Dairy Heifer Development and Nutrition Management

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KEYWORDS

• Dairy heifer • Development • Growth • Nutrition

KEY POINTS

- High rates of milk feeding decrease age at breeding, first calving, and increase first-lactation milk yield.
- Adequate prepubertal growth rate is needed to attain a breeding age for a 22-month to 24-month first calving age.
- Proper nutritional management postbreeding is needed to control growth rate and minimize cost and nutrient inputs.

INTRODUCTION

Raising dairy heifers requires significant resources (feed, time, facilities) that make up about 25% of a dairy farm's production costs. Of these costs, feed typically comprises about 50% of the total cost of raising dairy heifers.[1] The goal of raising dairy heifers is to have optimal growth to calve between 22 and 24 months of age while minimizing inputs (feed, time, labor) and nutrient output in manure. Understanding impacts of nutritional management on heifer development is essential to raising heifers that are efficient and profitable. This article focuses on current feeding strategies and impacts on calf and heifer growth, feed efficiency, nutrient use/output, and future lactation performance.

HEIFER GROWTH

Calving first-lactation cows at 22 to 24 months of age with an optimal body weight is most favorable for decreasing feed costs for heifer rearing and increasing productive life.[2] Calving at this age requires adequate growth rates to attain target weights at breeding and calving. The desired weights at breeding, precalving, and postcalving are 55%, 94%, and 85% of mature body weight (MBW), respectively, to maximize future milk yield.[3] Desired growth rate thus depends on the desired age at calving and estimated body weight at calving (94% of MBW) to calculate the number of

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days for growth and the total weight gain before calving. Typical recommended body weight gain from birth to calving (included conceptus gain) is 0.8 kg per day for Holstein heifers with a breed average MBW of 682 kg and a calving age of 24 months.

- The calculation to derive the gain needed from birth to precalving is:

$$((682 \text{ kg MBW} \times 0.94) - 42 \text{ kg birth weight})/730 \text{ days} = 0.82 \text{ kg gain per day}$$

However, MBW is variable depending on breed and genetic variance of mature weight, which can be as large as differences between breeds.[4] To determine MBW of heifers can be difficult and simply using an average body weight of mature cows (in third or greater lactation) as a starting point may not reflect the mature body size of the heifers. Hoffman[4] suggested to use a surrogate MBW (MBWs) to more accurately estimate MBW of the heifer. The MBWs is the 0 to 2- day postcalving dam body weight multiplied by an adjustment factor to adjust to a fourth-lactation MBW if the cow is in lactation 1 to 3. This value should better reflect genetic inheritance of body size from the dam.

Factors to adjust in 0 to 21-day postcalving cows:

First lactation	1.176
Second lactation	1.087
Third lactation	1.042

An example calculation for a 13-month-old heifer (breeding age):

Heifer weight = 400 kg; dam weight beginning of second lactation = 670 kg

$$400\text{-kg heifer}/(670\text{-kg dam} \times 1.087) = 400\text{-kg heifer}/728\text{-kg dam MBWs} = 54.9\% \text{ of MBW}$$

Overall, heifer growers should focus on growing heifers with an adequate rate of gain without excessive body condition.

Maintaining optimal gains ensures favorable heifer development. Inadequate gains extend the breeding and calving ages, causing additional feed costs of rearing. Higher rates of growth may allow breeding and calving at target age but excess gain (especially adipose tissue) may cause dystocia or calving difficulties and other transition cow metabolic diseases. Also, excess gain as a prepubertal heifer between 3 and 10 months of age has been thought to cause accumulation of adipose deposits in the mammary gland, reducing mammary excretory tissue and subsequent milk production.[5] However, recent research shows that feeding for higher prepubertal weight gain does not negatively affect mammary development or lactation performance.[6,7]

Breed and genetic variance on each farm leads to heifers having different weights at different ages. Regular measuring of weight (ideally using an electronic scale) and height at approximately 12 months of age and before calving provides important information for managing and evaluating heifer growth and breeding and calving size/age. Weighing at 12 months of age also allows herd managers to evaluate whether the heifer is large enough for subsequent breeding starting at approximately 13 months of age. **Fig. 1** shows growth curves for heifers with 3 different MBW causing different growth rates needed to reach their MBW. A Universal Growth Chart estimation tool has been developed by Pat Hoffman, Emeritus Professor at the University of Wisconsin-Madison (http://fyi.uwex.edu/heifermgmt/growth-charts) to assess body weight based on percentage of estimated MBW, which is more useful than simply using a growth

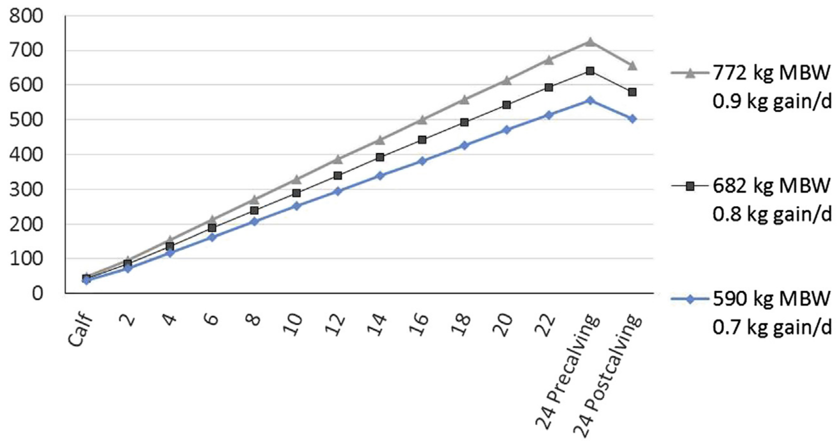

Fig. 1. Growth curves for heifers with estimated MBW of 590, 682, and 772 kg. Legend includes average daily gain needed to attain precalving weight. (*Courtesy of* P.C. Hoffman, MS Dairy Science, Marshfield, WI: Universal Heifer Growth Chart; http://fyi.uwex.edu/heifermgmt/growth-charts.)

chart with breed average data. The spreadsheet tool can be used to estimate the body weight that heifers should reach each month of growth depending on the estimated MBW.

HEIFER DEVELOPMENT: NEWBORN CALF TO WEANING

Before discussing development of calves, a short review of the importance of colostrum is needed. As most producers, nutritionists, and veterinarians know, proper colostrum management is necessary to provide passive immunity to newborn calves. Three main factors are important to managing colostrum: timing, quantity, and quality. Colostrum should be given as soon as possible after calving (preferably within 3 hours). Intestinal absorption ability of colostrum immunoglobulins decreases rapidly, with only 50% absorption by 9 hours after birth. Calves should be fed colostrum at 12% to 15% of body weight (for a 40-kg [90 lb] calf this would equal 3.8 L [4 quarts]). A second feeding of 2.0 L (2 quarts) of colostrum at 12 hours after birth is generally recommended. Colostrum quality refers to both cleanliness and immunoglobulin content. Colostrum should be free from blood, dirt, and manure, and be from cows not testing positive with *Mycoplasma paratuberculosis*. Good-quality colostrum should contain at least 50 g of immunoglobulins per liter measured using a colostrum meter or a refractometer. Samples measured using a Colostrometer must be at room temperature for accuracy. If colostrum is found to be of poor quality and no frozen source of quality colostrum is available, a colostrum supplement (to supplement colostrum with low immunoglobulin content) or colostrum replacer (as the only feed if usable colostrum is not available) can be used.

Calves, defined as animals individually fed liquid feed diets, are able to have the highest lean muscle growth compared with all other stages of heifer development. The goal for calf growth is to double the weight of the calf by weaning, so, for a calf weighing 42 kg at birth, the calf should weigh 84 kg by weaning. To reach this goal at a 6-week weaning age the calf must gain 1 kg per day and, if the weaning age is 8 weeks, the calf must gain 0.75 kg per day. The ability to attain this goal depends on the liquid feeding nutrition program (covered later in the article). For calves, muscle and skeletal growth should be the primary sources of weight gain, with minimal fat deposition. The amount of fat and muscle growth are highly dependent on the feeding rates of liquid feed and metabolizable energy and protein content of the milk replacer. If the diet is a conventional milk replacer with 20% protein and the calf is fed at a higher intake level with hopes to increase growth, the protein content will be inadequate to meet protein gain needs and the additional energy will cause excess fat gain. In another circumstance, if calves are fed an intensive program of milk replacer (ie, 28% protein) at lower levels of intake, the calves will have insufficient energy intake to use the protein for muscle growth.

Although body weight gain is often of primary consideration when discussing heifer development, digestive system (mainly the reticulorumen) development is essential for transition of calves from liquid to solid feed diets. Calves are born with a small, nonfunctional rumen that has minimal epithelial papillae and muscle development. Liquid feed does not initiate rumen development of either epithelial papillae or muscle growth. Solid feed fed to calves (mainly calf starter) containing high levels of highly fermentable carbohydrates (starch and sugars) is necessary for growth of the rumen papillae. This requirement is caused by the rumen microbial population fermenting starch and sugars to volatile fatty acids. One of the volatile fatty acids, butyric acid, is used preferentially by the rumen epithelial tissue for growth of papillae.[8] Growth of rumen papillae is important for calf digestive system development because rumen papillae are essential for absorption of volatile fatty acids. Feeding of forages to heifers increases rumen muscular development because of increased stimulation of the rumen contractions needed to move the rumen digesta. However, forages are not thought to be needed until after weaning because they may restrict starter intake and do not enhance the rumen papillae development needed for volatile fatty acid absorption.

NUTRITIONAL STRATEGIES FOR CALVES

During this phase of development, calves are functionally considered to be nonruminant animals with minimal to no dry feed intake the first 2 weeks of life. As nonruminants, calves receive their nutrients through liquid feed, which can have various forms and nutrient contents. Much recent research has shown that increasing growth rate of young calves leads to earlier breeding and calving, greater productive life, and greater first-lactation milk production.[2,9] An excellent review of calf nutrition from birth to weaning by Drackley[10] explains in detail the calf's nutrient requirements, liquid feeding options, milk replacer ingredients, and practical feeding regimes.

Producers have the option to feed a conventional limit fed, accelerated growth, or a moderate (between conventional and intensive) liquid feeding program to attain desired rates of growth before weaning. The conventional program is a strategy to feed liquid feed at approximately 8% to 10% of body weight, whereas the intensive program offers liquid feed at 16% to 20% of body weight. Typical formulation of conventional milk replacer is 20% protein and between 15% and 20% fat on an as-fed basis and is reconstituted to 12.5% solids. Intensive milk replacers are usually 26% to 28% protein on an as-fed basis with fat content similar to conventional milk replacer and are reconstituted between 12.5% and 17.5% solids. Pasteurized whole or waste milk is also an option and is often economical for large dairies that have enough waste milk to feed their calves. The greater liquid feed intake of intensive feeding programs is thought to be closer to what calves would eat if suckling from their mothers. The conventional program typically results in calves that have increased calf starter intake at an earlier age than calves on the intensive feeding program, but calves fed a conventional feeding program have lower energy and protein intakes from liquid feed compared with calves on an intensive program, resulting in lower growth rates, especially in the first 2 weeks of life[2,9] (**Table 1**). Calves fed an intensive feeding program have significantly greater daily gains from birth to weaning. Costs of feeding an intensive program are higher compared with conventional programs; however, heifers are bred and calve about 15 to 30 days earlier, which increases productive time. In addition, heifers fed an intensive feeding program have been shown to have increased first-lactation milk yield. The increase in first-lactation milk production may be further improved when the intensive program feeds whole milk compared with milk replacer. Calves fed ad-libitum whole milk and fed a higher protein diet from 150 to 320 days of age had increased first-lactation milk production compared with calves fed ad-libitum milk replacer. This finding was attributed to increased mammary fat pad mass, which had a paracrine and endocrine effect on mammary gland development[11] (**Table 2**). Feeding additional protein during the prepubertal period had a larger impact on milk yield than feeding whole milk[11] (**Table 3**). Expected growth rates of calves on conventional or intensive programs are 0.5 to 0.6 kg/d and 0.6 to 0.8 kg/d, respectively.[10] Postweaning nutrition to maintain higher gains of 0.9 kg/d are recommended until breeding age to attain an earlier breeding age.

An alternative to hand-feeding liquid diets that has gained much interest is the use of automatic milk feeding stations. Automatic feeders allow calves to consume liquid feed (ie, milk replacer, saleable milk, or waste milk) in more frequent meals than individual manual feeding systems. Calves are able to access the feeder a set number of times per day and eat a set meal size per visit. Managers can set the total feeding amount allowed, number of visits, and meal size per visit. The feed allowance per visit and total feed allowed per day affect the feeding behavior of calves. When the total feed allowance was 4 L per day compared with 8 L per day with 4 feeding visits allowed per day, the calves fed the lower amount had more unrewarded visits (no feed offered when visiting feeder) and more nonnutritive suckling after a feeding,[12] caused by the calves' hunger not being satisfied by the low feeding amount allowed and low amount allowed per visit. A manager can set a larger meal size and a low minimum number of visits to allow the calves greater feeding pattern flexibility.[13] To help diagnose health issues, the feeding system is able to alert managers to assess

Table 1
Effect of intensive milk replacer feeding on heifer development and lactation performance

	Treatment		
	Conventional	**Intensive**	***P* Value[a]**
Milk Replacer Intake (kg DM)[a]	0.60	1.03	<.01
Starter Intake (kg DM)[a]	0.39	0.20	<.01
Starter Intake 6–8 weeks (kg DM)	2.33	2.29	.58
Average Daily Gain 2–42 d (kg)	0.44	0.64	<.01
Hip height at 42 d (cm)	83.6	86.3	<.01
Age at Puberty (d)	301	270	<.01
Body Weight at Puberty (kg)	307	287	<.01
First-lactation Average Milk Yield Through 150 DIM (kg/d)	33.1	33.3	.86
First Lactation PA Corrected Projected 305-d Milk Yield (kg)	9712	10,128	.08

Abbreviations: DIM, days in milk; DM, dry matter; PA, parent averages used as covariate.
[a] Milk replacer and starter intake were from preweaning period (birth to 6 weeks of age).
Data from Davis Rincker LE, VandeHaar MJ, Wolf CA, et al. Effect of intensified feeding of heifer calves on growth, pubertal age, calving age, milk yield, and economics. J Dairy Sci 2011;94:3554–67.

Table 2
Effect of feeding ad-libitum milk replacer or whole milk on heifer development and milk production

	Treatment		
	Milk Replacer	**Whole Milk**	***P* Value**
Milk Intake (kg DM)	1.19	1.09	<.01
Starter Intake (kg DM)	0.17	0.18	.62
Body Weight at Weaning (kg)	82.7	85.8	.03
Average Daily Gain to Weaning (kg/d)	0.733	0.807	.01

Data from Moallem U, Werner D, Lehrer H, et al. Long-term effects of ad libitum whole milk prior to weaning and prepubertal protein supplementation on skeletal growth rate and first-lactation milk production. J Dairy Sci 2010;93:2639–50.

calves for disease when individuals have fewer than the expected number of visits to the feeders; however, regular observation for calf health is still needed with these systems. Group feeding reduces socialization problems associated with housing changes at weaning; however, these systems can also increase disease incidence if proper facility ventilation and cleanliness are not maintained.

Transition of calves from a diet that combines both liquid and solid feed to a diet that consists of only solid feed requires adequate dry feed intake (typical recommendations are at least 1.2 kg starter intake per day for 3 consecutive days before weaning) to maintain growth rates after weaning. It is recommended to allow a 1-week time frame to reduce liquid feedings to once per day, during which time starter intake is stimulated and rumen development is increased so that the calves are prepared for weaning. Intensive feeding programs may require 2 weeks to reduce liquid feedings to allow increased starter intake to transition calves before weaning. The same calf starter should be used before and after weaning to reduce feed changes and encourage feed intake.

A controversial topic in calf feeding is the optimum time to start feeding forages, with the common recommendation to wait until after weaning to offer high-quality

Table 3
Effect of feeding ad-libitum milk replacer or whole milk and increased dietary protein during prepubertal period (150–320 days of age) on heifer development and milk production

	Treatment				*P* Value		
	MRC	**MRP**	**WMC**	**WMP**	**Milk**	**Protein**	**M × P**
Age at First AI (d)	452	456	426	434	.05	.61	.87
Age at First Calving (d)	750	740	705	745	.24	.39	.15
Body Weight at Calving (kg)	532[ab]	521[b]	535[ab]	559[a]	.10	.57	.14
4% Fat-corrected Milk Yield (kg)	28.5[bc]	27.6[c]	29.1[b]	31.0[a]	.001	.27	.03

Means within rows with different superscript letters (a–c) differ ($P<.05$).

Abbreviations: AI, artificial insemination; MRC, ad-libitum milk replacer with no added protein during prepubertal period; MRP, ad-libitum milk replacer with 2% added protein during prepubertal period; WMC, ad-libitum whole milk with no added protein during prepubertal period; WMP, ad-libitum whole milk with 2% added protein during prepubertal period.

Data from Moallem U, Werner D, Lehrer H, et al. Long-term effects of ad libitum whole milk prior to weaning and prepubertal protein supplementation on skeletal growth rate and first-lactation milk production. J Dairy Sci 2010;93:2639–50.

hay. Forages are less digestible than concentrates such as calf starter mixes and can reduce intake of starter and thus energy intake if fed before weaning. Cellulose digestion is limited in calves because of their limited capacity for rumen digesta, limited microbial fermentation, and rumen pH less than 6, which reduces cellulolytic bacteria fermentation.[14] However, recent research with calves fed an intensive liquid feeding program showed improved dry feed intake when offered both calf starter and chopped orchard grass hay compared with being offered only calf starter.[15] Rumen weight, size, and pH were also increased when feeding hay, but no differences in rumen thickness, papillae length, body weight, or size were found. Additional research is needed to evaluate feeding forages (including silages such as corn silage that contain high levels of fermentable starch) before weaning.

HEIFER DEVELOPMENT: WEANING TO BREEDING

After weaning, heifer development continues with high rates of protein/muscle weight gain and low rates of adipose gain desired. During this period, heifers can be fed to gain 0.9 kg/d to reduce days until breeding, and thus calving, compared with lower rates of daily weight gain. The farm's goal for age at first calving dictates when the heifers need to be bred in order to meet that goal. For instance, if the farm wants heifers to calve at 22 months of age, then the heifers must be bred by 13 months of age. Heifer body weight at breeding should be 55% of MBW. Thus, if the weaning weight, breeding weight, and goal for age at breeding are known, the growth rate from weaning to breeding can be calculated. If a heifer has an estimated MBW of 682 kg, a weaning weight of 82 kg at 2 months of age, and a weight at breeding (13 months of age) of 375 kg, then the heifer must gain 0.9 kg per day.

From about 3 to 9 months of age, mammary development occurs at a faster rate than in other organs (allometric growth) and can be affected by nutrition during this period. When fed excess energy, epithelial tissue cell proliferation was decreased and additional adipose tissue was deposited in the mammary gland, which was associated with reduced later milk production.[5] More recent work has shown that additional energy during the postweaning time frame increased mammary parenchymal DNA but no improvement in milk production was observed.[7] Prebreeding heifer diets should be formulated with adequate metabolizable protein to meet the demand for lean growth. Excess energy intake should be avoided prebreeding to reduce adipose tissue deposition. Heifer body condition should be observed for excess adipose deposition, especially when feeding for faster weight gains to allow for earlier breeding and calving. Nutrient recommendations for an 0.8-kg gain per day for various weight class heifers are provided in **Table 4**. Additional details on nutrient requirements for metabolizable protein, minerals, and vitamins can be found in the 2001 *Nutrient Requirements of Dairy Cattle*.[16] Producers should consult with a nutritionist to balance diets that meet specific animal groups' needs because the National Research Council recommendations do not consider MBW or environmental effects (temperature, wind, mud) that affect nutrient needs.

Research into controlled or restricted growth rates during the prepubertal rearing period has shown improvements in lactation performance compared with ad-libitum prepubertal feeding. Lammers and colleagues[17] fed prepubertal heifers differing amounts of the same diet (16% crude protein; 2.7 Mcal/kg of metabolizable energy) resulting in gains of 0.7 kg and 1 kg per day. The heifers with 0.7-kg daily gain had 7% greater milk production than those with 1-kg daily gain, which was attributed to different mammary development (**Table 5**). No differences in age or weight at first calving were found because the heifers fed to gain 0.7 kg/d had significant

Table 4
Diet energy and protein requirements for large-breed dairy heifers gaining 0.8 kg/d in a thermoneutral environment

	Heifer Body Weight (kg)			
	150	**300**	**450**	**600 (240 d Pregnant)**
DM Intake (kg/d)	4.2	7.1	11.3	13.0
Crude protein (% of DM)[a]	15.9	12.3	11.0	12.9
Rumen-undegradable Protein (% of CP)	4.5	2.6	1.4	3.1
Rumen-degradable Protein (% of CP)	10.4	9.7	9.6	9.8
Total Digestible Nutrients (% of DM)	67.7	63.4	57.7	64.0
Metabolizable Energy (Mcal/kg)	2.45	2.28	2.08	2.31
Calcium (% of DM)	0.74	0.50	0.37	0.46
Phosphorus (% of DM)	0.36	0.24	0.18	0.23

Abbreviations: CP, crude protein; DM, dry matter.
[a] Crude protein required only if rumen-degradable and undegradable protein balanced.
Data from NRC. Nutrient requirements of dairy cattle: seventh revised edition. Washington, DC: National Academy Press; 2001. p. 276–9.

compensatory growth posttreatment. Ford and Park[18] assessed a stair-step feeding system with periods of restricted feeding followed by feeding a high-energy diet to enhance compensatory growth. The investigators fed heifers at 70% of ad-libitum intake of a high-protein diet (17% crude protein and 2.35 Mcal/kg metabolizable energy) to allow similar protein, mineral, and vitamin intakes as the controls but lower energy intakes during 3 specific time periods of isometric growth in which the mammary gland develops at similar rates to other tissues. They then followed the growth restriction by feeding a high-energy diet (12% crude protein and 3.05 Mcal/kg metabolizable energy) during periods of allometric mammary development. This stair-step feeding pattern led to improved milk production in first (21% greater) and second (15% greater) lactations. The increase was attributed to altered growth hormone levels and increased mammary development, especially during periods of compensatory growth during gestation. The 3-step method described would be difficult for producers to implement so the investigators are now investigating a simpler 1-step system during the last trimester of gestation because the most critical stage for mammary development occurs at that time.

Table 5
Effect of accelerated prepubertal gain (19–39 weeks of age) on weight and age at first calving, and first-lactation performance

	Treatment		
	0.7 kg/d	**1 kg/d**	***P* Value**
Puberty Age (mo)	334	311	.01
Body Weight at Puberty (kg)	294	306	NS
Body Weight at Calving (kg)	632	620	NS
Age at Calving (mo)	22.9	22.9	NS
4% Fat-corrected milk yield (kg)	8040	7750	.01

Abbreviation: NS, no significant treatment effect.
Data from Lammers BP, Heinrichs AJ, Kensinjer RS. The effects of accelerated growth rates and estrogen implants in prepubertal Holstein heifers on estimates of mammary development and subsequent reproduction and milk production. J Dairy Sci 1999;82:1753–64.

Determining the proper timing of heifer breeding ensures that heifers are of adequate size for carrying a calf to term and to minimize later negative effects (dystocia and low milk production) when heifers calve earlier than 22 months of age. However, overly cautious age at first breeding can delay conception and the start of lactation. Consideration of both age and body size is useful to ensure that heifers are bred in a timely manner and are of proper size. Prescreening heifers at 12 months of age for body weight provides valuable information to indicate whether individuals are ready for breeding (at or greater than a certain goal weight at breeding)[19]; for example, having a goal of heifers weighing at or greater than 390 kg at 12 months of age to be eligible for breeding. This specific weight goal depends on the MBW and the percentage of MBW at breeding (55%–60% of MBW).

In addition to muscle, skeletal, and mammary growth during this time, the rumen is still developing by increasing in size and microbial populations. As the rumen size increases, heifers are able to consume high-forage, lower cost diets because of increased volume and retention time of slowly fermented fiber. At weaning, heifers are usually eating only a starter concentrate mix with minimal fiber content. After weaning, forages should be slowly increased in the heifers' diet to avoid decreasing concentrate intake and weight gain. High-quality, fine-stemmed hay is preferred to encourage forage intake. Silages are generally not recommended until 3 months of age because of lower dry matter intakes, possible mold contamination, and poor ruminal use of highly degradable protein and nonprotein nitrogen by young heifers. Research by Dennis and colleagues[20] showed that heifers (approximately 4 months of age) fed grass hay had increased growth compared with those fed grass baleage because of increased dry matter intake of the grass hay diet. Additional research is needed to evaluate the possibilities of feeding silages to preweaned and postweaned calves and associated impacts on growth and future production. Total mixed rations containing forage and concentrates are useful to reduce sorting of forages to ensure that heifers eat the desired diets. A useful method to transition heifers to a total mixed ration is to slowly replace part of the concentrate/hay diet with the total mixed ration each day over 2 to 4 weeks.

HEIFER DEVELOPMENT: BREEDING TO CALVING

Heifer development after breeding should focus on maintaining adequate growth rates while minimizing excess body condition gains. As heifers mature, the rate of lean tissue deposition decreases while adipose deposition rate increases. Heifers can quickly become overconditioned even on moderate-quality forages fed ad libitum or if diets with higher energy contents are not limited appropriately. Excess adipose tissue deposition during this period results in negative effects on heifers as they transition to lactation. These negative effects include increased metabolic problems,[21] dystocia,[22] and lower milk production.[23] Body condition scoring is a simple method for managers to monitor the condition of the cow and heifer herd, with a body condition score of 3.5 desired at calving.

NUTRITIONAL STRATEGIES FOR OPTIMUM HEIFER DEVELOPMENT

After weaning, most nutritional strategies focus on growing heifers at an adequate rate to breed and calve at the desired age with the least amount of feed and cost inputs. Ensuring heifers are bred at the correct weight and age range for calving between 22 and 24 months of age also ensures that producers are not feeding heifers for an extended period of time. An excellent reproductive program that results in heifers being bred at the correct age and weight with a high service and conception rate ensures that heifers calve within a producer's first calving age goal. A poor reproductive program that has a low service rate and conception rate causes a wide range in calving ages and additional days on feed, which significantly increases costs. A useful tool to evaluate a heifer reproductive program was developed by Pat Hoffman and Victor Cabrera from the University of Wisconsin-Madison Department of Dairy Science (http://dairymgt.uwex.edu/tools/heifer_pregnancy_rate/index.php). Producers enter each heifer's first calving age and the tool calculates average age at first calving, graphs the distribution of calving ages, and calculates the number of excess days on feed and the costs associated with these additional growing days.

Improving heifer feed efficiency has received much interest from producers and researchers in an attempt to reduce feed inputs and manure output. In addition to targeting high feed efficiency, heifer nutritional programs must minimize risk of overconditioning. Limit-feeding heifers to only the energy amount needed and not allowing ad-libitum intake greatly improves feed efficiency and helps control body condition. Another option for bred heifers is to feed forages with lower nutritive values with higher neutral detergent fiber (NDF) content because these heifers have lower requirements for energy and protein compared with lactating cows. Feeding higher fiber diets has the potential to reduce ad-libitum feed intake because heifers have an intake limit of approximately 1% of body weight as NDF.[24] Several alternative forages and low-nutritive-value roughages can be used, which control energy intake and fat gain but can result in reduced feed efficiency. The use of these strategies should be based on the producer's management potential, facility stocking rate/bunk space, and feed costs.

Limit-feeding is a strategy to feed heifers to meet nutrient requirements (amounts of energy, protein, minerals) but at lower feed intake by feeding a diet with a greater nutrient density. Reasons for using limit-feeding include control of heifer overconditioning, improved feed efficiency by reducing feed usage with similar weight gains, and reduced fecal output. A limit-fed diet has a higher nutrient density that is offered in a daily amount to meet the nutrient amount required by the heifer for maintenance and growth. For example, if a heifer requires 5 kg of total digestible nutrients (TDN) and the diet contains 70% TDN on a dry matter basis, then the heifer only needs to be fed 7.1 kg of dry matter in the diet. This system is different from an ad-libitum feeding system, in which a less nutrient-dense diet is fed and the animals are allowed to eat as much as they are able to eat to satisfy their gut fill. Feeding an ad-libitum diet leads to lower feed efficiency and possibly excess body weight and condition gain if the diet is not balanced correctly for lower energy content. Hoffman and colleagues[25] fed bred heifers diets with either 67.5%, 70%, or 73.9% TDN, dry matter basis. The different energy contents were formulated by increasing dry corn and soybean meal and decreasing corn silage and oatlage. The 67.5% TDN diet was fed ad libitum and the 70% and 73.9% TDN diets limit-fed at 90% or 80% of their ad-libitum intake. The limit-fed heifers had similar weight gains with 10% to 20% less dry matter intake, 10% to 25% less manure excretion, and 30% higher feed efficiency (**Table 6**). Nitrogen and phosphorus excretion were similar between the ad-libitum and limit-fed heifers because the diets were fed so heifers had similar intakes of both nutrients. Zanton and Heinrichs[26] compared feeding an ad-libitum high-forage (75% forage) diet and a limit-fed high-concentrate (75% concentrate) diet to prepubertal heifers for 35 weeks. The limit-fed high-concentrate diet was fed so the heifers received nutrient amounts that were similar to the ad-libitum diet. Results were similar to those of Hoffman and colleagues,[25] with similar weight gains, skeletal growth, and improved feed efficiency for the limit-fed diet (**Table 7**). However, feeding the higher concentrate limit-fed diet caused increased paunch girth, which was thought to be caused by greater fat deposition. Also, the limit-fed heifers had increased milk fat yield and

Table 6
Effect of limit-feeding on bred heifer growth and first-lactation milk yield

	Treatment			
	C100	L90	L80	Contrast C vs L (*P* Value)[a]
Intake (kg DM)	10.0	9.1	7.8	.002
DM Excretion (kg)	3.5	3.1	2.6	.10
Average Daily Gain (kg/d)	0.754	0.872	0.835	NS
Feed Efficiency (kg DM/kg Gain)	12.8	10.4	9.9	.09
3.5% Fat-corrected Milk (kg/d)	32.3	31.6	32.9	NS

Treatments: C100, ad-libitum feed allowance; L80, fed 80% of C100 diet; L90, fed 90% of C100.
Abbreviation: DM, dry matter.
[a] Contrast comparing the ad-libitum fed diet (C100) versus the mean of the limit-fed diets (L90 and L80).
Data from Hoffman PC, Simson CR, Wattiaux M. Limit feeding of gravid Holstein heifers: effect on growth, manure nutrient excretion, and subsequent early lactation performance. J Dairy Sci 2007;90:946–54.

fat-corrected milk yield, which was thought to be caused by increased body fat available for mobilizing into milk. There is some concern that limit-feeding has some negative carryover effects on rumen volume and milk yield. However, Kruse and colleagues[27] found no differences in rumen volume, digesta weight, postcalving body weight, or milk production of heifers fed ad-libitum or limit-fed diets at either 85% or 80% of ad-libitum intakes.

The cost of using a limit-feeding strategy needs to be considered because the diet possibly contains additional purchased ingredients (energy and protein sources) leading to increased feed costs. Bach and Ahedo[28] in 2008 calculated the feed costs for the limit-fed rations used by Hoffman and colleagues[25] and found that the ad-libitum ration was $1.70 per day, whereas the 90% and 80% limit-fed diets were $2.10 and 2.70 per day respectively. Use of linear programming to reformulate the limit-fed diets with lower cost byproduct feeds to decrease feed cost may result in limit-fed diets with more similar costs to a high-forage diet. However, the feed costs do not consider the important aspect of reducing manure excretion and possibly lower nutrient excretion compared with a high-forage ad-libitum diet.

Table 7
Effect of controlled feeding of a high-forage diet or high-concentrate diet on prepubertal heifer growth and first-lactation milk yield

	Treatment		
	HF	HC	*P* Value
Intake (kg DM)	5.96	5.32	<.001
Prepubertal Daily Gain (kg/d)	0.828	0.827	.94
Feed Efficiency (kg Gain/kg DM)	0.142	0.156	<.002
Body Weight at Calving (kg)	536	560	.17
Body Weight Loss to Nadir (kg)	43	76	.01
305-d 4% Fat-corrected Milk (kg)	8343	9681	.02

Both diets fed to attain 0.8 kg daily prepubertal gain.
Abbreviations: DM, dry matter; HC, diet with 75% concentrate; HF, diet with 75% forage.
Data from Zanton GI, Heinrichs AJ. The effects of controlled feeding of a high-forage or high-concentrate ration on heifer growth and first-lactation milk production. J Dairy Sci 2007;90:3388–96.

Implementation of limit-feeding programs requires precise feeding management to ensure that animals are fed correct feed amounts and to void overfeeding or underfeeding heifers. Use of a mixer wagon with weigh scales is necessary and regular analysis of dry matter content of wet feeds (at least weekly and whenever feeds change) is needed to adjust ratios of as-fed ingredients in the diet because small changes in dry matter content change the amounts of nutrients fed. Working with a nutritionist is needed to balance limit-fed diets according to heifer requirements and adjust intake amounts as heifers increase intake as they increase in size. After feeding a limit-fed diet, animals have aggressive feeding behavior, with most of the feed being consumed within 1 to 2 hours. A feed push-up should be done within 1 hour so that heifers are not reaching for feed, which could cause increased shoulder abrasions and inner hoof wear on the front hoofs caused by pushing forward to reach feed. Having adequate bunk space is important when feeding limit-fed diets to ensure that all heifers can eat at the same time. If inadequate space is available, submissive heifers may have lower intakes and insufficient weight gain.

Feeding a high-forage diet with higher NDF and lower energy density is also an option for producers to control weight gain and prevent overconditioning of heifers. However, corn silage–based diets can have excess energy for bred heifers, causing overconditioning and subsequent negative lactation effects. Heifers are only able to consume approximately 1% of body weight at NDF[24] and this can be used to formulate diets to control intakes and weight gain, especially for bred heifers. Use of high-fiber forages such as straw or mature forages with high-energy feedstuffs has the potential to reduce diet dry matter and energy intake. Coblentz and colleagues[29] evaluated eastern gamagrass, straw, and corn stover as options to increase diet NDF content and dilute energy content. The control diet contained corn silage and alfalfa silage and was 44% NDF, 66.8% TDN, and 13.9% crude protein, dry matter basis. Treatment diets contained the diluting forages to increase NDF to about 50%, decrease TDN to approximately 60%, and maintain protein between 13.6% and 13.8%. Heifers fed diets with the diluting forages had lower feed and energy intake leading to a more desirable average daily gain of between 0.8 and 1.0 kg/d, compared with 1.16 kg/d for those fed a corn silage/alfalfa silage diet (**Table 8**).

Table 8
Effect of feeding a corn silage/alfalfa silage diet with or without forage dilution on bred heifer growth

	Treatment				Contrast *P* Value (Control vs Mean of EGH, WS, CF)
	Control	EGH	WS	CF	
Intake (kg DM)	11.06	10.55	9.48	10.09	<.001
Digestible NDF (kg)[3]	2.92	3.04	2.82	2.91	.98
TDN Intake (kg)[4]	7.39	6.22	5.66	5.97	<.001
Fecal DM Output (kg/d)	3.76	4.12	3.48	3.58	.62
Average Daily Gain (kg/d)	1.16	0.98	0.79	0.97	<.001
Final Body Condition Score	3.7	3.6	3.3	3.5	.001
Feed Efficiency (kg DM/kg Gain)	9.6	10.8	12.1	10.5	.002

Control was a corn silage-alfalfa silage diet.

Abbreviations: CF, control diet diluted with chopped corn fodder; DM, dry matter; EGH, control diet diluted with eastern gamagrass haylage; NDF, neutral detergent fiber; TDN, total digestible nutrients; WS, control diet diluted with chopped wheat straw.

Data from Coblentz WK, Esser NM, Hoffman PC, et al. Growth performance and sorting characteristics of corn silage-alfalfa haylage diets with or without forage dilution offered to replacement Holstein dairy heifers. J Dairy Sci 2015;98:8018–34.

Use of the diluting forages reduced body condition score, which may help reduce metabolic and dystocia issues at calving. In addition, use of eastern gamagrass haylage resulted in minimal sorting, which is often a problem with using straw or corn fodder and can lead to variable intake and weight gains between animals within a pen. Further research is needed to identify forages that can dilute diet energy, lead to minimal sorting, and are economical to produce.

SUMMARY

Heifer development and production are vital parts of a dairy farm and deserve close attention to ensure proper growth and subsequent lactation performance. The main goal of heifer production is to raise heifers to calve between 22 and 24 months of age while minimizing costs and nutrient excretion and potentially improving subsequent milk production. The optimal first calving age is 22 to 24 months of age, with early calving (especially before 22 months of age) leading to lower first-lactation milk yield, whereas calving after 24 months of age results in excess days on feed and cost of heifer rearing. Feeding higher milk or milk replacer amounts preweaning improves subsequent milk production compared with conventional feeding programs. Prepubertal rates of gain should be based on desired first calving age and estimated MBW and the proper nutrition program balanced for that gain. Excessive energy intake leading to overconditioning should be avoided, especially postbreeding because of potential dystocia and metabolic disease. Understanding of heifer development principles is useful to improve heifer rearing practices and management.

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