical for the first two groups of heifers, which differ only in mature size. However, the 400-pound, 6-month-old heifers with a mature size of 1,650 pounds must grow at 2.14 pounds per day to meet the AFC targets; while heifers of the same current size and age, but with a 250 lb lighter mature body weight must gain only 1.56 pounds per day. This is a substantial difference in growth rate and the consequences of feeding the lighter mature body weight heifer the diet for 2.14 lb/d gain will be over-conditioning and a potential loss of milk if it persists to calving.

Table 9. Example target growth calculations using different mature body weights and target ages at first calving.

Mature weight, lb.	AFC, mo	Current age, mo	Current weight, lb	Target 1st postcalving wt., lb	Target weight at preg., lb	Target age at preg., mo	Target growth rate, lb/day
1,400	23	6	400	1,190	770	14	1.56
1,650	23	6	400	1,403	908	14	2.14
1,650	25	6	400	1,403	908	16	1.71

Table 10. Relationship of stage of growth and rate of gain to body composition[1].

Mature weight	Requirements during growth						
	Shrunk body weight during growth (kg)						
478 kg	200	250	300	350	400	450	500
600 kg	250	314	376	439	500	565	627
650 kg	272	340	408	476	544	612	680
Shrunk weight gain, kg/day	*NE_g required, Mcal/d*[2]						
0.6	1.68	1.99	2.28	2.56	2.83	30.9	3.34
0.8	2.31	2.73	3.13	3.51	3.88	4.24	4.59
1.0	2.95	3.48	4.00	4.49	4.96	5.42	5.86
	Protein in gain, percent[3]						
0.6	20.4	19.5	18.8	18.0	17.3	16.6	16.0
0.8	18.7	17.6	16.5	15.5	14.6	13.6	12.7
1.0	17.0	15.6	14.2	13.0	11.7	10.5	9.3
	Fat in gain, percent[4]						
0.6	5.9	9.7	13.2	16.6	19.9	23.1	26.2
0.8	13.6	18.7	23.6	28.2	32.8	37.1	41.4
1.0	21.4	27.9	34.1	40.1	45.6	51.5	56.9
	Body fat, percent of SBW[5]						
0.6	11.6	10.8	10.9	11.5	12.3	13.4	14.5
0.8	11.6	12.5	13.9	15.6	17.5	19.4	21.4
1.0	11.6	14.2	17.0	19.9	22.8	25.6	28.5

[1]Adapted from Fox et al. (1999). The shrunk body weights within a column have the same equivalent shrunk body weight.
[2] NEg requirement is computed from the 1996 NRC equation which was determined from 72 comparative slaughter experiments (Garrett, 1980); Retained energy (RE) =0.0635 $EBW^{.75}$ $EBG^{1.097}$, where EBW is 0.891 SBW and EBG is 0.956 SWG.
[3,4]Computed from the equations of Garrett (1987), which were determined from the Garrett (1980) database; Proportion of fat in the shrunk body weight gain = .122 RE - .146, and proportion of protein = .248 - .0264 RE. The proportion of fat and protein in the gain is for the body weight and SWG the RE is computed for.
[5]Computed from accumulated body fat when grown at the respective SWG.

The information found in Table 10 describes the energy and protein and fat content of the gain of heifers growing at three different rates of gain based on percentage of three different mature body sizes.

Summary

The nutrition and management of the dairy heifer requires a more systematic approach to meeting the targets for both body growth and energy utilization. The system described in this paper provides a basis for a more systematic and mechanistic approach that de-emphasizes universal age-weight relationships for dairy replacements. The use of this system should enhance our ability to successfully develop heifers with optimum milk producing ability.

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