Modeling Preweaning Dairy Calf Performance

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KEYWORDS

• Modeling • Preweaning • Growth • calf nutrition

KEY POINTS

- Concerted research efforts to ascertain the underlying mechanisms associated with and factors affecting body composition and weight gain during the preweaning phase have led to the development of a modeling construct for young calf growth.
- Factors including plane of nutrition (ie, protein and fat), breed of calf, and environmental conditions can be modeled to estimate and compare body weight gain between differing feeding programs.
- The relationship between liquid and dry feed intakes needs to be more clearly defined over a wider range of liquid feed intakes so the impact on growth during weaning and post-weaning can be more accurately assessed.

INTRODUCTION

Nutrition and growth of the dairy calf through weaning has evolved beyond the "one size fits all" approach. Historically dairy calves have been fed a "conventional" feeding program, whereby whole milk/milk replacer is limited fed during the liquid feeding phase to typically 0.08 to 0.10 of body weight as liquid (∼1.0 lb (0.454 KG) solids/head/d) in an effort to encourage consumption of dry starter feeds and earlier weaning. This approach to feeding dairy calves has differed from nursery feeding practices in other sectors of the animal livestock world, whereby ad libitum intakes of nutrients are the norm and lead to more biologically allowable growth during the early life of the animal.

There have been many technologies used and much research conducted in the last 10 to 20 years that has led to feeding strategies providing an increased plane of nutrition to nursery calves. Some of these innovations include:

1. Proliferation of on-farm milk pasteurizers, leading to increased supply and utilization of nonsalable milk to feed to calves.
2. Increased use of automatic calf feeders, allowing for more frequent and larger volumes of nutrients to be delivered to the young calf.

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3. Research into how feeding the young dairy heifer calf affects body composition and mammary development during the early growth period along with impacts on later-life health, productivity, and longevity.
4. Paired- and group-housing of calves leading to labor efficiencies, less stressful weaning, and increased ability of calves to adapt to novel situations.

The industry as a whole has migrated from these historical conventional feeding rates to adopting feeding practices with increased daily feeding rates (≥ 1.25 lb (0.567 KG) solids/head/d) and increased milk replacer crude protein contents (≥ 22%). The new normal has become "moderate" and "intensive" or "accelerated" feeding programs designed to increase the supply of energy and protein to meet the maintenance needs associated with the basic metabolic functions of life, to regulate body temperature outside the calf's thermoneutral zone (cold and heat stress), to provide increased energy to the immune system in response to disease challenges as well as the stressors associated with transportation and new surroundings, and to support an acceptable rate of growth during the nursery phase. In addition, feeding programs will include step-up procedures during the first 2 weeks of the liquid feeding phase to minimize digestive upsets as well as step-down procedures before weaning to minimize decreases in postweaning performance as the calf transitions to becoming a fully functional ruminant. All of these factors contribute to creating site-specific feeding programs based on the goals and objectives of the calf raising operation (eg, dairy heifer replacements vs dairy beef).

Some historical growth rates associated with conventional, modified, and intensive nutritional programs are shown in **Table 1**.[1] In a more recent review of research conducted at the Nurture Research Center Data (Provimi US), a comprehensive data analysis on 491 calves across 10 published studies was used to examine the effects of moderate or high milk replacer feeding rates on growth performance through 56 days of the nursery feeding period (**Table 2**).[2] In a summary of more than 1200 dairy heifer calves fed an intensive feeding program (28% CP–15% fat or 28% CP–20% fat milk replacers fed at 2%–2.5% of birth weight) at the Cornell University Teaching and Research dairy herd, calves had a mean preweaning average daily gain of 1.81 lb/d (0.82 kg/d).[3] As a point of reference, a study conducted by von Keyserlingk and colleagues showed Holstein heifer calves fed whole milk on an ad lib basis averaged approximately 2.4 lb/d (1.1 kg/d).[4]

Table 1
Expected average growth rates for calves of various ages under different nutritional programs

	Expected Growth Rate	
Feeding Program & Stage	**lb/d**	**kg/d**
Conventional, ad libitum starter, d 0–42[a] (Typically, 1.00 lb solids/hd/d of a 20% CP, 20% Fat MR)	1.10–1.32	0.5–0.6
Moderate, ad libitum starter, d 0–42[c] (1.25–2.0 lb solids/hd/d of a 22%–25% CP, 18%–20% Fat MR)	1.21–1.43	0.55–0.65
Accelerated, ad libitum starter, d 0–42[b] (Typically, 2.25 lb solids/hd/d of a 28% CP, 15%–20% Fat MR)	1.32–1.76	0.6–0.8
Weaned calves, ad libitum starter, < 1.1 lb/d forage, d 56–84	1.87–2.09	0.85–0.95

[a] Gains during d 0–21 would be 0.44–0.66 lb/d (0.2–0.3 kg/d)
[b] Gains during d 0–21 would be 1.10–1.32 lb/d (0.5–0.6 kg/d)
[c] Gains during d 0–21 would be 0.88–1.10 lb/d (0.4–0.5 kg/d)
Data from Drackley, JK. Calf Nutrition from Birth to Breeding. Vet Clin Food Anim 2008;24:55-86.

Developing modeling programs for complex biologic functions such as milk production or growth are done under controlled conditions in experimental settings to limit as many external variables as possible. Caution is advised when applying modeling programs in commercial settings as multiple external factors not included in the development of the modeling equations may have an impact on the results obtained. For example, lack of colostrum feeding practices and subsequent exposure to infectious disease can have profound impacts on calf performance as energy is diverted from body weight gain to fueling the immune system. In addition, comparing modeling results between calf raising operations with differing management practices not directly related to nutrition may lead to different findings. But within a calf raising operation, making comparisons using modeling concepts can provide value when evaluating different feeding programs that provide differing planes of nutrition (ie, moderate vs accelerated feeding) or under different environmental conditions (ie, cold stress).

This article will provide some background on the development and existence of calf growth modeling principles and consider some of the variables that have been shown to have an impact on the energy and protein requirements of the young calf.

BACKGROUND

NRC 2001 calf submodel

The 2001 NRC (National Research Council Nutrient Requirements of Dairy Cattle)[5] devoted an entire chapter to the nutrient requirements of the young calf. In addition to reviewing and updating the nutrient requirements of the young calf with the latest research available at the time, a section of the software associated with the publication was used to model the energy and protein requirements during the liquid feeding phase.

The Young Calf Sub-Model within the NRC 2001 software introduced the concept of energy allowable growth (EAG) and protein allowable growth (PAG). A summary of the energy allowable gain calculations is as follows:

(1) Basal maintenance requirement of the calf without stress is calculated based on body weight.

Table 2
Performance of calves fed moderate or high rates of milk replacer (MR) in the nursery period (day 0–56).

Parameter	Moderate MR[a]	High MR[b]
Initial Body Weight, lb	93.0	95.2
ADG, lb/d	1.21	1.39
Gain/DMI, lb/lb	.466	.488
MR Intake, lb/d (DM basis)	1.03	1.77
Starter Intake, lb/d (DM basis)	1.53	1.04

[a] Moderate MR = 1.41 to 1.46 lb DM/d for the first 35 to 39 d, followed by half the allotment per day for 3 to 7 d.
[b] High MR = 2.03 to 2.36 lb DM/d for the first 35 to 44 d, followed by half the allotment per day for 5 to 7 d.

Data from Hu et al. Effects of milk replacer feeding rates on growth performance of Holstein dairy calves to 4 months of age, evaluated via a meta-analytical approach. J Dairy Sci 2020; 013:2217-2232.

(2) If the calf is subjected to cold stress, an additional multiplier factor is applied to the basal maintenance requirement based on the ambient temperature to which the calf is exposed.
(3) The total amount energy available in the diet is calculated.
   a. The metabolizable energy (ME), net energy maintenance (NEm), and net energy gain (NEg) values for the individual feeds in the diet are calculated. Various efficiency factors are used to proceed through the energy cascade calculations for ME, NEm, and NEg based on the type of feed used in the diet (whole milk/milk replacer vs dry feed (eg, calf starter, calf grower).
   b. A composite ME, NEm, and NEg for the diet is calculated based on the individual dry matter (DM) contributions of the individual feeds to the overall diet.
(4) The NEm requirement of the calf and the NEm concentration of the diet are used to calculate the diet DM amount needed to meet the calf's maintenance requirement.
(5) Any additional diet DM available after meeting the calf NEm requirement along with the NEg concentration of the diet is used to calculate the EAG value.

Protein allowable gain calculations are as follows

(1) An apparently digestible protein (ADP) maintenance requirement is calculated based on endogenous losses through urine and feces.
(2) The total amount of ADP supply in the diet is calculated based on the individual DM contributions of the individual feeds in the diet, their crude protein concentrations, and crude protein to ADP efficiency factors.
(3) The ADP maintenance requirement is subtracted from the ADP supply, and any remaining surplus is used to calculate the PAG value.

The NRC 2001 Calf Sub-Model allows for inputs of calf body weight, temperature, and individual feeds and amounts comprising the diet for a single point in time. The model allows for differences in body weight, rate of gain, and environmental temperatures to be used in determining nutrient requirements. Providing estimates of EAG and PAG were a huge step forward in understanding the energy and protein requirements at various calf weights/ages. For example, cold stress has the impact of increasing the energy maintenance requirement of the calf and decreasing the amount of energy left over to go toward gain if the energy content of the diet is not increased. This is especially evident during the first 3 weeks of age, when calves are at increased susceptibility to cold stress.

Cornell–Illinois equations

In the early 2000s after the publication of the 2001 NRC Nutrient Requirements of Dairy Cattle, much research was devoted to the underlying physiology of young calf growth, specifically how feeding differing amounts of dietary energy and protein to the young calf affected overall body composition. Research by Diaz,[6] Tikofsky,[7] Blome et. al,[8] and Bartlett and colleagues[9] provided a large data set that led to a better understanding of the ME and crude protein requirements of dairy calves. Subsequently, these data allowed the development of the Cornell–Illinois equations which provided an update to the NRC 2001 Calf Sub-Model. **Table 3**[10] shows the effect of these modifications, with the modified equations resulting in slightly lower values for ME and slightly higher values for crude protein when compared with NRC 2001 estimates.

Agricultural Modeling & Training Systems Calf Model

Agricultural Modeling & Training Systems (AMTS) have incorporated growth modeling for the preweaned calf into their commercially available AMTS.Farm.Cattle Pro ration

Table 3
Comparison of nutrient requirements for a 50-kg calf between 2001 NRC and Cornell–Illinois equations (thermoneutral conditions).[1]

Rate of gain, lb/d (kg/d)	Dry matter intake, % BW	Metabolizable energy, Mcal/d		Crude protein, gm/d		Crude protein, % of diet dry matter	
		NRC 2001	Cornell-Illinois	NRC 2001	Cornell-Illinois	NRC 2001	Cornell-Illinois
0.44 (0.20)	1.05	2.37	2.34	78	94	18.7	18.0
0.88 (0.4)	1.30	3.00	2.89	125	150	21.4	22.4
1.32 (0.6)	1.57	3.70	3.49	173	207	23.7	26.6
1.76 (0.8)	1.84	4.46	4.40	220	253	25.1	27.4
2.20 (1.0)	2.30	5.25	4.80	267	318	26.1	28.6

Adapted from Drackley, JK. Calf Nutrition from Birth to Breeding. Vet Clin Food Anim 2008;24:55-86.

formulation program.[11] The modeling incorporates the underlying concepts of the NRC 2001 Calf Sub-Model, updated information from the Cornell-Illinois Equations (discussed above), and internal AMTS development. The AMTS Calf Model allows for multiple animal (breed, age, weight) and environmental inputs to define the nutrient requirements of the calf along with a dedicated feed library designed for use in non-ruminating, milk-fed calves. More information is available at https://agmodelsystems.com/.

Milk Specialties Global Toolkit Calf Growth Model

Milk Specialties Global (MSG), a manufacturer of milk replacers for the dairy industry, has developed a web-based calf growth modeling program (https://toolkit.milkspecialties.com/). This commercially available program is viewable across multiple formats (Android and Apple) and multiple devices (laptop, tablet, and phone).

Whereas the NRC 2001 Calf Sub-Model program evaluates calf growth at a single point in time, the MSG Calf Growth Model is unique in that it evaluates calf growth over an entire feeding period. The program uses the basic concepts outlined in the NRC 2001 Calf Sub-Model, calculating an energy allowable gain, protein allowable gain, and an average daily gain (ADG) for each day of the feeding period based on user inputs. User inputs include breed of calf, starting weight, temperature, and feeding period length. The diet inputs can consist of multiple feeds that are components of the liquid diet (eg, milk replacer, whole milk) and of the dry diet (ie, calf starter). For each feed, the user enters an average daily consumption on a weekly basis. For liquid diet feeds, the program uses the same inputted value for each day of the week (ie, 1.25 lb/hd/d of milk replacer) (0.567 KG/hd/d of milk replacer). For dry diet feeds, the program performs a regression analysis of the inputted weekly values to calculate a daily feed consumption across the entire feeding period. Multiple result parameters can be selected and are presented in graphical and tabular formats on the web-based platform. As new information on young calf growth is continuously being generated, refer to the User Guide on the website for the latest information on the underlying principles and calculations associated with the MSG Calf Growth Model.

National Academies of Science, Engineering, and Medicine Dairy 2021

The National Academies of Science, Engineering, and Medicine (NASEM) is expected to release an updated Nutrient Requirements for Dairy Cattle in the latter half of 2021.

This publication will provide updated concepts and equations for the energy and protein requirements of the young calf based on research conducted since the NRC 2001 Nutrient Requirements of Dairy Cattle. In addition to including more refined estimations of calf growth during the preweaning period, this publication will provide prediction equations for starter intake based on calf body weight and energy consumption from the liquid diet as well as an updated software program for modeling young calf growth. This author refers you to the AMTS and MSG Toolkit websites for updates on incorporation of the calf growth modeling concepts from the NASEM publication's official release.

GROWTH MODEL CONSIDERATIONS

Cold stress and heat stress

The thermoneutral temperature range for young-adapted calves is estimated to be 59° to 77° F (15°–25° C) (Van Amburgh[10]). For cold stress, the lower critical temperature (LCT) of 59° F (15° C) is most appropriate for the young calf in the first 3 weeks of age. The LCT decreases with increasing body weight and age and is approximated to be 41° F (5° C) for calves older than 3 weeks of age through weaning. The NRC 2001 Calf Sub-Model used a stair-step approach to estimating the increase in maintenance requirement for the young calf, applying multiplier factors for various temperature ranges below the LCT (Table 4). In place of this stair-step approach, the MSG Calf Growth Model and AMTS Calf Model apply an adjustment factor for every degree below the LCT based on a regression analysis. The impact of cold stress on the calf growth is most noticeable in the calf less than 3 weeks of age as calves are born with limited energy stores and minimal consumption of dry feed is not providing much additional energy to the diet. Cold stress does not appear to impact the calf's protein requirement to any large degree.

Heat stress has a negative impact on average daily gain and calf performance. In a 2006 study conducted by Wiedmeier and colleagues[12] that considered the effects of season, preweaning average daily gain of calves started in June was lowest (1.39 lb/d)

Table 4
Multiplier factors applied to the maintenance requirement for young calves exposed to cold stress

Temp° F	Temp° C	Calves < 3 wk of age	Calves > 3 wk of age
> 59	> 15	1.00	1.00
50–59	10–15	1.13	1.00
41–50	5–10	1.27	1.00
32–41	0–5	1.40	1.13
23–32	−5 to 0	1.54	1.27
14–23	−10 to −5	1.68	1.40
5–14	−15 to −10	1.86	1.54
−4 to 5	−20 to −15	1.94	1.68
−13 to −4	−25 to −20	2.08	1.81
−22 to −13	−30 to −25	2.21	1.94
< −22	< −30	2.34	2.07

Data from National Research Council. Nutrient requirements of dairy cattle. 7th edition. Washington, DC: National Academy Press; 2001.

(0.631 kg/d), whereas the average daily gain of calves started in September and March was highest (1.55 and 1.53 lb/d) (0.704 and 0.695 kg/d), respectively). Calves started in December had an intermediate average daily gain (1.46 lb/d) (0.663 KG/d). Place and colleagues[13] also found lower average daily gains in calves born in summer and fall. A review by Chester-Jones et al.[14] of data on over 2800 Holstein calves from 2004 to 2012 also showed that birth season had an effect on average daily gain, with calves born in the summer averaging significantly less (1.37 lb/d) (0.622 kg/d) than calves born in fall and winter (1.46 lb/d) (0.663 kg/d). The energetic costs of heat stress on calf performance have not yet been quantified in an experimental setting to the level that has been done for cold stress. The AMTS Calf Model applies the same regression logic used for calculating cold stress maintenance energy increases to the heat stress side of the thermo-neutral zone for young calves.

Breed differences

A majority of the research done to elucidate the underlying physiology of young calf growth has been conducted on large breed calves (Holsteins). Small breed or Jersey calves have a greater surface area to body weight relationship, which translates to a greater heat loss potential. Research at Virginia Tech (Bascom[15]) on Jersey calves showed the maintenance energy requirements of Jersey calves are higher than for Holstein calves and most likely need to be fed higher fat diets. Both the AMTS Calf Model and MSG Calf Growth Model provide the option to select the breed of calf being fed and make an appropriate adjustment to the maintenance energy requirements in the model.

Calf starter intake

Several studies have demonstrated the inverse relationship between liquid and dry feed intakes during the preweaning phase of the feeding program for a young calf.[2,16,17] A meta-analysis of the effects of preweaned calf nutrition and growth on first-lactation performance by Gelsinger and colleagues[18,] showed a strong inverse relationship between liquid and starter intakes (**Fig. 1**). This is most likely due to the calf's limited capacity for daily DM intake. This correlation was especially strong when the liquid feed DM feeding rate was greater than 1.76 lb/d (0.8 kg/d). Starter DM intake was more variable at lower liquid feed DM intakes.

When modeling a particular feeding program, accurate determinations of liquid and dry feed intakes are essential. In most situations, liquid feeding rates will be more easily known, either because restricted amounts are being offered and consumed or in robotic feeding situations, the amounts consumed are being recorded. Conversely, dry starter feed is generally offered on an ad-libitum basis and ascertaining actual consumption can be difficult to obtain or is not routinely tracked on commercial calf raising operations. Under research settings, however, actual daily dry starter intakes can be accurately determined under differing liquid feeding rates (**Fig. 2**).[2] This can lead to mathematical representations and regression equations being developed for dry starter intakes during the nursery phase that can be used as a basis in calf growth modeling. Data from 2 experiments at the Martin Experiment Station, Martin TN from 1992 to 1993 were used to develop a regression equation to predict calf starter DM intake in calves fed commercial milk replacer and calf starter.[19] Significant variables in the determination of calf starter intake included calf sex, age, body weight, average daily gain, and milk replacer DM intake. However, this regression analysis was limited due to the upper limit of milk replacer fed (1.9 lb/d or 0.86 kg/d). Updated regression analyses are needed to predict calf starter intake over a wider range of liquid feeding rates.

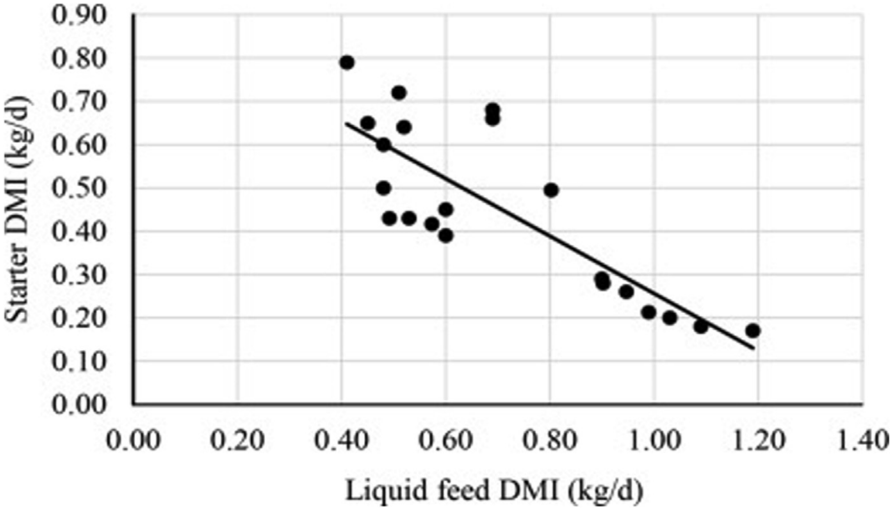

Fig. 1. Relationship (r = −0.82; Y = −0.66X + 0.92) between daily DMI before weaning as liquid feed (milk of milk replacer) and as starter grain. Each data point represents 1 of 21 treatments from 9 individual studies comparing preweaned calf management with first-lactation performance. (*Data from* Gelsinger et al. A meta-analysis of the effects of preweaned calf nutrition and growth on first lactation performance. J Dairy Sci 2016;99:6206-6214.)

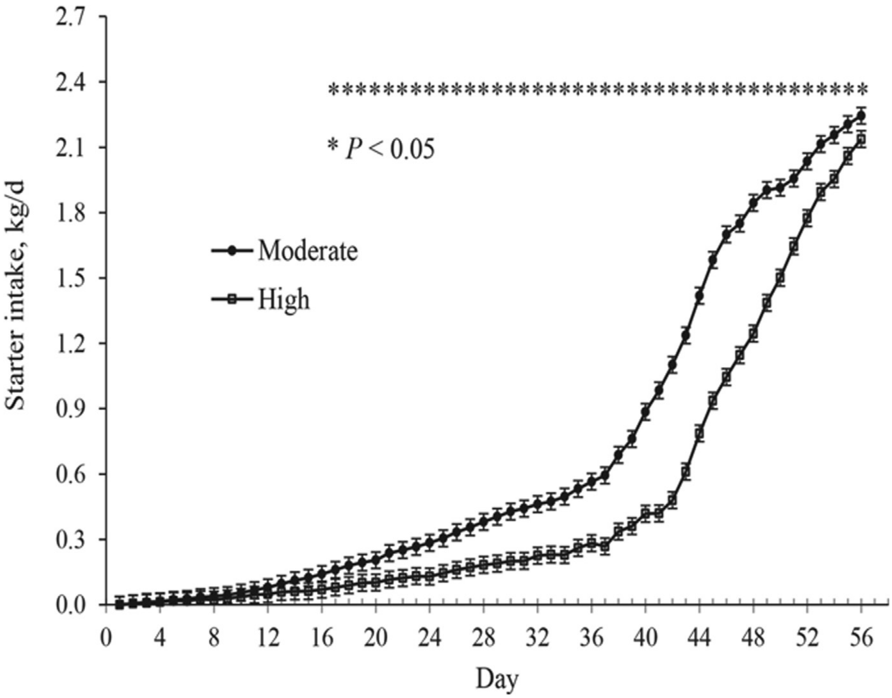

Fig. 2. Starter intake pattern for Holstein calves fed moderate rates (1.41–1.46 lb DM/d) or high rates (2.03–2.36) of milk replacer in the nursery period. Asterisks indicate that starter intake at the same week differed in the calves fed moderate versus high rates of milk replacer ($P < .05$). (*Data from* Hu et al. Effects of milk replacer feeding rates on growth performance of Holstein dairy calves to 4 months of age, evaluated via a meta-analytical approach. J Dairy 2020;013:2217-2232.)

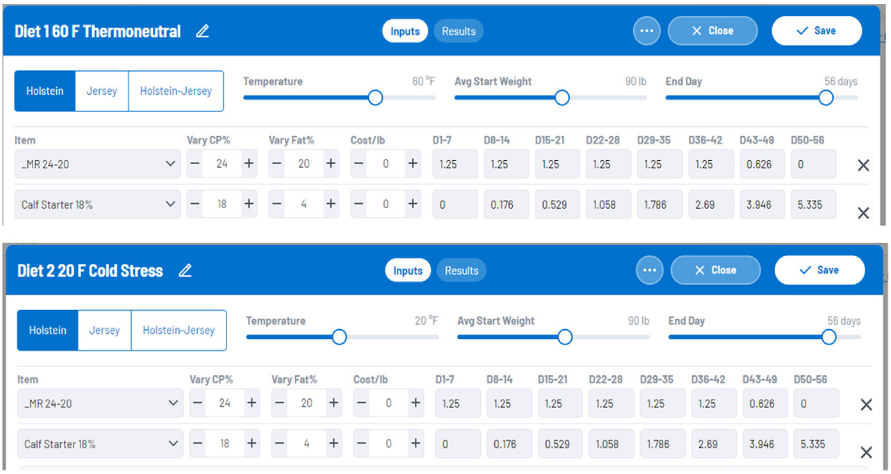

Fig. 3. Data inputs for the comparison of calf growth performance between thermoneutral (60° F) and cold stress conditions (20° F) using the Milk Specialties Global Calf Growth Model (https://toolkit.milkspecialties.com/).

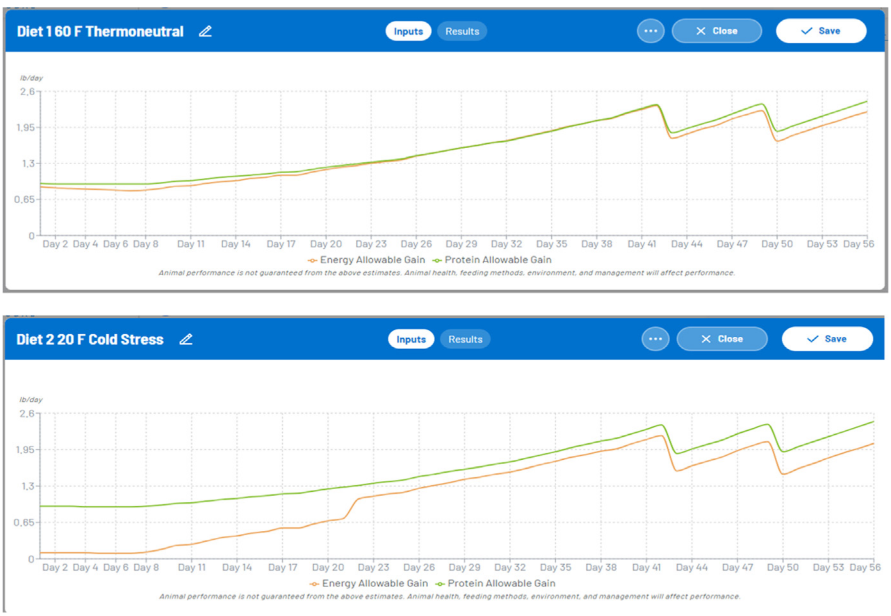

Fig. 4. Energy allowable gain (EAG) and protein allowable gain (PAG) results for comparison of calf growth performance between thermoneutral (60° F) and cold stress conditions (20° F) utilizing the Milk Specialties Global Calf Growth Model (https://toolkit.milkspecialties.com/).

EXAMPLE APPLICATION

As mentioned in the Introduction, one potential application of calf growth modeling programs is the evaluation of the impact of cold stress on the overall gain during the preweaning phase. The Milk Specialties Global Calf Growth Model will be used to demonstrate this application.

Two diets were created and the inputs are shown in Fig. 3. An MR 24 to 20 (24% CP – 20% Fat) was used as the liquid feed ingredient and a Calf Starter 18% (18% CP) was used as the dry feed ingredient. The feeding rates of the ingredients remained the same between the 2 diets. Calf inputs were also the same between the 2 diets, with the only difference being the temperature inputs. The thermoneutral diet temperature input was set to 60° F (15.6° C) and the cold stress diet temperature input was set to 20° F (−6.7° C).

The results of the modeling analysis are displayed in Fig. 4. Energy allowable gain (EAG) and protein allowable gain (PAG) are represented graphically for each day of the feeding period. Cold stress diverts energy resources from the diet toward meeting the increased maintenance energy needs of the calf, resulting in less energy available for gain. This is particularly noticeable during the first 3 weeks of the feeding period.

Fig. 5. Comparison of body weight gain between thermoneutral (60° F) and cold stress conditions (20° F) using Compare function within the Milk Specialties Global Calf Growth Model (https://toolkit.milkspecialties.com/).

The compare function within the Milk Specialties Calf Growth Model allows one to select and compare a result parameter between any 2 diets (**Fig. 5**). In this example application, cold stress resulted in a decrease of body weight gain of approximately 19 lb when compared with thermoneutral conditions. In a real-world situation, there are going to be daily fluctuations in the ambient temperature. Nonetheless, this example underscores the impact that cold stress can have on calf performance and although the predicted actual body weight gains may not exactly mirror real-world situations, the relative differences seen in body weight gain is enough to warrant a modification in the feeding program to provide more energy in the face of cold stress.

SUMMARY

The development of modeling concepts with the 2001 NRC[5] represented a big step toward understanding and applying the underlying mechanisms associated with young calf growth. Refinement of the modeling equations progressed with a series of well-designed detailed research studies in the early 2000s looking at the impact of varying levels of protein and energy on body composition and overall gain. Factors such as breed and environmental stressors impact calf growth. Investigation into delivering the proper amounts of energy and protein through the liquid and dry feeds to optimize growth needs to continue as well as further defining the most effective means to transition from the nonruminant to ruminant phase while minimizing postweaning lag.

As calves of superior genetic merit continue to be identified, the management and nutrition practices used to commercially raise dairy calves, either as replacements for the dairy herd or for meat, will require an ongoing refinement and utilization of tools to optimize calf growth. Calf growth modeling, not only during the preweaning phase but throughout the entire growth period, will be one such tool that can be used in this age of continuous improvement.

DISCLOSURE

Rich Larson has worked part-time and on a consulting basis for Milk Specialties Global, a manufacturer of rumen bypass fat supplements and milk replacers for the dairy industry.

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