

Effects of Three Prepubertal Body Growth Rates on Performance of Holstein Heifers During First Lactation

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ABSTRACT

The effects of body weight (BW) gain, different sources of protein during the prepubertal period (90 to 320 kg of BW), and the performance of Holstein heifers during their first lactation were studied. Heifers ($n = 273$) were assigned to one of three dietary energy treatments that were designed to achieve average daily gains of 0.6, 0.8, and 1.0 kg/d. Within each energy treatment, different protein sources (plant protein and urea or both plant and animal proteins) were imposed. Actual average daily gains by heifers on each energy treatment were 0.68, 0.83, and 0.94 kg/d for heifers that were fed diets formulated for average daily gains of 0.6, 0.8, and 1.0 kg/d, respectively, which allowed the following ages at first calving: 24.5, 22.0, and 21.3 mo. Breeding was initiated when heifers weighed approximately 340 kg. Protein sources did not affect average daily gain or milk yield. Analysis of the preplanned comparisons of actual 305-d and 4% fat-corrected milk yields indicated that yield was significantly reduced for heifers grown at 0.94 kg/d (9387 and 8558 kg, respectively) compared with that of heifers grown at 0.68 kg/d (9873 and 9008 kg, respectively). However, further regression analysis of fat-corrected milk and residual milk from a test day model on prepubertal BW gain only explained 8 and 2% of the variation in milk yield, respectively. Postcalving BW and body condition score were different among treatments. Posttreatment factors, such as postcalving BW, accounted for more of the variation in milk yield than did prepubertal BW gain. Prepubertal BW gains, when evaluated on a continuum from 0.5 to 1.1 kg/d, explained little of the variation in milk yield; therefore, BW gain during the prepubertal period did not significantly affect milk yield during first lactation.

(**Key words:** heifer, growth, first lactation performance)

Abbreviation key: ADG = average daily gain, AFC = age at first calving, BCS = body condition score, BWG = BW gain, TDM = test day model.

INTRODUCTION

Studies (11, 13, 27, 46) have indicated that when prepubertal growth rates of heifers increase, time to conception, age at first calving (AFC), and milk yield during first lactation decrease. Swanson (46) using Jerseys and Little and Kay (27) using British Friesians demonstrated a 15 to 48% decrease in first lactation milk yield by heifers fed high energy diets for higher rates of BW gain (BWG). A Danish study (11) reported reductions in milk yield of 10 to 25% when prepubertal growth rates were increased beyond 0.6 kg/d. Holstein heifers that calved at 19.7 mo yielded 18% less milk during their first lactation than did heifers that calved at 26 mo. Heifers that calved earlier yielded 48% more milk than did the control heifers by 36 mo of age, indicating greater lifetime profitability (13). Other research (14, 50) has found no effect on the milk yield of Holstein heifers fed at an average daily gain (ADG) in excess of 0.9 kg/d during the prepubertal period.

Because puberty is associated primarily with BW (28, 37) and because the length of gestation is fixed, AFC is a function of age at which puberty and conception occur. During the prepubertal period of heifer growth, the mammary gland is sensitive to BWG (35, 42, 43, 47). The period that is most negatively affected by BWG appears to be between 90 and 300 kg of BW (11, 43). Sejrsen (40) and Sejrsen et al. (42, 43) postulated and later demonstrated that increased BWG had significant effects on the development of the prepubertal mammary gland. Other research (17, 34, 45) suggested there was a rate of BWG for prepubertal heifers beyond which mammary development was inhibited. The current recommended upper limit for BWG is 0.8 kg/d for heifers of a mature size (800 kg) (31).

After conception, factors such as BW (3, 9, 29, 30) and body condition score (BCS) (15, 16) at calving

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influence feed intake and first lactation milk yield. Foldager and Sejrsen (11) reported a linear relationship between postpubertal BWG and milk yield. High energy intake during the postpubertal period did not negatively influence mammary development (43) and might have even enhanced development (17), although accelerated growth during the postpubertal period has demonstrated equivocal changes in milk yield (21, 26).

The potential to accelerate prepubertal body growth and reduce AFC may exist if our current knowledge of nutrient requirements is applied and breeding decisions are based on physiological maturity. This study was designed to determine the effects of accelerated rates of prepubertal body growth on first lactation milk yield of Holstein heifers.

MATERIALS AND METHODS

Design

The prepubertal growth regimen was discussed in a companion paper (48). Treatments were designed to coincide with the prepubertal period of mammary development (90 to 320 kg of BW). Treatments were terminated at 320 kg of BW to minimize the residual effects of treatment on the second phase of mammary development (43). An ADG of 0.6 kg was imposed based on Danish findings (11) that suggested that optimal milk yield was observed when prepubertal heifers did not exceed 0.6 kg/d of BWG. An ADG of 0.8 kg was designed to represent the rate of gain recommended by the NRC (31). The target BWG for the third energy treatment (ADG = 1.0 kg) was designed to allow for breeding by 12 mo for an earlier AFC of 21 mo. The target postcalving BW for all treatments was 545 kg.

Heifer Breeding Program

Breeding was initiated at 340 kg of BW. The breeding BW was chosen to allow heifers to have at least three estrous cycles prior to first breeding; however, puberty and the actual number of estrous cycles were not determined. Greater mammary development and higher milk yields have been reported for heifers that had two to four estrous cycles prior to first breeding (13, 44). Calving ease was not a criterion for the selection of sires. Prostaglandin (PGF_{2α}) (Lutalyse™; The Upjohn Co., Kalamazoo, MI) was administered to heifers that were not observed to be in standing estrus after heifers had reached a BW greater than 360 kg. Heifers were allowed six inseminations prior to removal from the study.

TABLE 1. Description of scores used to rank calving difficulty.

| Score | Description |
|-------|--|
| 1 | No assistance |
| 2 | Minor assistance |
| 3 | Rigorous calf manipulation; healthy cow and calf |
| 4 | Extreme difficulty; cow or calf left incapacitated |
| 5 | Cesarean or dead calf because of extreme trauma |

Precalving Period

Three to 4 wk prior to the expected calving date, heifers were weighed and fed a precalving diet for *ad libitum* intake until parturition. From May to October, heifers were housed in an exercise lot with access to fresh water.

Postcalving Period

A calving difficulty score was recorded on a five-point scale (Table 1). Within 24 h of parturition, heifers were weighed and assessed for BCS [five-point scale where 1 = thin to 5 fat (8); increments of 0.25]. Lactating heifers were housed together in pens of 15 to 20. Heifers were milked three times daily, and milk weights were recorded electronically. Milk samples were taken every 3 wk for analysis of fat, protein, and SCC (Northeast DHIA, Ithaca, NY). Heifers were weighed and evaluated for BCS (8) every 21 d after the second daily milking.

Feeding Program

The ration for the milking herd was fed as a TMR three times per day at 0200, 0800, and 1700 h to yield 5% orts daily (Table 2). One ration was fed to all heifers for the entire lactation to ensure that nutrient supply was adequate to meet any requirements for growth and lactation. The DM content of the dietary ingredients and TMR was analyzed weekly for reformulation. Because of the length of the trial period, the composition of the TMR changed as the availability of the forage supply changed. Compositional changes in the ration were primarily due to changes in the amount of corn grain in the corn silage. As corn grain content decreased or increased in the silage according to growing season, ground corn was increased or decreased, respectively, to maintain a similar NE_L content.

Lactation Reproduction Program

During lactation, PGF_{2α} was administered every week until insemination of heifers that were greater

TABLE 2. Mean ingredient and chemical composition of diet fed during lactation.

| Composition | (% of DM) | SE |
|--|-----------|------|
| Ingredient | | |
| Corn silage | 21.6 | ... |
| Alfalfa silage | 15.6 | ... |
| Corn, ground | 27.7 | ... |
| Soybean meal | 6.1 | ... |
| Whole linted cottonseed | 9.1 | ... |
| Expeller soybean meal | 5.1 | ... |
| Dairy pellets ¹ | 11.4 | ... |
| Sodium bicarbonate | 0.5 | ... |
| Vitamins and minerals ² | 2.9 | ... |
| Chemical | | |
| DM, % | 52.7 | 3.0 |
| CP | 18.0 | 0.4 |
| DIP, ³ % of CP | 61.2 | 1.2 |
| NDF | 31.8 | 1.7 |
| ADF | 19.4 | 1.0 |
| Calcium | 0.97 | 0.04 |
| Phosphorus | 0.57 | 0.02 |
| Magnesium | 0.31 | 0.01 |
| Potassium | 1.24 | 0.01 |
| NE _L , ⁴ Mcal/kg of DM | 1.72 | ... |

¹Pellet composition: 65% soybean hulls, 20% corn meal, and 15% animal protein.

²Nutri-Min Dairy Pre-Mix 3.2 (Agway Inc., Syracuse, NY; composition: 19.6% calcium, 12.0% phosphorus, 8.0% magnesium, 3.0% sulfur, 0.7% potassium, 26 ppm of selenium, 90 ppm of iodine, 63 ppm of cobalt, 1000 ppm of copper, 7000 ppm of iron, 4500 ppm of manganese, 4500 ppm of zinc, 440,000 IU/kg of vitamin A, 110,000 IU/kg of vitamin D, and 2200 IU/kg of vitamin E) and trace mineral salt (Cargill Inc., Minneapolis, MN; composition: 98.5% sodium chloride, 0.35% zinc, 0.20% manganese, 0.20% iron, 0.03% copper, 0.007% iodine, and 0.005% cobalt).

³Degradable intake protein estimated using NRC (31) tabular values.

⁴Estimated from NRC (31).

than 70 DIM without a breeding. Pregnancy was confirmed by rectal palpation. Heifers that failed to conceive by 200 DIM were not rebred and were milked until at least 305 DIM.

Statistical Analysis

Sample size was determined based on a mean milk yield of 7000 kg and a standard deviation of 1135 kg of milk for the research herd; the expected detectable difference in milk yield was less than 10% at a 98% confidence level (minimum of 24 heifers per energy and protein combination with a completed lactation). Assumptions were made about potential losses of heifers from weaning; therefore, increases in sample size were made based on a planned loss of 10% of the heifers from weaning. The statistical design was a 2 × 3 factorial with replication. The model for the preplanned statistical comparison included energy

TABLE 3. Distribution of heifers within treatments for ranking postcalving BW measured within 24 h of calving.¹

| BW Range | Heifers | Average daily gain | | |
|------------|---------|--------------------|--------|--------|
| | | 0.6 kg | 0.8 kg | 1.0 kg |
| | (no.) | | | |
| <499 kg | 46 | 13 | 31 | 56 |
| 500–549 kg | 104 | 34 | 33 | 33 |
| 550–599 kg | 46 | 58 | 25 | 18 |
| >600 kg | 16 | 50 | 12 | 38 |

¹Values for each treatment are percentages of the treatment group represented in each BW range.

level and protein source as fixed effects and replication as a random effect defined as the replication of the energy and protein treatment combination. Interactions tested were energy and protein; replication and energy; replication and protein; and replication, energy, and protein. Nonsignificant interactions were removed from the model.

Because of the significant effects of BW and possibly BCS at calving, a second analysis of the 305-d FCM was conducted using BW at calving as a covariate. Body weight at calving might have implications for nutrient utilization and DMI; however, others (J. Foldager and K. Sejrsen, 1994, personal communication) have suggested that BW at calving was a treatment effect and should not be used as an adjustment for milk yield.

Although heifers were assigned to target BWG treatments, the 305-d 4% FCM yields and residual milk from the test day model (**TDM**) were regressed on prepubertal BWG and calving age by heifer to assess the effects of these variables on milk yield. Linear and quadratic effects were tested. To evaluate the effects of postcalving BW on milk yield, BW at calving was ranked as described in Table 3, independent of treatment assignment. Differences between least squares means were compared by least significant difference using the GLM procedure of SAS (39).

Because of the potential effects of calving year, season, management, and environment on lactation performance, a linear model that described the biology of those influences was applied to the yield data. Residuals from the TDM (49) were adjusted for herd test day, age, DIM, month of calving, pregnancy, and management effects. Test day residuals are yields that are above or below herd contemporaries after adjustment and include cow effect, random effect, and treatment effect. Differences among residuals were considered to be the treatment differences.

The TDM concept was based on the assumption that global conditions are inappropriate to evaluate

management or animals located in different herds. The model assumed that conditions vary from herd to herd as well as from environment to environment and that conditions change over time within a herd.

Data are presented as least squares means. Differences among means were compared by least significant difference using the predicted difference option of the GLM procedure of SAS (39). Other variables analyzed in the model included posttreatment BWG without the weight of pregnancy, BW at calving, calving difficulty, and changes in BW and BCS over the lactation. Posttreatment BWG without the weight of pregnancy was calculated by subtracting the BW of the heifer on the day that the heifer was confirmed to be pregnant from the BW taken within 24 h postcalving. Postcalving BCS was analyzed using the non-parametric one-way analysis of SAS (39), which is a rank sum analysis. All analyses were declared significant at $P < 0.05$.

Inseminations per conception and rate of conception for the heifers were evaluated by ANOVA to determine whether growth rate or protein source had an effect on reproductive efficiency. The effects of treatment on days open during the lactation were quantified using survival analysis. The predictor variable of interest was energy level. The outcome variable was days open, defined as the time between parturition and conception. Season of parturition was used in the analysis as a covariate. Seasonal categories were March to May, June to August, September to November, and December to February (25, 32). Survival analysis allowed for the simultaneous evaluation of censored and uncensored heifers and calculated the probability of an event (e.g., conception) that occurred using all heifers, whether all heifers experienced the event or not. Censored heifers were heifers that survived beyond the voluntary wait period (70 DIM) and were eligible to be bred but were never known to have conceived. Heifers that were culled prior to 70 DIM were not included in the analysis because they were never eligible to be bred. For censored heifers that were inseminated, days open were calculated as days from parturition to dry-off. Survival data were analyzed using the Cox proportional hazards regression model:

$$h_i(t) = h_0(t) \exp(\text{treatment} + \text{season}).$$

The probability of a heifer becoming pregnant at t days after parturition was described as $h_i(t)$, the hazard function. When the covariate was equal to 0, the unknown baseline probability of pregnancy was characterized as $h_0(t)$, the baseline hazard function.

For each independent variable in the model, a hazard ratio (relative risk) was estimated. Hazard ratios estimated the rate of pregnancy and were calculated by raising 2.718 to the β power. The pregnancy rate calculated in the survival analysis was a true rate because survival analysis estimates the number of conceptions per unit of time (4, 22, 23). The differences among treatments were described by plotting the Kaplan-Meier estimators for all treatments to determine the median days open. All tests of statistical significance were done using the likelihood ratio test. Tests of the independence of censoring and conception also were done; the assumptions of independence were not violated. Survival analysis was conducted using BMDP Statistical Software (5).

RESULTS AND DISCUSSION

Two hundred sixty-five heifers calved, and 8 heifers were culled prior to parturition because of poor health and injuries (heifers fed for an ADG of 0.6 kg = 1; heifers fed for an ADG of 0.8 kg = 2; heifers fed for an ADG of 1.0 kg = 5); 1 heifer died (ADG = 0.6 kg), and 2 other heifers were paralyzed because of difficult calving (ADG = 1.0 kg). Three of the heifers fed for an ADG of 1.0 kg died because of injuries incurred by not lying in the stalls (heifers were too large for the stalls because of accelerated growth); these heifers broke legs by getting caught in the gutter cleaner. The three calving difficulties occurred during the winter months and were attributed to human intervention too early in the calving process. Twenty-one heifers (6 heifers fed for an ADG of 0.6 kg; 7 heifers fed for an ADG of 0.8 kg, and 8 heifers fed for an ADG of 1.0 kg) with DIM ranging from 4 to 268 d were not included in the analysis because of health problems.

Growth Performance

Growth data were analyzed for heifers ($n = 234$) with complete lactations (Table 4). Source of protein supplementation during the prepubertal period did not affect growth or milk yield ($P > 0.05$) (48). Thus, source of protein supplementation was omitted in the analysis. The data were analyzed by energy treatment. Daily BWG were different ($P < 0.05$) according to rates of ADG. Hip heights were greatest for heifers fed the diet formulated for an ADG of 0.6 kg ($P < 0.05$) and decreased as energy intake increased when heifers were measured at similar BW.

The mean BCS and maximum BCS recorded within treatments increased ($P < 0.05$) as energy intakes increased for heifers fed the diet formulated for an

TABLE 4. Least squares means by treatment for heifers targeted for three rates of prepubertal BW gain.¹

| | Average daily gain | | | SE |
|---|--------------------|--------|--------|------|
| | 0.6 kg | 0.8 kg | 1.0 kg | |
| Heifers, no. | 84 | 65 | 85 | |
| Average daily gain, kg/d | 0.68 | 0.83 | 0.94 | 0.01 |
| Mean BCS ² | 3.0 | 3.1 | 3.4 | 0.02 |
| Mean maximum BCS ³ | 3.3 | 3.5 | 3.9 | 0.03 |
| Final hip height, cm | 128.0 | 127.0 | 125.1 | 0.33 |
| Mean days on treatment | 365 | 290 | 258 | 3.6 |
| Posttreatment average daily gain ⁴ | 0.67 | 0.64 | 0.58 | 0.01 |

¹All variables were different ($P < 0.05$) among treatments. Results presented are for heifers included in the lactation analysis.

²Body condition scores (BCS) were evaluated according to Edmonson et al. (8) using a five-point scale where 1 = thin to 5 = fat.

³Highest BCS recorded per heifer per treatment averaged over all heifers on that particular treatment.

⁴Calculated by subtracting the BW recorded on the day that the heifer was confirmed to be pregnant from the postcalving BW.

ADG of 0.6 kg to heifers fed the diet formulated for an ADG of 1.0 kg, suggesting a higher rate of fat deposition to lean tissue growth for heifers growing at a more rapid rate because heifers finished at a similar BW (Table 4). The maximum BCS are the highest recorded BCS for each individual heifer in a treatment and are presented as the mean of the highest scores observed for all heifers on the treatment. The maximum BCS are presented to demonstrate the highest scores observed over the prepubertal period because fat deposition and obesity during this period have been negatively associated with mammary development and milk yield (27, 43).

Posttreatment BWG were different ($P < 0.05$) among treatments (Table 4). Posttreatment BWG was calculated from the BW of the heifer on the day

the heifer was confirmed to be pregnant to the BW obtained at 24 h postcalving. Pregnancy was confirmed by rectal palpation at 35 to 40 d postinsemination. After the treatment period, heifers were housed in one group, and the diet was available for ad libitum intake, which resulted in compensatory growth during the early posttreatment period for heifers fed the diet formulated for an ADG of 0.6 kg. Conversely, heifers fed for an ADG of 1.0 kg were fed a higher energy diet (2.5 vs. 2.3 Mcal/kg) for ad libitum intake during the treatment period; thus, heifers fed for an ADG of 1.0 kg likely had higher maintenance requirements because of the previous plane of nutrition and experienced a decrease in BWG when managed in one group. The difference in posttreatment BWG led to significant differences in postcalving BW ($P < 0.05$)

TABLE 5. Body weight and body condition score (BCS) changes at various stages of lactation by treatment.

| | Average daily gain | | | SE |
|----------------------------------|--------------------|------------------|-------------------|------|
| | 0.6 kg | 0.8 kg | 1.0 kg | |
| Calving BW, kg | 550 ^a | 529 ^b | 520 ^c | 2.7 |
| BW Loss, ¹ kg | 53 ^a | 55 ^a | 61 ^a | 2.2 |
| BW at Nadir, kg | 497 ^a | 474 ^b | 459 ^c | 2.6 |
| BW at 40 wk of Lactation | 574 ^a | 573 ^a | 565 ^a | 2.6 |
| Overall BW change from nadir, kg | 77 ^c | 99 ^{bc} | 106 ^{ab} | 2.3 |
| BCS at Calving ² | 3.8 ^a | 3.5 ^b | 3.9 ^a | 0.02 |
| BCS Loss ³ | 1.3 ^a | 1.2 ^a | 1.3 ^a | 0.04 |
| BCS at Nadir | 2.5 ^a | 2.3 ^a | 2.6 ^a | 0.03 |
| BCS at 40 wk of Lactation | 3.5 ^a | 3.2 ^b | 3.6 ^a | 0.03 |
| Overall BCS change from nadir | 1.0 ^a | 0.9 ^a | 1.0 ^a | 0.04 |

^{a,b,c}Means in rows with no common superscripts differ ($P < 0.05$).

¹Means of the lowest recorded BW for each heifer independent of time minus calving BW.

²The BCS were evaluated according to Edmonson et al. (8) using a five-point scale where 1 = thin to 5 = fat.

³Means of the lowest recorded BCS for each heifer independent of time minus BCS at calving.

among treatments (Table 5), although heifers were bred at similar BW. Reproductive performance was similar for all growth treatments; inseminations per conception were not different ($P > 0.05$) (1.8 AI for heifers fed diets formulated for an ADG of 0.6 kg, 2.0 for heifers fed diets formulated for an ADG of 0.8 kg, and 2.0 for heifers fed diets formulated for an ADG of 1.0 kg).

Lactation Performance

Heifers fed for an ADG in excess of 0.7 kg/d during the prepubertal period had reduced milk yield during first lactation (2, 11, 13, 27, 33). Results of this study indicated that actual 305-d and 4% FCM yields analyzed according to the preplanned comparison were also significantly affected by prepubertal treatment (Table 6).

The actual FCM and 305-d milk yields of heifers on the accelerated growth treatment (ADG = 1.0 kg) were approximately 5% lower than the milk yields of heifers fed for an ADG of 0.6 kg. However, this decrease in milk yield was dramatically less than the reduced milk yield reported by previous researchers (11, 13, 27). A previous study (13) indicated a 10 to 25% reduction in first lactation milk yield when prepubertal growth rates exceeded 0.8 kg/d. Contrary to the analyses for actual 305-d and 4% FCM yield,

residual milk from the TDM was not affected ($P > 0.05$) by prepubertal BWG (Table 6). Residual fat was also not different ($P > 0.05$); however, residual protein was significantly affected by prepubertal BWG (Table 6). Fat and protein percentages were not different; thus, differences in fat and protein yield were parallel to differences between the actual 305-d and FCM yields (data not shown).

The TDM accounted for sources of biological variation that were not associated with the preplanned comparisons and indicated that prepubertal growth rate did not affect first lactation milk yield. The TDM analysis accounted for variation within the herd that might have influenced the results of the traditional analyses for 305-d yield.

Further analysis of the effect of prepubertal BWG on first lactation performance was conducted using linear and quadratic regression. The 305-d FCM yields and residual effects of TDM were regressed on prepubertal BWG to evaluate the effects of BWG on milk yield. The regression of the residual effects of 305-d 4% FCM yields and residual effects of the TDM on actual prepubertal BWG (Figures 1 and 2) indicated that prepubertal BWG did not affect first lactation milk yield (Table 6). The regression of FCM yield on prepubertal BWG was significant ($P < 0.05$); however, the relationship explained none of the variation in milk yield ($R^2 = 0.08$). A similar relationship

TABLE 6. Least squares means of growth rate effects from 90 to 320 kg of BW on lactation performance.

| | Average daily gain | | | SE |
|-----------------------------------|--------------------|--------------------|-------------------|-----|
| | 0.6 kg | 0.8 kg | 1.0 kg | |
| Heifers, no. | 84 | 65 | 85 | |
| Actual 305-d milk yield, kg | 9873 ^a | 9620 ^{ab} | 9387 ^b | 134 |
| 305-d 4% FCM Yield, kg | 9008 ^a | 8810 ^{ab} | 8558 ^b | 130 |
| Covariate analysis ¹ | | | | |
| Actual 305-d milk yield, kg | 9797 | 9655 | 9501 | 127 |
| 305-d 4% FCM Yield, kg | 8918 | 8814 | 8674 | 98 |
| Test day model ² | | | | |
| Residual milk, kg | 435 | 648 | 186 | 171 |
| Residual fat, kg | 4.7 | 6.8 | -3.5 | 5.4 |
| Residual protein, kg | 7.0 ^a | 10.9 ^{ab} | 0.2 ^b | 4.6 |
| Residual SCC | -105 | -41 | -69 | 20 |
| Second lactation | | | | |
| Heifers, no. | 50 | 43 | 60 | |
| 305-d Milk yield, ³ kg | 11,030 | 10,940 | 11,116 | 116 |

^{a,b}Means in rows with different superscripts differ ($P < 0.05$).

¹Covariate analysis conducted on 305-d milk yield using postcalving BW as the covariate in the model and energy, protein, and replications as predictor variables.

²Differences among mean residuals were considered to be the true treatment differences for the lactation.

³Heifers used for analysis were greater than 150 DIM; 305-d projections were used for heifers that did not have a completed lactation.

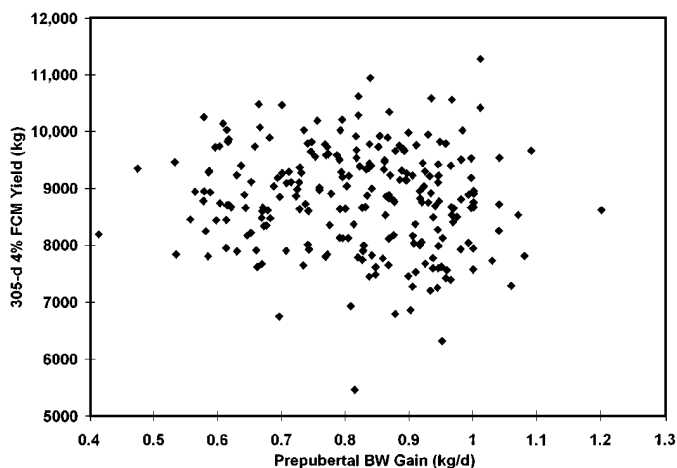


Figure 1. Regression of 305-d 4% FCM yield on prepubertal BW gain for all heifers independent of treatment. The linear equation was $Y = -676X + 9370$; $R^2 = 0.08$.

was found between residual milk and prepubertal BWG ($R^2 = 0.02$). Furthermore, because rate of BWG and fat accretion are highly correlated and because the prepubertal rate of BWG did not significantly affect first lactation milk yield, the BCS achieved by heifers on this study were not detrimental to first lactation milk yield.

Researchers (17, 35, 43, 45) found that high body growth rates during the prepubertal period had detrimental effects on parenchyma development, resulting in decreased secretory tissue. A recent study (36) compared the effects of prepubertal growth rates (0.8 and 1.2 kg/d) in Holsteins on mammary develop-

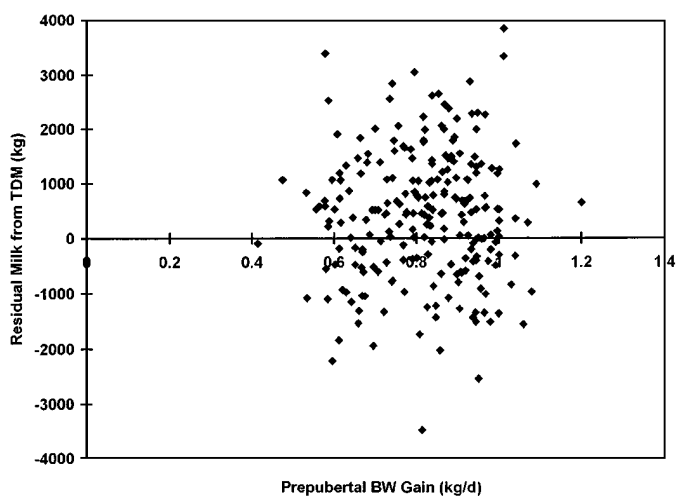


Figure 2. Regression of the residual milk from the test day model (TDM) on prepubertal BW gain for all heifers independent of treatment. The linear equation was $Y = 86X + 344$; $R^2 = 0.02$.

ment. Evaluation of the mammary tissue obtained from slaughtered Holstein heifers demonstrated that DNA content (milligrams per kilogram of BW) was not significantly different for heifers grown at the two rates of gain. Those researchers (36) suggested that high energy combined with higher protein intakes might have allowed for greater expression of mammary development in heifers on the higher energy treatment. An increase in protein concentration (15% vs. 20%) in the diet of prepubertal lambs resulted in increased mammary tissue development when the lambs were slaughtered after 7 wk of lactation; however, no differences in mammary parenchyma were observed in comparison with lambs slaughtered at puberty (52). The results of these studies (36, 52) supported the findings of this experiment in which energy was balanced to achieve the target rates of BWG and protein was formulated to meet the ruminal nitrogen requirements and exceed tissue requirements.

The differences in actual 305-d and 4% FCM yields identified by the preplanned comparisons might have been due to the lighter postcalving BW, higher BCS of the heifers fed diets formulated for an ADG of 1.0 kg, and potential effects on DMI and nutrient partitioning for growth as compared with heifers fed diets formulated for an ADG of 0.6 kg. The reduction ($P < 0.05$) in residual protein in heifers fed diets formulated for an ADG of 1.0 kg suggested a reduced DMI because BW and milk protein yield can account for 80% of the variation in DMI (38). Further analysis of the preplanned comparisons using postcalving BW as a covariate indicated that the treatment effect of prepubertal BWG and energy intake became nonsignificant (Tables 6 and 7), which suggests that postcalving BW, and thus posttreatment management, might have impacted lactation yield more than prepubertal growth rate and supports the regression

TABLE 7. Relationships among 305-d 4% FCM yield, residual effects of the test day model, and prepubertal BW gain independent of treatment group with and without BW as a covariate in the analysis of milk yield.

| | Linear | Quadratic | R^2 |
|---------------------------------|--------|-----------|-------|
| | P | | |
| 305-d 4% FCM Yield | 0.01 | 0.13 | 0.08 |
| Residual milk | 0.08 | 0.26 | 0.02 |
| Residual fat | 0.23 | 0.26 | 0.01 |
| Residual protein | 0.16 | 0.26 | 0.01 |
| Covariate analysis ¹ | | | |
| 305-d 4% FCM Yield | 0.21 | 0.28 | 0.00 |

¹Covariate analysis conducted on 305-d milk yield using postcalving BW as the covariate in the model and prepubertal BW gain as the predictor variable.

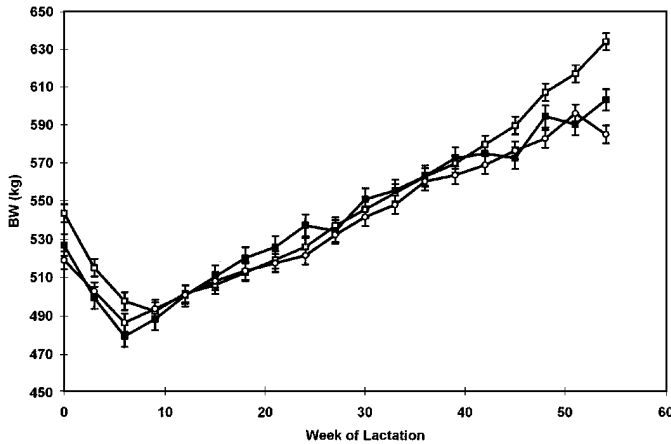


Figure 3. Change in BW by week of lactation for prepubertal average daily gain (ADG) treatments. Legend: 0.6 kg of ADG (□), 0.8 kg of ADG (■), and 1.0 kg of ADG (○). Body weight at calving was different ($P < 0.05$) among treatments. By 40 wk of lactation, the BW of heifers on all treatments were similar.

analysis of the residual effects of FCM yield and those of the TDM on prepubertal BWG.

When analyzed by the preplanned comparisons, heifers that were fed diets formulated for an ADG of 1.0 kg were 30 kg lighter at calving (Table 5). The BCS at calving was greater ($P < 0.05$) for heifers fed diets formulated for an ADG of 0.6 kg and for heifers fed diets formulated for an ADG of 1.0 kg, but losses in BW and BCS during first lactation were similar for heifers on all treatments (Table 5). Body weight was

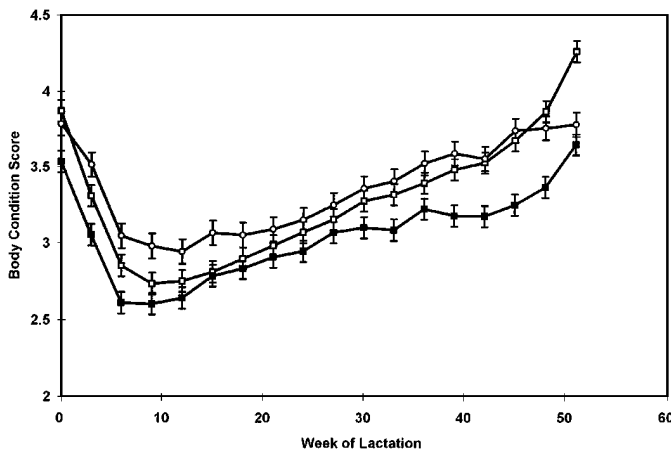


Figure 4. Change in body condition score by week of lactation and prepubertal average daily gain (ADG) treatments. Legend: 0.6 kg of ADG (□), 0.8 kg of ADG (■), and 1.0 kg of ADG (○). Body condition scores of heifers fed for ADG of 0.6 and 1.0 kg differed ($P < 0.05$) at parturition from heifers fed for an ADG of 0.8 kg. Body condition score was assessed on a five-point scale where 1 = thin to 5 = fat (8).

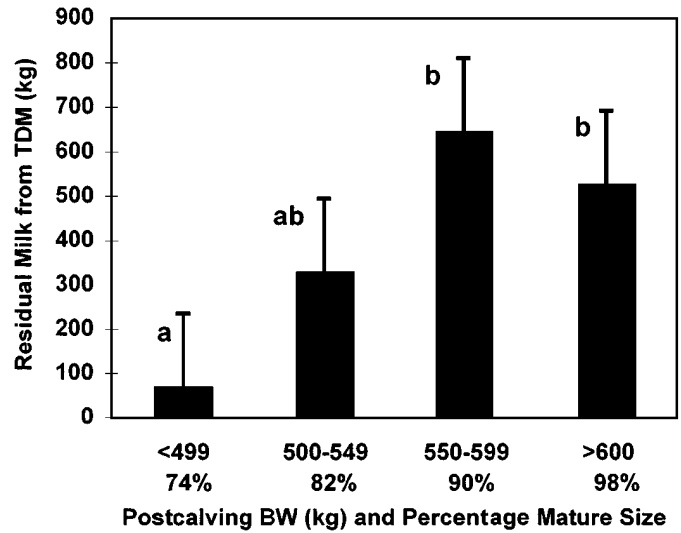


Figure 5. Relationship between residual milk yields from the test day model (TDM) and postcalving BW independent of treatment. Postcalving BW were measured within 24 h of parturition. Different letters indicate significant differences ($P < 0.05$) between residual milk yields at different BW. The relationship between postcalving BW as a percentage of mature size and the residual milk yield from the TDM is also shown. Mature size was determined to be 641 ± 57 kg for the research herd by weighing all cows at third and greater lactations ($n = 102$).

increasing by 9 wk postpartum for heifers on all treatments, and change in BCS was not positive for all heifers until 12 wk postpartum (Figures 3 and 4). By 40 wk of lactation, heifers fed diets formulated for an ADG of 1.0 kg were at a similar BW and BCS compared with heifers fed diets formulated for an ADG of 0.6 kg (574 vs. 565 kg), suggesting that more nutrients were partitioned for growth than for lactation. This subtle difference in growth potential might have been identified in the fixed effects analysis and might help explain the 5% difference in milk yield observed between heifers fed diets formulated for an ADG of 0.6 kg and heifers fed diets formulated for an ADG of 1.0 kg by the analysis of 305-d FCM yield.

Positive relationships between first lactation milk yield and BW at first calving have been previously reported (3, 9, 24). Keown and Everette (24) showed that first lactation milk yield increased as BW increased up to 635 kg. The optimal economic calving BW at first lactation was approximately 550 kg because the increase in milk yield beyond 550 kg did not offset the cost of the increase in first lactation milk yield as BW increased to 635 kg. A survey (19) of Holstein herds showed that milk yield was highest in herds for which the calving age was less than 26 mo and postcalving BW was greater than 520 kg. For comparison, heifers from this study were categorized by postcalving BW (Table 3), independent of treat-

ment, and plotted against residual milk (Figure 5). This relationship suggested that postcalving BW should be at least 525 kg to optimize first lactation milk yield. The relationship of milk yield to postcalving BW was similar to the relationship described by Keown and Everett (24). To apply the concept of optimal postcalving BW, the mature size of the Cornell dairy herd was determined by weighing cows in their third and greater lactation ($n = 107$) on 2 consecutive d after the second daily milking with no sorting by stage of lactation. Mean BW was 641 ± 57 kg. Using this BW to evaluate calving BW recommendations for this herd, the minimum percentage of mature body size that is necessary to optimize first lactation milk yield should be at least 82% (Figure 5). This concept warrants further investigation.

In this study, AFC were 24.5, 22, and 21.3 mo for heifers fed diets formulated for ADG of 0.6, 0.8, and 1.0 kg, respectively. Effects of AFC on first lactation milk yield have been reported (1, 3, 18). Effects of AFC and BW are difficult to separate because the relationship is highly correlated. Studies (2, 51) with AFC ranging from 21 to 33 mo reported decreased milk yield (approximately 15%) between the extremes in AFC. In the same studies, BW at calving was 91 to 100 kg lighter at the earliest AFC. Effects of BW in these studies (2, 51) might have been more important than age effects and might correspond to the weight effects described by Keown and Everett (24).

In this study the relationship between 305-d FCM and AFC was significant (linear, $P < 0.05$; quadratic, $P < 0.05$) but explained little variation in milk yield ($R^2 = 0.07$). Because gestation length is fixed, the only period of mammary development that may be temporally affected is the prepubertal period. If hormonal changes associated with puberty signal an end

to the prepubertal growth period (42, 44) and puberty is primarily related to BW (28, 37), the rate at which puberty is achieved can affect the length of time the prepubertal mammary gland has to develop. This concept has been discussed by others (26, 41). Because milk yield was not significantly affected by prepubertal growth rate, the heifers on the highest growth rate apparently had adequate time for mammary development. The development of the postpubertal mammary gland is not negatively affected by increased energy intake (43). However, lactation responses to increased energy intake during this period have been equivocal, because of the milk yield and increased postpartum metabolic disorders (12, 20, 26). In this study, AFC effects paralleled the overall treatment effects because AFC encompassed prepubertal growth rate, reproductive efficiency, post-treatment growth rate, and BW at calving.

Reproductive Performance

Previous studies (6, 7) have shown the effects of negative energy balance on reproductive performance, especially in primiparous cattle. Reproductive performance was not affected significantly by prepubertal treatment, although the survival analysis suggested the time to pregnancy was less in heifers fed diets formulated for an ADG of 1.0 kg. Kaplan Meier estimators were used to describe the pregnancy rates of heifers fed diets formulated for ADG of 0.8 and 1.0 kg. From this analysis, the median days open for heifers fed diets formulated for an ADG of 0.08 kg was 135 and, for heifers fed diets formulated for an ADG of 1.0 kg, was 120. Mean days open and inseminations per conception did not differ because of treatment (Table 8). There were no significant variables in the Cox proportional hazards model for days open because of insufficient numbers of heifers (Table 9). However, the technique is applied because it more accurately

TABLE 8. Descriptive statistics for reproductive performance by treatment during first lactation.

| | Average daily gain | | |
|---|--------------------|--------|--------|
| | 0.6 kg | 0.8 kg | 1.0 kg |
| Heifers, no. | 85 | 65 | 84 |
| Days open (all heifers) | 152 | 154 | 147 |
| Days open (heifers conceiving) | 128 | 140 | 121 |
| Heifers failing to conceive, no. | 14 | 8 | 9 |
| Inseminations per conception (for heifers conceiving) ¹ | 2.3 | 2.7 | 2.4 |
| First service conception rate (for heifers conceiving) ² | 39.4 | 32.2 | 41.6 |
| Overall conception rate, ³ % | 43.5 | 37.0 | 41.7 |

¹(Total services for heifers that conceived/heifers conceiving) \times 100.

²Total conceptions resulting from first service for heifers conceiving/total heifers with a first service that conceived) \times 100.

³(1/services per conception on all services) \times 100.

TABLE 9. Cox proportional hazard regression model, hazard ratios, and 95% confidence intervals for days open model.

| Term | Coefficient ¹ | SE | Wald <i>P</i> Value | LRCS ² <i>P</i> Value | Hazard ratio ³ | 95% Confidence interval |
|------------------------|--------------------------|------|---------------------|----------------------------------|---------------------------|-------------------------|
| Season ⁴ | | | | | | |
| 1 | 0.07 | 0.22 | 0.75 | ... | 1.01 | 0.7 to 1.7 |
| 2 | 0.01 | 0.20 | 0.95 | ... | 1.01 | 0.7 to 1.5 |
| 3 | 0.04 | 0.19 | 0.82 | ... | 0.96 | 0.7 to 1.4 |
| Treatment ⁵ | | | | | | |
| 2 | 0.05 | 0.19 | 0.77 | 0.77 | 1.06 | 0.7 to 1.5 |
| 3 | 0.21 | 0.18 | 0.26 | 0.26 | 1.23 | 0.9 to 1.8 |

¹The coefficients for the categorical variables represent the log *e* (2.718) of the ratio of hazard functions for different levels compared with the base level.

²Likelihood ratio chi-square statistic for treatment.

³Hazard ratios were calculated by raising the log *e* (2.718) to the β power. The hazard ratio estimates the rate of pregnancy for different treatments compared with the base treatment (0.6 kg/d of BW gain).

⁴Seasons: March to May, 1; June to August, 2; and September to November, 3.

⁵Treatments: heifers fed for an average daily gain (ADG) of 0.6 kg, 1; heifers fed for an ADG of 0.8 kg, 2; and heifers fed for an ADG of 1.0 kg, 3.

describes the rate at which heifers became pregnant than more traditional analyses. The hazard ratios for heifers fed diets formulated for an ADG of 0.8 kg and those for heifers fed diets formulated for an ADG of 1.0 kg indicated that those heifers had a 6 and 23% higher pregnancy rate, respectively, than did heifers fed diets formulated for an ADG of 0.6 kg, although the difference was not statistically significant (Table 9). To detect a 10-d significant difference in days open, considering censoring and losses to follow-up, Pankowski et al. (32) required a minimum of 415 cows per treatment. In this study, 30 heifers did not conceive and were considered censored heifers for the survival analysis. Data from this study suggested that the reproductive performance of heifers was not negatively affected by AFC and BW at first calving.

Second lactation data are presented in Table 6 and indicate that milk yield in the second lactation was not affected ($P > 0.05$) by previous treatment.

The SCC was analyzed using the residual SCC from the TDM. Residual SCC indicated that mastitis was not a significant factor in first lactation performance of heifers on any treatment.

CONCLUSIONS

In this study, AFC was decreased 3.3 mo to 21.2 mo. Regression analysis indicated that first lactation milk yield of Holsteins was not compromised by prepubertal BWG up to 1.1 kg/d from 90 to 320 kg of BW. Preplanned comparisons of the residual milk from the TDM indicated that milk yield was not significantly reduced by accelerated prepubertal

growth. However, preplanned comparisons of actual 305-d and 4% FCM yields demonstrated a significant reduction in milk yield. This reduction in yield was 5% for heifers targeted for an ADG of 1.0 kg versus that for heifers targeted for an ADG of 0.6 kg.

In this experiment, posttreatment effects, such as BW and BCS at calving, accounted for more of the variation in milk yield than did prepubertal BWG as evaluated by the preplanned comparisons. A postcalving BW that was 82 to 90% of mature size optimized first lactation milk yield. Protein supplementation to meet the tissue requirements for the higher rates of gain allowed by the energy in the diet might have allowed for an earlier breeding weight without detrimental effects on prepubertal mammary development. An increased understanding of the nutrient requirements of prepubertal Holstein heifers may aid in the development of recommendations for lowering the AFC without detrimental effects on milk yield.

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