Growth Standards and Nutrient Requirements for Dairy Heifers - Weaning to Calving

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Take Home Message

- Age and size at first calving has a large bearing on lifetime production and profit.
- Holstein heifers should calve the first time by 22 to 24 months of age weighing 550 – 600 kg.
- In addition to body size at calving, rate of growth during various times of the rearing period can have an impact on mammary development, and lifetime performance.

The goal of a dairy heifer-rearing program is to provide a regimen, which will enable the heifer to develop her full lactation potential at the desired age and at a minimum of expense. There is almost uniform agreement that the Holstein heifer should enter the milking string at a post-calving weight of no less than 545 kg and at no more than 24 months of age. This recommendation has been generated from numerous studies and the examination of several different DHI data sets. Ohio State workers (Gill and Allaire, 1976) found that optimum age at first calving for lifetime performance was 22.5 to 23.5 months. Profit per day of herd life was optimized at a first calving age of 25 months. Although age at first calving has a strong influence on profit and heifer performance, body weight has been shown to be more important in determining first lactation yield.

Keown and Everett (1986), in an examination of Northeast DHI records found highest yield occurred when heifers weighed between 544 and 567 kg. after their first calving. A more recent examination of this data in the northeast concurred with their findings. It has also been shown that production declines as post calving body weights exceed 660 kg probably due to problems associated with over conditioning and dystocia.

■ Growth Standards

Growth standards used in the 6th revised edition of the Nutrient Requirements for Dairy Cattle were questioned as they represented data collected 30 to 50 years ago from a limited number of experiment stations. Historically, body size has been measured by body weight. Only within the past 10 years has sufficient data on wither height been collected to enable workers to evaluate the relationship of height to weight and its association with 1st and later lactation performance. Experience tells us that these measurements may not completely describe body growth of dairy heifers. Heinrichs and Hargrove (1987) studied 6,000 Holstein heifers in 148 herds located in 33 different counties in Pennsylvania from 1983 to 1985 in an effort to better describe body size and relate it to herd performance under field conditions. They found heifers to be larger, on the average, in nearly every age as compared to previously quoted standards. Rolling herd average for milk yield was positively correlated with height (+. 41) and weight (+. 34) and negatively with age at first calving (-.22).

Later in 1992, as a part of the National Animal Health Monitoring System (NAHMS) survey, Heinrichs and Losinger (1997) examined data collected on hearth girth and wither height on over 650 Holstein dairy farms from across the U.S. Means and standard deviations for height and weight (as estimated by heart girth measurements) were determined from .5 to 23.5 months of age. The data (Table 1) showed a slight increase in height and weight in current heifers as compared to those measured over 40 years ago. The NAHMS study showed a strong positive association between heifer growth and rolling herd average milk production. This was particularly true when examining body size of younger animals. Heifers were largest in the midwestern states, intermediate in the west and Northeast and smallest in the southeastern states. These differences in size were attributed to differences in feeding strategies. In the southeastern U.S., heifers are typically reared in less intensive pasture systems where monitoring of heifer growth and routine supplementation are the exception rather than the rule.

Table 1. Median, 75th and 95th percentile weights and heights indicated for Holstein heifers in the NAHMS project.

	Weight (kg)			Height (cm)		
Age (mo.)	Median	75th	95th	Median	75th	95th
1	54	62	65	79	84	84
3	96	106	129	89	91	96
5	141	154	187	96	99	102
7	192	213	246	104	109	114
9	241	271	320	109	114	119
11	290	324	353	117	119	124
13	331	368	415	119	124	129
15	383	423	485	124	129	135
17	423	466	541	127	132	137
19	458	494	581	129	134	137
21	494	541	624	132	137	142
23	522	581	645	135	137	145
24	532	591	702	135	140	145

From Heinrichs, A. J. and B. Lammers, 1998. Monitoring Dairy Heifer Growth, Pennsylvania State University Cooperative Extension, University Park, PA.

Based upon a survey of existing literature Hoffman (1997) provided recommendations for optimum body size for Holstein heifers of the current genotype present in the U.S. and Canada, which include weights from birth to calving at 24 months. (Table 2) Note that 24-month weights represent pre-calving weights; with seven and 30-day post partum weights for comparison. The breed average optimal <u>prepartum</u> body weight was determined to be 620 kg, which was midpoint in the range between 590 and 635 kg. Based on the data from Yerex et al (1988), 25 kg body weight was added or subtracted from the midpoint to account for genetic variance of weight. Calves were assumed to weight 42 kg at birth and weaning was at 2 months with a weight of 84 kg. Linear growth was assumed to occur between 2 months and the prepartum body weight of 620 kg. These assumptions necessitate an average daily gain of approximately 800 kg. Postpartum body weight at 7 and 30 days were achieved by reducing prepartum body weight by 9.9 and 16.1% respectively. The agreement of the commercial herd survey data of Heinrichs and Losinger and that of Hoffman instills confidence that these values represent realistic growth targets for North American Holsteins.

Table 2. Optimum body size criteria of Holstein replacement heifers at first calving.

Criteria	Average	Lower	Upper
Body weight, kg (14 d prepartum)	621	596	646
Body weight, kg (7 d postpartum)	560	537	582
Body weight, kg (30 d postpartum)	522	500	542
Wither height, cm	139	138	141
Body length, cm	171	169	173
Pelvic area, cm^2	>260	>260	>260
Body condition score	3.5	3.5	3.5

[1] Measured from the point of shoulder to the ischium.
All measurements other than weight represent the animal after calving.
Adapted from Hoffman, PC. (1997) J. Animal Science 75:836-845.

Although body weight data is more readily available, other measures of heifer growth should be considered. Skeletal measurements such as wither height; body length and pelvic area are related to first lactation yield and dystocia. Heinrichs and Losinger (1997) obtained estimates of body weight through use of heart girth measurements. Prior to the NAHMS study they developed equations to predict body weight based upon various body measurements obtained from research data sets (Heinrichs et al., 1992). These equations are shown in Table 3. Based upon an examination of numerous studies it is obvious that there is considerable agreement in the relationship between wither height and body weight. Body length (from the point of the ischium to the hip) appears to be another measure with considerable potential for describing skeletal growth. The equation shown in Table 3 accurately predicts body length up to a body weight of approximately 500 kg. Beyond this point the prediction is less accurate due to the lack of sufficient data. Pelvic area is negatively correlated to dystocia and is another measure with merit in defining skeletal size.

Table 3. Equations to predict body weight of Holstein replacement heifers from various body measurements [a]

Measurement (x)	Quadratic Equation	R^2
Heart girth, cm	$BW = 102.71 - 2.876x + .02655x^2$	.99
Wither height, cm	$BW = 632.13 - 16.837x + .11989x^2$	.96
Hip width, cm	$BW = 5.28 - 1.613x + .23436x^2$	.98
Body length, cm	$BW = 96.0 - 3.324x + .03432x^2$	.96

[a] Adapted from Heinrichs et al. (1992)
[b]Measured from the point of the shoulders to the ischium.

The value of these measures in predicting body size and weight must be considered under practical heifer management conditions. Unfortunately, these indices are not as easily measured as body weight on a scale. Variation between repeated measures and between individuals performing these measures is high. Measurement of wither height requires the heifer to be standing still with the head positioned horizontally and in an area with a dry footing. Heifers on commercial dairies are also wary of the wither height stick making measurement difficult. Heifer growers have been successful in mounting measuring tapes on the top of weigh scales or handling chutes and obtaining estimates of heights by difference from the top of the chute to the heifer's hip. As a result, researchers are currently measuring hip height as a possible substitute measurement. However, at this time, insufficient data has been collected to enable development of reliable prediction equations. For similar reasons as wither height, body length is a difficult measurement to obtain reliably on commercial dairies and heifer growing establishments.

Body composition of the growing heifer (% fat, % protein and % ash) is strongly related to lactation performance. Numerous studies have observed that overfattening of the prepubertal heifer by feeding high-energy diets results in an animal in which body fat is excessive and mammary parenchymal development is impaired. The influence of overfeeding on body composition of heifers during the gestation period and at first calving has been less extensively studied. Grummer et al. (1995) investigated the effects of body composition on replacement heifers fed two different levels of energy from 19 mo. until calving at 24.7 mo. of age. Feeding high-energy diets increased body weight and body condition scores, but did not influence first lactation yield. In addition, heifers fed the high-energy diets had higher levels of blood NEFA's, ketone's and liver triglycerides. Post partum DMI was lower. These observations are indicative of the likelihood of a higher incidence of postpartum metabolic disorders.

Unfortunately body composition in growing dairy heifers is not easily measured. Non-invasive measures such as urea space, ultrasound and electrical conductivity have all proven to provide information of limited value in measuring composition in dairy heifers, partly due to their low body fat content relative to beef cattle. The most useful data relating body composition of the growing heifer to mammary development and lactation yield has come through experiments in which a portion of the animals have been slaughtered and a composition of the carcass has been measured – an expensive and time consuming proposition.

Nearly all surveys of dairy heifer growth have been conducted with Holstein cattle since they represent over 90% of the dairy cattle in the U.S. Heinrichs and Hargrove (1991, 1994) measured heifers of the other major dairy breeds in Pennsylvania and used this data to publish recommended height and weight measurements as shown in Table 4.

Table 4. Range of recommended weight (kg) and height (cm) for other breeds.

Age (mo)	Jersey		Guernsey		Ayrshire		Brown Swiss	
	Weight	Height	Weight	Height	Weight	Height	Weight	Height
1	42-49	74-81	55-65	79-84	59-70	79-81	61-64	81-86
3	70-80	81-86	92-106	89-94	101-116	86-91	109-129	91-96
5	106-126	89-96	136-161	96-104	143-162	94-99	157-183	99-107
7	138-164	96-102	174-204	104-109	184-208	102-107	203-237	107-114
9	169-198	102-107	219-258	109-119	224-252	107-112	249-289	112-122
11	194-227	104-109	261-301	114-119	264-295	112-117	293-341	117-127
13	227-259	109-114	292-344	117-122	303-338	117-122	336-390	122-132
15	257-291	112-117	336-394	122-127	340-379	119-124	377-438	124-135
17	277-316	114-119	377-432	127-132	375-419	122-127	415-482	127-137
19	296-349	117-119	409-461	129-132	409-458	124-127	452-524	129-140
21	327-376	119-122	439-505	129-135	442-495	124-129	485-561	132-142
23	345-399	122-124	466-508	132-137	472-531	127-132	516-595	135-145
24	359-406	122-127	466-535	132-140	486-548	127-132	530-610	135-157
Ave. age at 1st calving	24.9		26.2		27.6		27.0	

From Heinrichs, A. J. and B. Lammers, 1998. Monitoring Dairy Heifer Growth, Pennsylvania State University Cooperative Extension, University Park, PA.

When evaluating heifer growth, the grower and the owner must take a balanced approach. For many years, body weight was the only information available. The increased emphasis in early calving and accelerated growth has led producers and researchers to seek ways to encourage rapid growth without overfattening. The grower has been bombarded with claims of feed additives and growth promotants that will ensure that their heifers will look like the winners coming out of the show ring at Madison or the Royal Winter Show in

Toronto. One grower reported that the owner expected his heifers to average over 152 cm at the withers when they returned to the dairy before calving. The heights shown in tables 1, 2 and 4 represent more of what one can expect from the average and the 95th percentile. Unfortunately, nutrition other than proper amounts of protein and energy has little influence on the rate of skeletal growth and body composition.

▪ Rate of Gain.

Much of the data used to establish the recommended body size for the growing dairy heifer has been achieved through the measurement of large numbers of animals in field surveys on commercial establishments. This data has been complemented with the addition of many data sets from research stations. Numerous studies have examined the influence of daily gain at various stages of the heifer's on short-term growth and feed efficiency. However, few studies have looked at the influence of growth rate throughout the rearing period on mammary development and later lactation performance.

Before proceeding with a discussion of the influence of gain on mammary development, it is beneficial to briefly review the biology of heifer and mammary growth. At birth the mammary gland is rudimentary with both the gland and teat cisterns evident and ducts present close to the gland cistern. From birth to 3 months of age the gland grows at a rate similar to the rest of the body. However, beginning at approximately three months of age the gland begins an allometric growth phase, where the mammary gland grows at a much faster rate than the rest of the body. This phase continues until puberty when once again the gland assumes the same rate of growth as the rest of the body. The timing of these shifts in differentiation and growth vary with species and the hormonal events triggering them have not been fully elucidated. Based upon our current knowledge, it appears that the rate of growth during the prepubertal period influences development of parenchymal tissue. During the postpubertal period, there is little influence of growth rate on mammary development until the last trimester of gestation.

The influence of feeding programs and rates of growth during the first two years has been the subject of much research. Unfortunately few studies have followed heifers throughout the rearing period or have investigated influences on mammary development or first lactation yield. There are indications that a higher rate of growth (700g/day) during the milk feeding period has a positive influence on mammary development. Israeli workers (Bar-Peled et al., 1997) found that calves allowed to suckle their dams three times per day as compared to calves limit-fed milk replacer, were larger at calving and produced more milk in the 1st 300 days of their 1st lactation. This bears further research and is the topic of a paper to be presented by Van Amburgh at this conference.

However, there is a large body of evidence that indicates that rapid growth (over 1 kg /day) during the prepubertal period has a negative impact on mammary development. Heifers fed for more rapid rates of gain exhibit depressed levels of growth hormone and decreased development of the mammary parenchyma. The critical rates of gain probably vary with breed as Hohenboken et al. (1995) have shown that decreased mammary development occurs at lower rates of gain in Jerseys and Red Danish heifers as compared to Friesians.

In one of the largest trials conducted to date, Van Amburgh et al. (1997) used 273 Holstein heifers to study effects of prepubertal rearing rate on first and later lactation yield. Heifers were assigned to one of three dietary energy treatments that achieved ADG of .6, .8 and 1.0 kg. Half of each treatment group received a dietary protein source of low rumen degradability. Heifers were bred when they reached 340 kg body weight and were housed together and fed similar diets after breeding. Results are shown in Table 5.

Table 5. Performance of Holstein heifers fed for three different rates of gain during the prepubertal period.

Proposed average daily gain	**.6 kg**	**.8 kg**	**1.0 kg**
Age at first calving (mo)	24.5	22	21.3
Start weight (kg.)	86	85	83
ADG weaning to breeding, kg./day	.68	83	.94
Mean body condition score	3.0	3.1	3/4
Mean max. body condition score	3.3	3.5	3.9
Final hip height – in.	128	127	125
Post treatment – ADG (kg)	.67	.64	.58
Pre-calving weight, kg	550	529	520
BW loss, kg	53	55	61
Number completing 1st lact.	85	65	84
First lactation yield , 305 d, kg	9873	9620	9387
Second lactation yield, 305 d, kg. (n)	11,030(50)	10,940(43)	11,116(60)

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

Differences in overall ADG were smaller due to compensatory gains of slowly grown heifers during the prepubertal period and a moderation of gains in those formerly receiving the higher energy diets. Rapidly reared heifers were fatter and shorter as evidenced by the higher body condition scores and lower hip heights. As a result, early calving heifers lost more weight during the first lactation and had lower first lactation yield. Van Amburgh noted that differences in body weight were responsible for a greater proportion of the differences in milk production than prepubertal weight gain. Unlike other similar studies, the Cornell workers observed no difference in production after the first lactation.

Most studies evaluating the effects of accelerated rearing find that rapidly reared heifers calving at ages below 22 months have less hip height, with greater body condition. Dystocia is not uncommon in rapidly reared heifers calving before 22 months of age.

Growth standards proposed by Heinrichs and Hoffman assume linear rates of average daily gain. However, several studies have shown promising results in rearing heifers in a stair step fashion.

Park et al. (1998) placed 40 crossbred beef heifers (287 kg body weight) on one of two rearing regimes beginning at 8 months of age. One-half were reared to grow in linear fashion while the other half were fed according to an alternating schedule of 130% of NRC requirements for energy followed by a phase of restricted energy (70% of NRC) and finishing with another 2 month period of 130% or NRC requirements for energy. The stair-step diet was formulated and fed to provide isonutrient intake of protein, vitamins and minerals similar to the control diet. Dietary treatments lasted 8 months. All heifers were bred at 14 months of age and were placed on similar diets at 16 months of age through their first lactation. Stair-step heifers gained nearly twice as much as control heifers during the final realimentation phase. RNA and protein content of mammary tissue was higher and lipid content lower for stair-step reared heifers. It was estimated that stair-step reared heifers' yielded 6% more milk than control heifers.

Choi et al (1997) fed 24 Holstein heifers in a similar rearing scheme as that described by Park. The test group was fed according to a schedule of 3, 2, 4, 2, 5, and 2 months in which intake was alternately 20 % below and 25% above NRC requirements. Heifers averaging 172 kg and 6 mo. of age when they began the study. Results are shown in Table 6.

Table 6. Growth, mammary composition and lactation yield of heifers reared for a linear rate of gain vs. a stair-step regime. (Choi et al., 1997)

Item	Control	Stair-Step
Body weight gain (kg)	373	385
Average Daily Gain (kg/d)	.66	.68
Average Dry Matter Intake (kg)	8.47	8.21
Growth efficiency %	7.79	8.28
(BW gain/DMI) X 100		
Mammary gland composition – Late Pregnancy		
DNA (mg/g of DM)	8.22	12.81
RNA (mg/g of DM)	8.44	13.59
Protein (mg/g of DM)	76	160
Lipid (mg/g of DM)	576	425
Milk yield (kg)	6765	7344

A subsequent study by Ford and Park (2000) made similar observations. Heifers fed and managed to grow in a stair step fashion grew more efficiently and composition of the mammary gland revealed more cell numbers and cell activity and less lipid. The stair-step rearing program shows great promise although it requires a departure from conventional thinking and it may present challenges to implement under practical feeding situations on many growing operations.

The studies of heifer growth emphasize that assuring growth during the 1st six months is critical to success in growing the dairy heifer and is where nutrition and management must be optimal. The window of opportunity is narrow. Sub-optimal nutrition will delay breeding and calving, while overfeeding may impair mammary development or lead to excessive nitrogen excretion to the environment.

▪ Nutrient Requirements for Growing Dairy Heifers

Dry matter intake and requirements for energy and protein are shown in Table 6 from the 1989 Nutrient Requirements of Dairy Cattle (NRC). The 1989 NRC used a maximum rate of gain of 770 g. per day for large breed heifers with a maximum body weight of 1300 lb. Mature body weight was assumed to be 800 kg which is probably unrealistic. A more realistic mature body weight is 660 kg with a post calving body weight of 568 kg. This represents a goal of a 1st lactation animal calving with a weight of 80 to 85% of a mature animal. Based on the 1989 NRC a large breed heifer bred at 363 kg and gaining 770 g per day would weigh 575 kg at calving. What is not clear is whether or not this included gain of the developing calf and associated membranes. If this included conceptus gain, then calving BW would be less than recommended.

The apparent need to provide high levels of UIP in the young calf is more a function of digestive function than characteristics of the diet. Due to the less developed rumen function in the young animal, considerable amounts of dietary protein escapes degradation in the rumen. Subsequently, most of the amino acid requirements of the older animal can be met via microbial protein synthesis and therefore the UIP or RUP content of the diet is not an important issue.

▪ Recent Modification to Heifer Nutrient Requirements.

The nutrient requirements for growing dairy heifers were recently revised (2001). The publication addressed higher rates of gain desired for earlier calving to reduce cost of rearing yet not impair mammary development. Dry matter intake is predicted using the equations developed in the 1996 Nutrient Requirements for Beef Cattle. The authors did note the lack of data available to predict intake of the heifer in late gestation and for breeds other than Holstein. In addition, they found that the influence of temperature and other environmental factors on intake was poorly described.

The prediction of energy and protein requirements has been achieved based upon the energy and protein content of tissue deposited. The data of Garrett (1980) with adjustments were used to predict energy content of gain. The amount of protein required is the sum of RDP given the level of rumen available carbohydrates and the RUP required to supplement the microbial protein produced to achieve the energy allowable gain.

Measures of skeletal size were not used to determine requirements owing to the strong relationship between wither height and weight demonstrated by Heinrichs and Losinger (1998). Because of the variation of mature size between and within breeds, the committee felt that it was necessary to consider mature size in estimating growth requirements. The scaling system developed by Fox et al. (1992) and modified by Tylutki et al. (1994) was used.

Target growth rates are determined by comparing the present size of the animal at a given age with the weight needed to reach mature size. Dairy heifers normally reach puberty at approximately 55% of mature weight, and calve the first time at 82% of mature weight. Nutrient requirements are also adjusted for previous temperature, cold and heat stress.

A simplified comparison of the requirements for large breed heifers at various body weights between the 1989 and 2001 NRC publications is shown in Table 7.

Table 7. Nutrient requirements for large breed heifers at 800g. gain/day (NRC, 1989)

Item	Unit	Heifer weight (kg)				
		150	250	350	450	550
Intake	kg/d	3.99	5.99	8.21	10.82	14.04
Energy						
ME	Mcal/kg	2.60	2.47	2.34	2.20	2.07
Protein						
CP	(%of DM)	16	12	12	12	12
RUP	(%of CP)	52	36	22	14	11
RDP	(%of CP)	16	54	60	62	61
CP/ME	g CP/Mcal ME	61	49	51	54	58

ME = metabolizable energy
RUP = Rumen undegradable protein
RDP = rumen degradable protein.
In the 1989 NRC, RDP + RUP did not equal CP g /day.

Nutrient requirements for large breed heifers at 800g. gain/day (NRC, 2001)

Item	Unit	Heifer weight (kg)				
		150	250	350	450	550
Intake	kg/d	4.2	6.2	7.9	10.5	12.2
Energy						
ME	Mcal/kg	2.29	2.27	2.30	2.33	2.32
Protein						
CP[a]	(%of DM)	15.9	13.1	11.7	14.2	13.3
RUP	(%of CP)	39	26	17	30	26
RDP	(%of CP)	61	74	83	70	74
CP/ME	g CP/Mcal ME	69	57	51	60	57

[a]Crude protein required only if ration is balanced for RDP and RUP.
ME = metabolizable energy
RUP = Rumen undegradable protein
RDP = rumen degradable protein

Recent studies have questioned the adequacy of recommendations for protein and energy to meet the height and weight goals currently desired for growing heifers.

More recent work suggests that the ratio of protein to energy needs to be considered, especially in light of higher rates of gain desired to achieve 560 kg post calving weights at ages of 24 months or less. VandeHaar (1998) in a review of 11 experiments evaluating protein and energy found a correlation of .84 between the ration of protein and ME level in the diet and mammary parenchymal growth. As energy in the diet increased and protein levels decreased, mammary secretory tissue development decreased. Penn State workers (Lammers and Heinrichs, 2000) found that feeding a greater proportion of protein relative to energy resulted in increased feed efficiency, hip width and height and heart girth. Teat length, as an indirect measure of mammary development, was increased 35 to 38% with greater amounts of protein relative to energy. However, the relationship of these improvements in growth has not always translated into greater milk production. Michigan State workers (Radcliff et al., 1998) found that heifers fed high energy: high protein rations for 1.2 kg of gain per day produced 3.6 kg less milk per day during the first 270 days of lactation as compared to heifers fed conventional diets growing at 800 g/day. Several studies have shown that feeding levels of protein in excess of requirements results in increased levels of plasma urea nitrogen and subsequently nitrogen excretion in the urine. In the future nutritionists must consider not only animal performance, but also efficiency of nitrogen utilization and minimization of nitrogen excreted to the environment. Research is conclusive that levels of protein above those shown here do not result in more growth but do greatly increase N excretion.

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