Innovations in Dairy Replacement Heifer Management

P. C. Hoffman
Department of Dairy Science,
University of Wisconsin, Madison 53706

Introduction

The goals of a dairy replacement management program are to rear heifers at a low economic and environmental cost without compromising future lactation performance. To meet these objectives, increased sophistication dairy heifer management is required. For example dairy heifer growth has commonly been evaluated as average daily gain and compared to breed based growth guidelines. This management system has severe limitations in developing comprehensive production record keeping systems for dairy heifers because genetic variance for growth has never been considered. Likewise dairy heifers have commonly been fed diets containing low cost, high fiber forages (MPS, 2003), which meet the low energy requirement (NRC, 2001) of replacement heifers. Feeding bred heifers low energy, high fiber forages minimizes over-conditioning at calving which can be detrimental to lactation performance (Hoffman et al., 1996) but feed efficiency of this feeding system is seldom considered. Feed efficiency and thus feed cost can be dramatically altered in dairy heifer nutrition programs by manipulating dry matter intake. This paper will review these and other new and potential innovations in dairy heifer management.

Evaluating Heifer Growth

Dairy heifers should be periodically weighed to monitor the performance of the management system but dairy producers and heifer growers have commonly struggled to find a utilitarian use for this information. It is common to evaluate the average daily gain of heifers or to plot the weights, or heights, of heifers on a graph for comparative purposes. Average daily gains and heifer weights are generally compared to breed standards. The fundamental problem with this approach is the desired average daily gain or weight of a heifer at a given age is a function of genetic size potential. In it’s simplest form, the size of a Jersey heifer is smaller than size of a Holstein heifer thus the average daily gain of a Jersey heifer is less than a Holstein heifer. The issue of how breed defines heifer growth criteria is well understood by the dairy industry. Heifer growth charts (Heinrichs and Lammers, 1998, MPS, 2003) identify ranges of heifer growth by breed-- but these ranges may be too wide for growth monitoring systems because they include both genetic and phenotypic variance. A second problem with breed based growth charts is an individual heifer’s growth or body weight may vary from breed standards because the individual heifer is simply genetically large or small. This problem occurs because genetic variance for size within a breed can be as great as between breeds. The dairy industry is aware that mature Holstein cows weigh between 1200 and 2000 lbs. Because size is very heritable the heifers from large or small Holstein cows will like be large or small which is normal.
Van Amburgh and Meyer, 2005 proposed a system to address this issue. The system proposed by Van Amburgh and Meyer expresses heifer growth or body weight as a simple function of

mature body weight (MBW). For example heifers should weigh (x) % of MBW, or (x) % of MBW at breeding etc. The mathematical concept of this system is very simple and is as follows.

$$\text{Example Heifer (14 months)} \qquad \frac{875 \text{ lbs}}{1500 \text{ lbs Mature Body Weight}} = 58.3\ \%\ \text{of MBW}$$

The paradox of this system is the mature weight of a heifer cannot be known before it is mature therefore MBW in the denominator of the equation above is an enigma. Therefore, a surrogate mature body weight (MBWs) for a heifer or group of heifers is required. A systematic MBWs would be the 0-21 day post calving body weight of the dam, adjusted to 4th lactation. Factors to adjust post calving body weights to 4th lactation MBWs are as follows.

Lactation	Actual BW	MBWs (Lactation Factor: Multiply by)
1st	0-21 day post calving BW	1.176
2nd	0-21 day post calving BW	1.087
3rd	0-21 day post calving BW	1.042

For the example heifer above her dam weighed 1275 post calving (1st lactation) therefore the denominator of the equation is changed to the MBWs as follows

$$\text{Example Heifer (14 months)} \qquad \frac{875 \text{ lbs}}{(1275 \text{ lbs} * 1.176)} = 58.3\ \%\ \text{of MBWs}$$

The lactation adjusted MBWs of the dam is used in the denominator of the equation because body size is heritable and should be a reasonable indicator of future size and is breed independent. Obviously, the sire of the heifer has an influence on future size but coefficients to adjust mature size for influence of sire do not exist and heifers born to young sires or natural service sires would have no proofs available for body size.

Upon first examination the system proposed by Van Amburgh and Meyer seems unwieldy but evaluating heifer growth on a MBWs system only requires two additional numbers, the weight of the dam and the lactation number. These two simple observations offer the opportunity to evaluate heifer growth and performance in a new manner. A simple body weight (or weigh tape) of the dam plus her lactation number allows for the simple calculation of a MBWs and heifer weight can now be express as percentage of MBW thereby helping to mitigate the effects of genetics in heifer performance evaluation. Other MBWs can be used such as an average weight of mature animals in the herd but it is the authors opinion that the systematic provision of post calving body weights of the dam for each calf (heifer) is a more sustainable methodology to derive an assess MBWs from any given herd. Problems with this system do however arise as it pertains to crossbred cattle because MBW of the heifer is influenced both by the size of the dam and breed of sire and the expression of size of the offspring is more random. However, a logical MBW prediction system can be developed as follows.

Where:

MBWcrossbred = ((Post Calving BW Dam x MBW Lactation Factor) + (Breed average MBW Sire))/2

Example:

An F1 Holstein x Jersey crossbred cow weighing 1175 lbs post calving 1st lactation is bred back to a Jersey bull (Breed MBW = 1000 lbs)

MBWcrossbred (1191 lbs) = ((1175 lbs x 1.176) + (1000 lbs))/2

Universal Heifer Growth Standards

Expressing heifer growth on a percentage of MBWs has advantages. First, the effects of heifer growth variance caused by genetics are in part suppressed. Second, multiple heifer growth charts by breed or by size within breed are not necessary. In essence, all heifer growth regardless of breed or genetic variance of size within breed is set to the same reference. The author evaluated the system of Van Amburgh and Meyer, 2005 using the Jersey and Brown Swiss growth charts of Heinrichs and Lammers, 1998.

One reference set of growth charts was chosen because data collection methodologies were the same (weigh tape). Heifer growth by age on a MBWs basis (% of MBWs) was calculated using a MBW of 946 lbs for Jerseys and 1422 lbs for Brown Swiss. Data are presented in Table 1. Extensively, when heifer growth by age is expressed on a MBW basis there is no appreciable difference between Brown Swiss heifer growth and Jersey heifer growth. Similar comparisons (data not shown) were made between all breed growth charts (Heinrichs and Lammers, 1998, Hoffman, et al., 1992, MPS, 2003) and only minor nuances in heifer growth occur between breeds when heifer growth is expressed on a MBW basis.

The author evaluated all breed growth charts (Van Amburgh and Meyer, 2005, Heinrichs and Lammers, 1998, Hoffman, et al., 1992, MPS, 2003) to explore the potential of a universal heifer growth chart where heifer growth is expressed as a percentage of MBWs (Table 2). There are minor nuances but data collection methodologies differed so the author chose to use a mid-point of Holstein body weights (MPS, 2003) only because derivation of these body weights was most familiar, represented true scale weights and because the Holstein is the dominate breed. The Holstein data in Table 2 fit all breeds (Heinrichs and Lammers, 1998) reasonable well (data not shown).

Example of Utility

To define how this concept would be used under field application the author plotted the age and weight relationship of 168 heifers from the Marshfield Agricultural Research Station (Figure 1). The age and weight of heifers was compared to a traditional Holstein growth benchmark (MPS, 2003). Figure 1 suggest large growth variance occurring in the herd but an explanation for the variance is not obvious. The heifers in Figure 1 however, represent 110 Holsteins, 51 F2 Holstein x Jersey crossbreds, 4 Brown Swiss, 1 Guernsey, and 2 Jerseys. In Figure 2, heifers were plotted as a percentage of MBWs using the percentages of MBWs in Table 2 as a benchmark. The change in presentation is striking. First, the genetic effect of breed is suppressed and true herd dynamics become apparent. Figure 2 suggest that older crossbred heifers (> 18.0 months) are well above MPWs guidelines. Figure 2 represents the exact condition of heifers at the Marshfield Ag Research station as older crossbred heifers are exhibiting excessive condition scores (> 3.75). Likewise, older Holstein heifers were exhibiting some degree of over-conditioning but not a severe as crossbred heifers. Heifer growth, < 16.0 months, appears to be satisfactory to slightly low. The example heifers at the Marshfield Ag Research Station represent real management challenges when there is mature size variance within a management scheme for heifers. The example presented in Figures 1 and 2 is a problem associated with trying to rear multiple breeds of heifers simultaneously. Management challenges are also likely to occur for custom heifer growers attempting to rear heifers for multiple herds from the same breed which likewise will vary in MBW. Hansen et al., 1999 defined the genetic size of US Holsteins derived from two breeding protocols implemented at the University of Minnesota. A small and large line of Holsteins was bred over a 30 year period (1966-1998) and body weights evaluated. After 30 years of AI breeding, MBW (3rd lactation) of US Holsteins ranged from 1135 lbs to 1951 lbs. These data suggest that MBW differences within the Holstein bred can be as great (or greater) than MBW differences between breeds (eg Holstein vs Jersey).

From this evaluation, the author concludes that a system of expressing heifer growth as a percentage of MBW as proposed by Van Amburgh and Meyer, 2005 may have excellent field utility and could especially aid professional heifer growers whom attempt to rear heifers in a single environment having multiple genetic bases. The utility of using a MBW system to evaluate and define heifer growth is only limited by a system to develop surrogate mature body weights which can be systematically estimated from the post lactation body weight of the dam and breed of the sire for each heifer or calf.

Finally use of a MBWs management system would shift where variance occurs in the heifer rearing program. This concept is presented in Table 2b. When breed benchmark management is used the attempt is to breed all heifers at the same weight and calve at the same weight at the same age. This forces variance in breeding age, calving age and body condition score at calving. If MBWs based management is employed heifers are bred as a percentage of MBWs and would be bred at more similar ages, calve at more similar ages and body conditions scores but weight at breeding and calving would be more variable which is more genetically normal.

Limit-Feeding

An immerging innovation in feeding dairy heifers to control over-conditioning, and improve feed efficiency, would be to limit-feed a more nutrient dense diet which provides an alternative management strategy to reduce feed cost and nutrient excretion both of which are becoming of greater concern in the dairy industry. Lammers et al., 1999 used a limit-feeding strategy to control growth rates of pre-breeding Holstein heifers and observed no negative effects on first lactation performance. Limit-feeding strategies have also been employed successfully with other livestock species such as beef cows, (Loerch, 1996), ewes (Susin et al. 1995) and beef heifers (Wertz et al. 2001). In dairy replacement heifer management systems limit-feeding of bred heifers may yield the maximum management benefit because bred heifers have high feed intakes (NRC, 2001) and excrete more manure DM (Wilkerson, et al., 1997) as compared to pre-breeding heifers.

Recently we explored a simple limit-feeding feeding system for replacement heifers (Hoffman et al., 2006). Bred Holstein heifers (1000 lbs) were fed diets (C-100, L-90 and L-80) containing 67.5, 70.0 and 73.9 percent TDN respectively but heifers fed the 70.0 and 73.9 percent TDN diets were limit-fed at 90 and 80 percent of their intake potential. The experimental feeding system resulted in heifers being fed less dry matter per day but the total amount of calories consumed per day was equal (Table 3). We did not observe any differences in the size or body condition scores of the heifers after a 111 day feeding period (Table 4). The limit fed heifers had numerically higher average daily gains as compared to control fed heifers. The limit-feeding regimen did however result in a 30 % improvement in feed efficiency (Table 4), and heifers excreted significantly less manure (Table 4). We observed no long term effects of limit feeding heifers and lactation performance was similar between control and limit-fed heifers (Figure 3). Recent research at the Pennsylvania State University observed similar responses when heifers were limit fed. Zanton and Heinrichs, (2006) limit fed 300 lb Holstein heifers for 35 weeks a diet containing 25 percent forage as compared to feeding a greater DM allocation of a diet containing 75 percent forage and observed no differences in average daily gain or skeletal growth of the heifers.

There are some limitations to implementing a limit-feeding strategy. First, heifers do vocalize to minor extent for approximately one week with vocalization ending thereafter. Second, adequate bunk space is required to assure all animals have full access to feed because heifers fed to 80 percent of their intake potential will consume all feed available within one hour. Lack of adequate bunk space could result in un-even rates of gain. Despite disadvantages the positive aspects of limit-feeding such as increases in feed efficiency, decrease manure output and ability to control over-conditioning without long term effects make limit-feeding and attractive management alternative but more data is required.

Bunk Management Systems

When feeding high fiber forages or corn silage it should be remembered that heifers will sort feed very similar to lactating dairy cows. Heifers like lactating dairy cows will preferentially consume smaller feed particles as compared to larger feed particles. This feeding behavior can be used as and innovation in feeding dairy heifers to improve feed efficiency and reduce feed cost. In a recent study (Hoffman et al., 2006) we fed heifers five different physical methods of feeding hay to explore possible differences in nutrient intake and feed sorting behavior. Diets were fed to eighty Holstein heifers, and included (1) incorporation of long hay (**LH**) in a total mixed ration (**TMR**) mixer (**TMR-LH**); (2) incorporation of bale cut hay (**BC**) in a TMR mixer (**TMR-BC**); (3) incorporation of chopped hay (**CH**) in a TMR mixer (**TMR-CH**); (4) top-dressing (**TD**) long hay (**TD-LH**) without TMR incorporation, and (5) top-dressing BC hay (**TD-BC**) without TMR incorporation. Top dressing LH or BC hay to heifers resulted in a suppression (0.5 kg/d) of DM intake as compared to heifers fed TMR diets in which hays were incorporated in the TMR. Heifers heavily refused long particles (>12.5 mm) on all diets. In particular, heifers refused 70 to 80 percent of corn cobs fed. Because long forage particles and or corn cobs generally contain more NDF or less energy than small feed particles, such as grain, data suggest heifers may consume diets higher in energy than formulated. Likewise data suggest bunk management of heifer diets is critical to assure heifers are consuming high fiber low energy feeds as intended.

Understanding this behavior affords the opportunity of producers and heifer growers to direct heifers to consume all feed particles. Precisely monitoring and controlling feed intakes and feeding heifers to exact intakes will reduce feed wastage and increase feed efficiency. The combination of proper bunk design and feeding heifers to exact intakes may result in a 10 percent improvement in feed efficiency. To feed heifers to exact intakes a bunk scoring management system should be utilized. A simplified bunk scoring system is 0) no feed remaining, 1) a few small scatter particles of feed remaining, 2) many feed particles remaining but concrete still visible and 3) large amounts of feed remaining with no bunk concrete visible. The objective of a controlled bunk management feeding system is to feed to a bunk score of 1 every day directing heifers to consume remaining large feed particles. If bunks are empty (Score 0) or excessive feed is remaining (Scores 2 and 3) then feed intakes are moved up or down in very small increments (2 %) to facilitate feeding heifers to a bunk score of 1. This type of feeding systems also helps assure that heifers consume all large feed particles and feeds such as corn cobs. Full consumption of diet also assures the formulated diet is actually being totally consumed.

Conclusions

New research is demonstrating feed efficiency of dairy replacement heifers can be improved 20.0-25.0 % by limit feeding and should be a primary discussion point between heifer growers and their nutrition consultants. Potential management innovations associated with limit feeding are numerous such as shift feeding, (utilizing one feed bunk to feed multiple heifer groups) and conscious abatement of manure production. Limit feeding data also suggest heifers may not require ad libitum feeding which is an inefficient feeding management feeding system. Feeding heifers in facilities with properly designed bunks to minimize feed loss, employing a bunk management system, feeding heifers to exact levels of intake (or slightly less) are potential tools to improve feed efficiency. Finally development of new production record schemes such as mature body weight adjusted growth records would allow heifer growers and dairy producers to better evaluate heifer production systems.

References

Hansen, L.B., J. B. Cole, G.D. Marx, and A. J. Seykora. 1999. Productive life and reasons for disposal of Holstein cows selected for large and small body size. J. Dairy Sci. 82:795-801.

Heinrichs, A. J., and B. L. Lammers. 1998. Monitoring dairy heifer growth. The Pennsylvania State University. University Park, PA.

Hoffman, P. C., et al. 1992. Growth rates of Holstein replacement heifers in selected Wisconsin dairy herds. College of Agriculture and Life Sciences Research Report. R551. University of Wisconsin-Madison.

Hoffman, P. C., N. M. Brehm, S. G. Price, and A. Prill-Adams. 1996. Effect of accelerated postpubertal growth and early calving on lactation performance of primiparous Holstein heifers. J. Dairy Sci. 79:2024-2031

Hoffman, P.C., S.R. Simson, and K.J. Shinners. 2006. Evaluation of hay feeding strategies on feed sorting behavior of dairy heifers fed mock lactation diets. Prof. Anim. Sci. 22:71-79

Hoffman, P.C., C.R. Simson, M. Wattiaux. 2006. Effect of a limit feeding regimen on growth and fecal excretion of gravid Holstein heifers. J. Dairy Sci. (In press).

Lammers, B.P., A.J. Heinrichs, and R.S. Kensinger. 1999. The effects of accelerated growth rates and estrogen implants in prepubertal Holstein heifers on estimates of mammary development and subsquent reproduction and milk production. J. Dairy Sci. 82:1753-1764.

Loerch, S.C. 1996. Limit-feeding corn as an alternative to hay for gestating beef cows. J. Anim. Sci. 74:1211-1216.

Loerch, S.C. 1990. Effects of feeding growing cattle high-concentrate diets at a restricted intake on feedlot performance. J.Anim. Sci. 68:3086-3095.

Midwest Plan Service, 2003. Raising Dairy Replacements. 3rd Edition. Midwest Plan Service, Iowa State University, Ames, IA.

NRC, 2001. Nutritional Requirements of Dairy Cattle. 7th Rev. Ed. National Academy Press. Washington, DC.

Susin, I., S.C. Loerch, K.E. McClure, and M.L. Day. 1995. Effects of limit-feeding a high grain diet on puberty and reproductive performance of ewes. J. Anim. Sci. 73:3206-3215.

Van Amburgh, M, and M. Meyer. 2005. Target growth and nutrient requirements of post-weaned dairy heifers. Pp 128 in Dairy Calves and Heifers, Integrating Biology and Management. NRAES, Ithaca, NY.

Wertz. A.E., L.L. Berger, D.B. Faulkner, and T.G. Nash. 2001. Intake restriction strategies and sources of energy and protein during the growing period affect nutrient disappearance, feedlot performance, and carcass characteristics of crossbred heifers. J. Anim. Sci. 79:1598-1610.

Wilkerson, V. A., D. R. Mertens, and D. P. Casper. 1993. Prediction of excretion of manure and nitrogen.

Zanton, G.I., and A.J. Heinrichs. The effects of restricted feeding high concentrate or high forage rations on nutrient digestibility and nitrogen utilization in dairy heifers. J. Dairy. Sci. 89:(Suppl 1):439(abstr.).

Table 1. Comparison of Penn State Jersey and Brown Swiss heifer growth charts when expessed as a percentage of mature body weight.

Heifer Age, months	Jersey Heifers % of Mature BW	Brown Swiss Heifers % of Mature BW	Breed Difference % of Mature BW	Actural BW. lbs Jerseys	Actural BW. lbs Brown Swiss
Mature BW, lbs	946	1422			
Calf	6.5	6.5	0.0	61.5	92.4
1	11.4	11.4	0.0	108.1	162.0
2	15.4	15.7	-0.2	146.1	223.0
3	18.7	19.9	-1.2	177.1	283.0
4	23.0	24.1	-1.2	217.1	343.0
5	29.4	28.3	1.1	278.1	403.0
6	33.9	32.5	1.5	321.2	462.0
7	38.3	36.6	1.6	362.2	521.0
8	43.6	40.8	2.8	412.2	580.0
9	46.1	44.8	1.3	436.2	637.0
10	51.1	48.8	2.3	483.2	694.0
11	52.8	52.7	0.0	499.2	750.0
12	58.0	56.6	1.3	548.3	805.0
13	60.4	60.4	0.0	571.3	859.0
14	63.7	64.1	-0.5	602.3	912.0
15	67.7	67.7	0.0	640.3	963.0
16	69.9	71.2	-1.3	661.3	1013.0
17	73.6	74.6	-1.0	696.3	1061.0
18	79.6	77.8	1.8	753.4	1107.0
19	81.3	81.0	0.3	769.4	1152.0
20	86.0	84.0	2.0	813.4	1194.0
21	87.5	86.8	0.6	827.4	1235.0
22	91.0	89.5	1.4	860.4	1273.0
23	92.9	92.1	0.8	878.4	1309.0
24 (7d Pre-calving)	94.4	94.4	0.0	893.4	1343.0
24 (7d Post-calving)	85.0	85.0	0.0	804.1	1208.7

Table 2. Universal heifer growth chart for 24 month age at first calving.

Heifer Age, months		% of Mature Body Weight
Calf		6.5
1		9.7
2		12.8
3		16.5
4		20.2
5		24.0
6		27.7
7		31.4
8		35.0
9		38.9
10		42.5
11		46.3
12		49.9
13		53.7
14	Breeding Ages	57.4
15		61.1
16		64.7
17		68.5
18		72.2
19		76.0
20		79.6
21		83.3
22		87.1
23		90.8
24 (7d Pre-calving)		94.0
24 (7d Post-calving)		85.0

Table 2b. Conceptual variance influence of breed standard or mature body weight based heifer management schemes on key heifer management criteria

	Management Scheme	
Holsteins (US)	Breed Standard	Mature Body Weight
Breeding weight	875	57.4 % of MBW
Pre-calving weight	1400	94.0 % of MBW
Age at first calving	24	24
	Conceptual variance influence	
Breeding weight	Static	Variable
Breeding age	Variable	Static
Calving weight	Static	Variable
Body Condition @ calving	Variable	Static
Calving age	Variable	Static

Table 3. Nutrient and energy intake of heifers fed treatment diets.

	Treatment[1]				Effect(P>)[4]		
Item	C-100	L-90	L-80	SEM	Treatment	Linear	C vs R
Nutrient intake, lbs/d							
DM	21.3	19.9	18.3	0.4	0.01	0.003	0.006
CP	2.42	2.54	2.57	0.03	0.07	0.03	0.03
NDF	10.06	8.29	6.50	0.16	0.0003	0.0001	0.0002
Digestible NDF[2]	6.11	4.90	3.87	0.09	0.0002	0.0001	0.0001
Non-fiber carbohydrate	7.26	7.60	7.85	0.17	…	0.07	0.09
P	0.057	0.058	0.058	0.001	…	…	…
Ca	0.086	0.090	0.089	0.001	…	…	0.08
Energy intake[3]							
TDN, lbs/heifer/d	14.4	13.9	13.5	0.3	…	0.08	0.09
ME, Mcals/d	23.8	23.0	22.3	0.4	…	0.07	0.09
NE_g, Mcals/d	9.4	9.4	9.5	0.2	…	…	…
NE_m, Mcals/d	13.7	13.3	13.0	0.2	…	…	…

[1] C-100, control heifers fed ad libitum, L-90, limited to 90.0 percent of intake, L-80, limited to 80.0 of intake.
Treatment means expressed on a per heifer basis.
[2] In vitro digestible NDF as determined by a 48 h incubation.
[3] Where ME = metabolizable energy, NE_g = net energy gain, NE_m = net energy maintenance.
[4] C=Control (C-100) vs L=limited (L-80,L-90). Entries without values are not significant (P>0.10).

Table 4. Effect of dietary regimen on body size and growth of replacement heifers.

	Treatment[1]				Effect(P<)[2]		
Item	C-100	L-90	L-80	SEM	Treatment	Linear	C vs R
Intial							
Weight, lbs	1036	1021	1011	21	…	…	…
Hip height, in	54.20	54.60	54.90	0.3	…	…	…
Body condition score	3.1	3.0	2.9	0.1	…	…	…
Final							
Weight, lbs	1220	1234	1217	19	…	…	…
Hip height, in	56.0	56.3	56.4	0.3	…	…	…
Body condition score	3.2	3.2	3.2	0.1	…	…	…
Growth							
Average daily gain, lbs/d	1.66	1.92	1.84	0.14	…	…	…
Hip height, in/111 d	1.8	1.7	1.5	0.3	…	…	…
Body condition score, units/111d	0.1	0.2	0.2	0.1	…	…	…
Feed efficiency, lbs DM/lb gain	13.2	10.7	11.1	0.9	…	…	0.09
Excretion							
DM, lbs/d	7.7	6.9	5.8	0.6	…	0.10	0.10
N, g/d	140.2	141.7	146.8	9.7	…	…	…
P, g/d	24.7	25.2	27.2	2.3	…	…	…

[1] C-100, control heifers fed ad libitum, L-90, limited to 90.0 percent of intake, L-80, limited to 80.0 of intake.
Treatment means expressed on a per heifer basis.
[2] C=Control (C-100) vs L=limited (L-80,L-90). Entries without values are not significant (P>0.10).

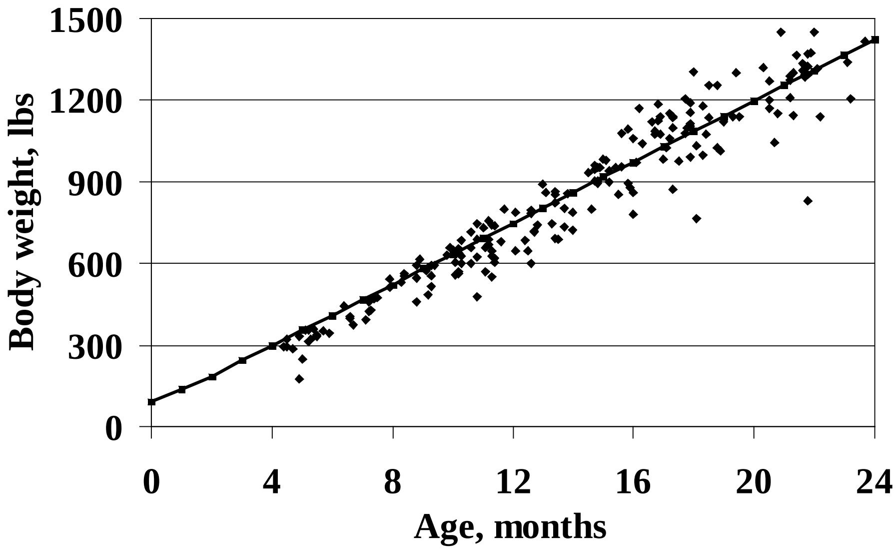

Figure 1. Age and weight relationship of 168 heifers from the Marshfield Agricultural Research Station, University of Wisconsin.

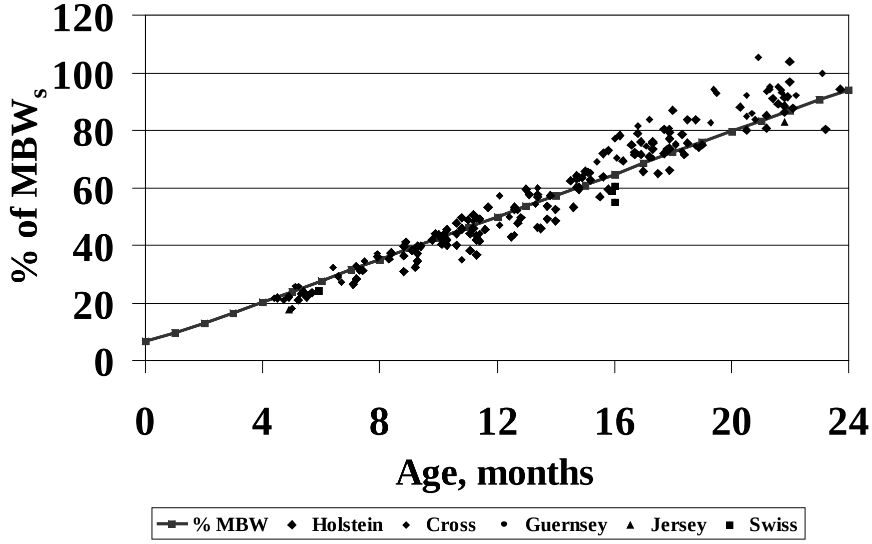

Figure 2. Mature body weight (MBW_s) relationship of 168 heifers from the Marshfield Agricultural Research Station, University of

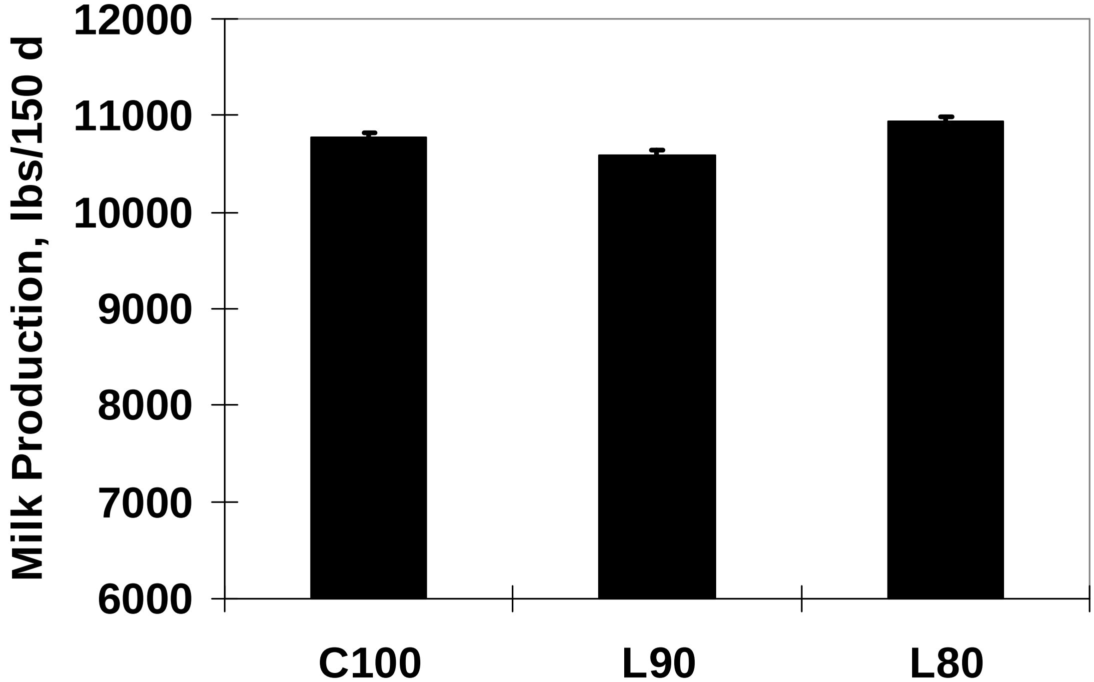

Figure 3. Milk production (150 d) of first lactation cows which were limit-fed prior to parturition, (Hoffman et al. 2006.)