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Reproductive performance of heifers offered ad libitum or restricted access to feed for a one hundred forty-day period after weaning[1]

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ABSTRACT: Reproductive performance was evaluated in composite heifers born over a 3-yr period that were randomly assigned to control (fed to appetite; n = 205) or restricted (fed at 80% of that consumed by controls adjusted to a common BW basis; n = 192) feeding for a 140-d period, beginning about 2 mo after weaning at 6 mo of age and ending at about 12.5 mo of age. Heifers were fed a diet of 67% corn silage, 18% alfalfa, and 9% of a protein-mineral supplement (DM basis). Restricted heifers consumed 27% less feed over the 140 d and had less ADG (0.53 ± 0.01 vs. 0.65 ± 0.01 kg/d; $P < 0.001$) than control heifers. After 140 d, all heifers were placed in common pens and subjected to an estrous synchronization protocol to facilitate AI at about 14 mo of age. Heifers were then exposed to bulls for the remainder of a 51-d breeding season. Average BW of heifers diverged within 28-d after initiation of feed restriction, and differences ($P < 0.001$) persisted through the prebreeding period (309 ± 1 vs. 326 ± 1 kg at approximately 13.5 mo of age) and subsequent grazing season (410 ± 2 vs. 418 ± 2 kg at about 19.5 mo of age). From the end of the 140-d restriction at about 12.5 to 19.5 mo of age, ADG was greater ($P < 0.001$) in restricted heifers than control heifers (0.51 ± 0.01 vs. 0.47 ± 0.01 kg/d). Proportion of heifers attaining puberty by 14 mo of age tended to be less ($P = 0.1$) in restricted (60 ± 3%) than control-fed heifers (68 ± 3%). Mean BW at puberty was less ($P < 0.01$) in restricted (309 kg) than control (327 kg) heifers. Pregnancy rate from AI tended to be less ($P = 0.08$) in restricted (48 ± 4%) than control heifers (57 ± 3%). Proportion of animals that were pubertal at breeding and pregnant from AI were positively associated ($P < 0.1$) with heifer age and ADG from birth to beginning of study. Final pregnancy rates were 87 and 91% for restricted and control heifers, respectively ($P = 0.27$). Day of breeding season that conception occurred was negatively associated with ADG from birth to weaning ($P = 0.005$), but was not associated with ADG within treatment ($P = 0.60$). Economic analysis revealed a $33 reduction in cost to produce a pregnant heifer under the restricted protocol when accounting for pregnancy rates and differences in BW and market prices between selection at weaning and marketing as open heifers at l.5 yr of age. A potential economic advantage exists for rearing replacement heifers on a restricted level of feeding during the postweaning period.

Key words: cattle, feed level, growth, heifer development, pregnancy, puberty

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INTRODUCTION

Development of replacement heifers at optimal rates of growth that promote puberty before breeding is critical for beef cattle production. Guidelines were established decades ago for developing replacement heifers to ensure attainment of puberty at an age that permits calving at 2 yr of age (reviewed in Patterson et al., 1992). However, forage conditions in many cow-calf production settings lack necessary nutrients to support recommended rates of development during the postweaning period, thereby requiring additional supplemental feed that increases overall cost. Thus, producers are faced with the challenge of balancing feed resources to achieve development goals, while minimizing cost of production by limiting harvested feed inputs. Recent research provides evidence that input of harvested feed can be reduced without major adverse effects on reproductive performance by altering pattern of BW gain (Freetly et al., 2001) or by feeding to lighter target BW than

[1]Mention of a proprietary product does not constitute a guarantee or warranty of the product by USDA or the authors and does not imply its approval to the exclusion of other products that may also be suitable. Authors thank USDA-ARS, Fort Keogh Livestock and Range Research employees B. Shipp, S. Reil, W. Kelly, and S. Bellows for contributions toward data collection and laboratory analysis of samples used in this manuscript.

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Table 1. Year of birth, forage quality, number per treatment, average BW, BW gain, and ages at different stages of production and breeding information for heifers from each year of the 3-yr study

Item	Yr 1	Yr 2	Yr 3	SE[1]
Year of birth	2003	2004	2005	
Forage quality,[2] % of CP	4.6	7.2	5.1	0.8
Restricted, n	62	64	66	
Control, n	63	73	69	
Birth, d of yr	104[a]	94[b]	95[b]	1.3
Wean age, d	177[b]	174[a]	190[c]	1.3
Birth to wean ADG, kg/d	0.90[a]	0.93[b]	0.95[b]	0.01
Wean BW, kg	196[a]	196[a]	214[b]	2.4
On test age, d	232[a]	250[c]	244[b]	1.3
On test BW, kg	212[a]	236[c]	224[b]	2.2
Wean to on test ADG, kg/d	0.29[b]	0.53[c]	0.20[a]	0.02
Off test age, d	372[a]	391[c]	384[b]	1.3
Age at AI, d	421[b]	430[c]	413[a]	1.3
AI sires,[3] n	18	19	30	
Breeding season, d	48	52	55	
Natural sires,[3] n	2	3	2	

[a–c]Means with in a row that do not have a common superscript differ ($P < 0.07$).

[1]Largest SE of the mean.

[2]Average CP in western wheatgrass (*Pascopyrum smithii*) clippings collected 2 to 3 times from July to October of each year ($P = 0.09$ for effect of year).

[3]Total of 42 sires were used by AI and natural service to produce heifers over the 3 yr, with each sire being used either naturally or by AI in 2 or 3 of the 3 yr.

those typically recommended (Funston and Deutscher, 2004), thereby reducing expense of raising heifers. The present research is a portion of a long-term project to evaluate the influence of 2 levels of nutritional input during heifer development and winter supplementation on lifetime productivity. The objectives of this research were to evaluate attainment of puberty before breeding and pregnancy rate in heifers offered ad libitum or restricted access to feed during the postweaning period and to provide an estimation of differences in cost to rear a pregnant heifer under the 2 feeding treatments.

MATERIALS AND METHODS

All research protocols were approved by the Fort Keogh Livestock and Range Research Laboratory Animal Care and Use Committee.

Animals

Heifers were sampled from a stable composite population (**CGC**; 1/2 Red Angus, 1/4 Charolais, 1/4 Tarentaise) produced by mating CGC dams and sires (n = 42) with consideration given to minimize inbreeding, but without emphasis on production traits. Heifers were born during a 3-yr period. Pertinent dates, total numbers of heifers assigned to each treatment in each year, and other information on heifers used in the study are provided in Table 1. After weaning, heifers were stratified into groups of 6 based on weaning weight. Groups were randomly assigned to 1 of 22 to 24 pens. Pens were 5.8 × 11 m in size and each pen contained 6 individual feed bunks equipped with electronic Calan gates (American Calan, Northwood, NH) to allow individual feeding. Heifers were randomly assigned to treatment within pen. Heifers were allowed a minimum of 1 mo for adaptation to experimental pens and to become trained to the electronic head gates. During this time, heifers were allowed ad libitum access to the test diet fed once daily. Feed restriction was initiated between December 2 and 9 of each year when heifers were 242 ± 15 d of age and 224 ± 25 kg of BW (Table 1). Control heifers were fed to appetite and restricted heifers were fed at 80% of that consumed by controls adjusted to a common BW basis, as described below. Composition of the diet fed during each year is shown in Table 2. Feed delivered to the bunk was weighed and recorded daily. Orts were removed from the feed bunk, and weight was recorded as necessary to ensure that fresh feed was provided for each heifer on a daily basis.

Measures of BW and hip height were recorded at initiation and conclusion of the 140-d study (ages shown in Table 1). Additional measures of BW were collected at approximately 28-d intervals throughout the study. Measures of BW were collected before feeding and were used to adjust feed level of restricted heifers using the following formula: [0.80 × (mean BW of restricted/mean BW control) × mean daily feed intake (as-fed basis) of controls over the preceding 28-d period]. Measures of BW were also made at about 1 mo (initiation of estrous synchronization) and 7.5 mo (about Dec 1) after the end of the restriction period, when heifers were approximately 13.5 and 19.5 mo of age, respectively. A final measure of hip height was also taken 7.5 mo after restriction. Data concerning feed intake, efficiency, and ultrasound carcass characteristics of heifers in this study have been previously published (Roberts et al., 2007).

Circulating concentration of progesterone was used as an indicator of pubertal status. Blood samples were collected into 10-mL Vacutainer tubes (Fisher Scientific, Pittsburgh, PA) via coccygeal venipuncture at 9- to 11-d intervals beginning at approximately 11.5 mo of age and ending at approximately 14 mo of age. Blood was placed on ice at collection and then stored overnight at 4°C. Samples were then centrifuged at 1,200 × *g* for 30 min. Serum was harvested and stored at −20°C until analyzed to determine concentrations of progesterone. Concentrations of progesterone were determined directly without extraction by solid-phase RIA (Coat-a-Count kit, Diagnostic Products Corp., Los Angeles, CA) as reported previously (Bellows et al., 1991). Intra- and interassay CV were 7.6 and 16.1%, respectively, and assay sensitivity was 0.08 ng/mL. Week in which puberty occurred was defined as the first week that serum concentration of progesterone exceeded 1.0 ng/mL (Byerley et al., 1987). Average BW of heifers at week of puberty was predicted from the regression of BW on age.

At the end of the 140-d study, heifers were placed into common pens and given ad libitum access to feed for approximately 50 d to allow for estrous synchronization and AI. At approximately 14 mo of age (30 to 40 d after end of restriction), heifers were weighed and subjected to an estrous synchronization protocol. In yr 1 and 2, heifers were subjected to the CO-Synch+ controlled internal drug-releasing device (**CIDR**; Pfizer Animal Health, New York, NY) protocol (Lamb et al., 2006) with timed AI of heifers not detected in heat by 72 (yr 1) or 48 (yr 2) h after CIDR removal and injection of $PGF_{2\alpha}$. In yr 3, a single injection of $PGF_{2\alpha}$ was given on d 7 of an 11-d AI breeding period and only heifers detected in estrus received AI. After AI, heifers were placed on native range and exposed to bulls for the remaining duration of a 48- to 55-d breeding season (Table 1). Differences in breeding protocols across years were due to heifers being part of a long-term study with multiple objectives beyond those of the present study. A total of 42 sires were used by AI and natural service to breed heifers (as well as cows from this herd) over the 3 yr to obtain specific family sizes from each sire as part of the long-term study. Thus, the breeding protocol was set up to facilitate accomplishment of the long-term objectives and was not specific for the present study. Heifers were evaluated for pregnancy by transrectal ultrasonography using a 5-MHz transducer (Aloka, Wallingford, CT) approximately 1 mo after AI and again at about 1 mo after bull removal. Date of AI, estimated age of fetus at pregnancy diagnosis, and date of calving were used to predict the day of the breeding season that conception occurred (n = 339; total number pregnant) and calculate AI and final pregnancy rate (number pregnant/397, the total number exposed for breeding). A final BW measurement was made in late November (yr 1 and 3) or early December (yr 2)

Table 2. Composition (DM basis) of diets fed to heifers each year

Item	Yr 1	Yr 2	Yr 3
	% of DM		
Ingredient composition			
Corn silage	67	67	68.4
Alfalfa	18	18	16.8
Barley	9	9	8.8
Soybean meal	4.2	4.2	4.2
Urea	0.9	0.9	0.9
Calcium carbonate	0.5	0.5	0.5
Salt	0.2	0.2	0.2
Vitamin A, D, E[1]	0.1	0.1	0.1
Trace mineral[2]	0.1	0.1	0.1
Chemical composition[3]	%		
DM	36.1	36.8	37.3
CP	15.1	15.1	17.1

[1]Contains 44,000,000 IU/kg of vitamin A, 880,000 IU/kg of vitamin D, and 880 IU/kg of vitamin E.

[2]Contains 20.0% Mg, 0.2% K, 2.6% S, 18,000 mg/kg of Cu, 60,000 mg/kg of Zn, 40,000 mg/kg of Fe, 300 mg/kg of Se, 60,000 mg/kg of Mn, 180 mg/kg of Co, and 1,140 mg/kg of I.

[3]Based on analyzed chemical composition of individual ingredients.

when pregnant heifers remaining in the herd (n = 331) were about 19.5 mo of age. Date of calving was used to calculate number of days from onset of breeding to calving (n = 321 heifers). Animal numbers shown in the preceding sentences reflect losses due to reproductive failure, structural problems, death, or abortion that occurred throughout the study between the end of feeding treatment (n = 397) and collection of calving data (n = 321).

Statistical Analysis

Differences across years for age of dam, day of birth, and ages and BW of heifers at weaning, on test, off test, and at AI were analyzed using an ANOVA (GLM procedure, SAS Inst. Inc., Cary, NC). Evaluation of treatment effects were analyzed using a mixed model (MIXED procedure of SAS). Hip height and BW at different time points, BW to height ratio, ADG during and after the restriction, proportion pubertal, age at puberty, and calculated BW at puberty were analyzed using heifer as the experimental unit and a model that included age, BW, and hip height of heifers at onset of the study as covariates; age of dam (2, 3, 4, or 5 yr and older) as a classification variable; fixed effects of year and treatment; and the interaction of these fixed effects. Pregnancy rate from AI, final pregnancy rate, predicted day of conception, proportion calving, and number of days from onset of breeding to calving were analyzed using the model described above, but without age of dam as a classification variable and hip height or age of heifer at onset of the study as a covariate (these variables did not account for variation in reproductive traits evaluated). The models described above were modified for a subsequent analysis of puberty and pregnancy data, where BW at start of the trial was deleted from the model and covariates for ADG from birth to weaning, ADG from weaning to initiation of the 140-d trial, and within treatment ADG during the 140-d trial were added to the model. In addition, age of heifers at start of the study was also included as a covariate for the analysis with ADG covariates. Because observations of pubertal status ended before all heifers attained puberty, observed mean ages and BW at puberty were biased downward depending on the percentage pubertal. To reduce this bias in comparing means differing in the percentage pubertal, means for age at puberty were adjusted assuming age at puberty to be normally distributed. Following Dickerson and Hazel (1944), the SD of the observed sample is related to the SD of the nontruncated distribution (s) by an adjustment factor equal to

$$1/[1 - (\mathrm{i}^2 + \mathrm{i}\cdot \mathrm{z})]^{0.5},$$

where i = the expected standardized deviation from the true mean of the observed mean derived from the proportion attaining puberty and z = the deviation in SD units from the true mean at the point of truncation. The mean age at puberty estimated from the mean of the truncated sample ($_t$) is

$$\overline{x_t} + h \cdot \frac{s}{p},$$

where h = height of the ordinate of the standard normal curve at the point of truncation defined by the proportion pubertal (p).

Additional analyses were performed to evaluate effects of pubertal status at 14 mo of age on subsequent reproduction traits and to determine if BW differed among animals classified by pubertal status. The model for these analyses included pubertal status at 14 mo of age (yes or no), year, treatment, and the interactions among these factors. Least squares means are presented from the different analyses described above, unless specified otherwise.

Economic Evaluation

The potential economic impact of rearing heifers using restricted feeding during the postweaning period on the cost of producing a pregnant heifer was evaluated. This cost-benefit comparison accounted for treatment differences in numbers needed to produce a pregnant female, BW and market prices of heifers at time of selection (about 1 mo after weaning) and of nonpregnant heifers in the subsequent fall. Average prices for heifer calves and nonpregnant heifers were calculated from September through November sales from Montana sale barns from 2000 to 2006 (Montana Agricultural Statistics, 2007). A conservative price of \$0.70/(heifer per day) was used as the cost of harvested feed when offered ad libitum. A monthly feed cost of \$16/heifer was assessed during the grazing period based on private grazing fee rates reported for the last 6 yr (Montana Agriculture Statistics, 2007).

RESULTS AND DISCUSSION

Over the 140-d trial, restricted heifers consumed 27% less feed than control heifers, which resulted in reduced ($P < 0.001$) ADG and lighter ($P < 0.001$) BW over the 140-d trial (Figure 1). Magnitude of differences in BW at the end of the treatment period tended to vary by year ($P = 0.12$, treatment × year interaction; Figure 1). Amount of increase in hip height that occurred from beginning to the end of the 140-d period was less ($P = 0.01$) in restricted (9.2 ± 0.2 cm increase) than control (9.7 ± 0.2 cm). Average off test hip height over the 3 yr was 118.6 ± 0.2 and 119.1 ± 0.2 for restricted- and control-fed heifers, respectively. Ratio of BW to height at the end of the 140-d period was greater in control heifers than restricted heifers ($P < 0.001$ for effect of treatment within each year), but magnitude of difference varied over the years ($P = 0.045$) for treatment × year interaction, Figure 1).

Differences in BW of restricted and control heifers persisted ($P < 0.001$) throughout the prebreeding period (309 ± 1 vs. 326 ± 1 kg at approximately 13.5 mo of age) and subsequent grazing season (410 ± 2 vs. 418 ± 2 kg at about 19.5 mo of age). Magnitude of difference in prebreeding BW due to treatment was greater for yr 1 (24 kg) than yr 2 (12 kg) or yr 3 (13 kg; $P = 0.01$ for treatment × year interaction). Although ADG was reduced during feed restriction, ADG from end of the 140-d trial to 19.5 mo of age was greater ($P < 0.001$) in restricted (0.51 ± 0.01 kg/d) than control heifers (0.47 ± 0.01 kg/d). This greater ADG likely reflects compensatory BW gain after the restriction period (Roberts et al., 2007). Average daily gain after restriction and BW at 19.5 mo of age differed over the 3 yr ($P < 0.001$), being greater in yr 1 (0.61 kg/d and 459 kg) than yr 3 (0.52 kg/d and 410 kg), and least in yr 2 (0.34 kg/d and 372 kg). Hip height at 19.5 mo of age remained less ($P = 0.013$) in restricted than control heifers (127.8 ± 0.4 vs. 129.3 ± 0.3cm) in yr 1, but not yr 2 (125.3 ± 0.3 cm) and 3 (131.3 ± 0.2 cm; $P = 0.04$ for treatment × year interaction).

Proportion of heifers that became pubertal by 14 mo of age tended to be less ($P = 0.098$) in restricted- than control-fed heifers and varied ($P < 0.001$) over the 3 yr of the study (Table 3). Assuming age of puberty to be normally distributed, means for age at puberty of each treatment by year classification were adjusted to reduce bias from differences in proportions of animals that attained puberty. Adjusted mean age at puberty ranged from 7 to 30 d older in restricted than control heifers over the 3 yr ($P < 0.05$ for effect of treatment in yr 1 and 3; Table 3). This range in magnitude of differences in age of puberty is consistent to differences reported for heifers developed at rates of ADG during the postweaning period that were similar (Short and

Bellows, 1971) or slightly below (Ferrell,1982) those in the 2 treatments of the present study. In heifers that achieved puberty before breeding, regression of BW on age was used to estimate BW of individual heifers at time of puberty, which was lighter ($P < 0.04$) for restricted than control heifers, and magnitude of difference tended to vary by year ($P = 0.09$ for year × treatment interaction; column 5, Table 3). In addition, adjusted mean age at puberty and mean ADG for each treatment within year grouping was used to predict mean BW at which all heifers within a treatment by year classification would be pubertal (column 6, Table 3). Average predicted BW at puberty over the 3 yr was less ($P < 0.01$) for restricted (317 kg) than control (330 kg) heifers. Predicted BW at puberty ranged from 53 to 65% of the expected mature cow BW (558 kg at BCS 5 for cows 5 yr old and older in this herd; Table 3), with averages of 57 and 59% for restricted and control heifers, respectively. Evaluation of off test and prebreeding measures of BW for heifers classified by treatment and pubertal status indicated a trend ($P = 0.08$) for interaction of treatment and pubertal status (Figure 2). For control heifers, off test and prebreeding measures of BW were greater ($P < 0.003$) for heifers that exhibited puberty before breeding than heifers that had not. However, average BW at these time points for restricted heifers that exhibited puberty before breeding were not different ($P = 0.3$) from heifers of either treatment that were not pubertal at initiation of breeding. These results show that restricted heifers attained puberty at lighter BW, albeit at a slightly older age, similar to findings from several decades ago that showed an inverse association between growth rate and age of puberty (Wiltbank et al., 1966, Short and Bellows, 1971; Ferrell, 1982). These and other studies conducted during the late 1960s through the early 1980s resulted in the conclusion that puberty occurs at a genetically predetermined age and BW. Collectively, these early studies led to the guidelines that replacement heifers should be fed to achieve 60 to 66% of their expected mature BW by the time breeding starts to assure that a large proportion have reached puberty (reviewed by Patterson et al., 1992). When averaged over 3 yr, heifers in the present study were developed to 55 and 58% of mature BW, which corresponded to 60 and 68% achieving puberty at start of breeding for restricted and control treatments, respectively. The 8% difference in pubertal status observed due to feed restriction in the present study is similar to the 11% difference in pubertal status observed between heifers developed to 53 or 58% of mature BW, as a consequence of feeding different quality diets (Funston and Deutscher, 2004). Recently, Martin et al. (2008) reported 17% fewer heifers were pubertal when fed to 51% compared with 57% of mature BW by time of breeding, indicating that greater restriction may have a greater effect on puberty. Association of puberty and percentage of mature BW at first breeding observed in these recent and the present studies are consistent with the early research discussed

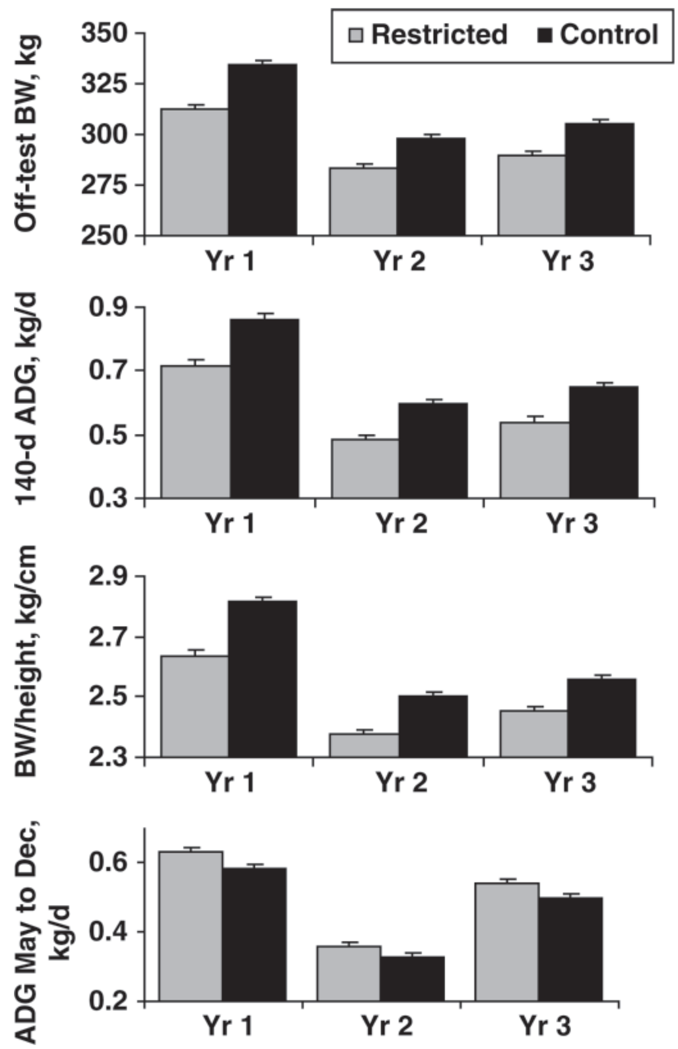

Figure 1. Growth of heifers from 3 different years that were provided ad libitum (control) or restricted access to feed during a 140-d period after weaning. Top panel: BW at the end of the trial. Upper middle panel: ADG for the 140-d trial. Lower middle panel: ratio of BW to hip height at the end of the 140-d trial. Bottom panel: ADG of heifers from the end of the feeding trial (April) to the beginning of December (Dec), while heifers were managed together on pasture. Each variable was influenced by treatment ($P < 0.001$) and year ($P < 0.001$). Magnitude of treatment differences varied by year for BW at the end of the trial ($P = 0.12$) and ratio of BW to hip height ($P = 0.05$).

above. However, yearly variation in BW at beginning of breeding in the present study (Figure 2) was not closely associated with yearly variation in proportion of heifers achieving puberty by the time of breeding (column 3, Table 3). The year that had the greatest proportion achieving puberty (yr 2) had the least prebreeding BW. It is also important to consider that average BW before initiation of breeding was below 60% of the expected mature BW (Figure 2) for all treatments except for control heifers in yr 1. Thus, variation in puberty rates among years in the present study did not associate well with the industry recommendation for the need to develop heifers to 60% mature BW by time of breeding.

In the present study, covariates of age ($P = 0.004$) and BW ($P = 0.005$) at beginning of the postweaning treatment indicated 0.53 ± 0.19 and 0.42 ± 0.15 in-

Table 3. Proportion (%) of restricted and control heifers from each year that achieved puberty by 14 mo, and predicted age (d), BW (kg), and percentage of mature BW (MBW) at time of puberty

Treatment	Yr	%[1]	Age,[2] d	BW,[3] kg	Predicted BW,[4] kg	% of MBW[5]
Restricted	1	47	426	334	341	61
Control	1	58	417	361	360	65
Restricted	2	88	390	292	294	53
Control	2	95	383	305	311	56
Restricted	3	39	431	301	313	56
Control	3	52	401	313	320	57

[1]Differs due to year ($P < 0.001$) and tends to differ due to treatment ($P = 0.098$).

[2]Means adjusted to account for differences in proportions reaching puberty in each year by treatment classification. Restricted were older ($P < 0.05$) than control for yr 1 and 3.

[3]Least squares mean BW of heifers that achieved puberty before breeding. Restricted were lighter ($P < 0.04$) than control within each year ($P = 0.09$ for year × treatment interaction).

[4]Predicted BW = predicted mean BW of heifers at estimated age of puberty.

[5](Predicted BW/558 kg) × 100 = percentage of expected mature BW at which heifers are predicted to be pubertal.

creases in percentage of heifers attaining puberty with each additional day of age and kg of BW, respectively. A 1-cm increase in hip height decreased ($P = 0.02$) proportion achieving puberty by 1.89 ± 0.82. These associations support the concept that puberty is influenced by age, preweaning growth, and expected mature size (reflected by height), which is the basis for selecting heifers that are born earlier and have heavier BW for replacement females. Several studies from the 1950s through the early 1980s indicated that preweaning growth rates had greater influence on puberty than postweaning growth rate (reviewed by Patterson et al., 1992). Thus, an additional analysis was performed with ADG from birth to weaning, weaning to beginning of the feeding treatment, and within treatment ADG during the 140-d trial included in the model to assess the impact of growth rate during these phases on puberty. Results indicated increases of 11.6 ± 2.6 and 3.6 ± 1.4 in percentage of heifers attaining puberty with each 0.1 kg/d increase in preweaning ADG ($P < 0.001$) and ADG from weaning to beginning of the feeding treatment ($P = 0.01$), respectively. Proportion of heifers achieving puberty tended to be influenced by the covariate of ADG during the postweaning trial for control ($P = 0.09$; 3.7 ± 2.2 increase in percentage of heifers attaining puberty with each 0.1 kg/d increase in ADG) but not restricted heifers ($P = 0.8$). Interestingly, yearly variation in mean ADG from weaning to onset of the study (shown in Table 1) corresponded to yearly variation in proportion of heifers that were pubertal by the beginning of the breeding season, which averaged 52, 91, and 46% for yr 1, 2 and 3, respectively. As observed several decades ago (Wiltbank et al., 1966; Laster et al., 1972), results from the present study indicate that puberty was much more affected by variation in rate of growth up to ~8 mo of age than subsequent growth up to the start of breeding. Although not evaluated in this study, earlier research indicated inverse association between genetic potential for milk production and age of puberty (Notter et al., 1978; Martin et al., 1992), which would be consistent with the preweaning ADG effects on age of puberty observed in the present study. Yearly variations in herd management and late summer forage quality likely contributed to annual variation in age and BW of heifers at weaning and the beginning of the feeding period (Table 1).

Pregnancy rate from AI tended to be reduced ($P = 0.08$; Figure 3) in restricted heifers. For heifers that became pregnant, treatment did not influence estimated day of the breeding season that conception occurred ($P = 0.18$; Figure 3) or average number of days from onset of breeding to calving ($P = 0.36$; 295 ± 14 d). Final pregnancy rate averaged 87 and 91% for restricted and control heifers, respectively ($P = 0.25$ for effect of feeding level; Figure 3). With exception of final pregnancy

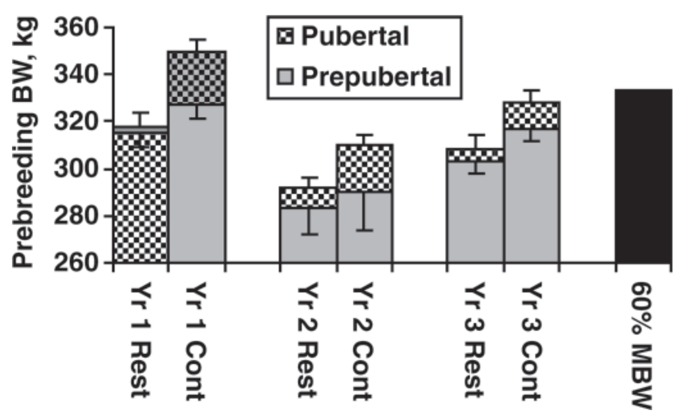

Figure 2. Heifer BW at 2 wk before breeding, approximately 1 mo after a 140-d feeding trial in which heifers were provided ad libitum (Cont) or restricted (Rest) access to feed during the postweaning period. The trial was replicated over 3 yr (x-axis). Heifer BW are subclassified by pubertal status (see legend) within each year by treatment classification. For control, but not restricted heifers, BW was lighter ($P = 0.003$) for heifers that did not achieve puberty than heifers that did achieve puberty ($P = 0.08$ for interaction of treatment and pubertal status). Note that for restricted heifers in yr 1, mean BW was less for heifers that achieved puberty than for heifers that did not achieve puberty. Bar on right side of graph depicts BW equivalent to 60% of the expected BW of mature cows in this herd.

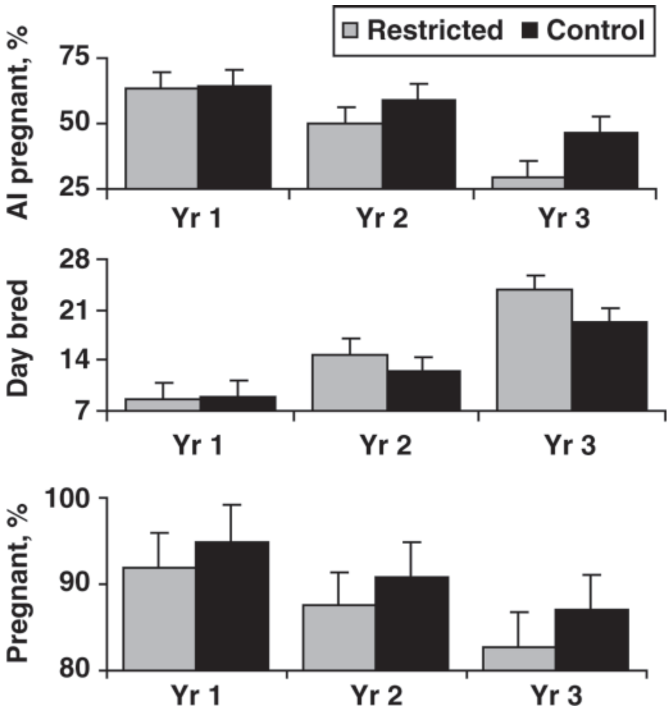

Figure 3. Reproductive performance of heifers from 3 different years that were provided ad libitum (control) or restricted access to feed during a 140-d trial during the postweaning period. Top panel: AI pregnancy rate (P = 0.08 for treatment). Middle panel: day of breeding season when conception occurred (P = 0.18 for treatment). Bottom panel: overall pregnancy rate (P = 0.27 for treatment). Each variable was influenced by year (P < 0.001).

rate, other measures associated with pregnancy varied by year (P < 0.001; Figure 3).

The covariate of BW at the initiation of the feeding trial indicated a 0.17 ± 0.10 increase in percent pregnancy rate from AI (P = 0.10), 0.089 ± 0.033 decrease in day of the breeding season that conception occurred (P = 0.01), and 0.077 ± 0.032 decrease in number of days from the beginning of breeding to calving (P = 0.02) for each additional kilogram of BW. These results indicate that BW at 7 to 8 mo of age may influence time of conception in the first breeding season. This conclusion was further evaluated by performing another analysis of pregnancy measures using the model that included covariates of ADG from birth to weaning, ADG from weaning to beginning of the feeding treatment, and within treatment ADG during the 140-d trial. Results indicated a 3.9 ± 2.3 and 3.4 ± 1.7 increase in percentage pregnancy rate from AI (P = 0.045) with each 0.1 kg/d increase in ADG from birth to weaning and from weaning to beginning of treatment, respectively. Pregnancy rate from AI was not influenced by within treatment ADG during the 140-d trial (P = 0.6). Thus, there may be merit in conducting additional research concerning the impacts of management practices and nutrition during early postweaning on subsequent AI conception. Final pregnancy rate was not influenced by any of the covariates (P > 0.2). Estimated day of the breeding season that conception occurred was negatively associated with ADG from birth to weaning (decrease of 1.9 ± 0.8 d to conception with each 0.1 kg/d increase in ADG; P = 0.01) and ADG from weaning to beginning of the feeding treatment (decrease of 1.4 ± 0.6 d with each 0.1 kg/d increase in ADG; P = 0.11), but not associated with within treatment ADG (P = 0.9). Older age at onset of the treatment also resulted in fewer number of days from start of breeding to conception (decrease of 0.13 ± 0.06 d with each day increase in age; P = 0.02). Influences of the aforementioned covariates on number of days from start of breeding to calving were similar in magnitude and significance as observed for estimated day of conception. Thus, greater ADG during the first 8 mo of life corresponded to earlier conception and subsequent calving. As was observed for puberty, these results provide evidence that rate of growth during the preweaning or early postweaning phase had much more of an influence on when heifers became pregnant than management-induced or animal variations in rate of growth during the later part of the postweaning period. It is important to recognize that much of the variation in growth early in life likely reflects innate (i.e., genetic) differences among heifers or their dams (i.e., milk production), and these differences are being compared with nutritional differences due to managerially imposed treatments.

Effects of year noted above for AI pregnancy rate and day of conception may be associated with differences in the estrous synchronization protocols used each year and variation in pubertal status at initiation of breeding. Heifers in yr 1 and 2 received progesterone and GnRH in the estrous synchronization protocol, and a cleanup TAI was used. This approach can result in conception in heifers that were not pubertal at time of initiation of the synchronization protocol (Lamb et al., 2006). In contrast, heifers in yr 3 received a single injection of $PGF_{2\alpha}$, which will not have any effect on heifers that were not pubertal, and only heifers exhibiting estrus were artificially inseminated (TAI was not used). These differences likely contributed to a decreased proportion of heifers from yr 3 getting bred by AI and the larger numerical differences between treatments in this year. The reduced proportion getting bred by AI in combination with longer AI period (heat check for 11 d vs. 2 or 3 d) would equate to a longer average number of days to conception in yr 3 (Figure 3). Thus, variations in estrous synchronization and AI protocols used across the years likely influenced the impact of pubertal status on AI pregnancy rate and average day of conception. With this consideration in mind, the impact of pubertal status on AI pregnancy and day of conception was further evaluated by an analysis of heifers classified by rearing treatment, pubertal status at beginning of breeding, and year. Results indicated that AI pregnancy rates were greater (P = 0.003) in heifers that were pubertal before initiation of breeding (58 ± 3%) than heifers that had not reached puberty (39 ± 6%). Average day of conception tended to be influenced by the interaction of pubertal status and year (P = 0.1); where heifers that had not reached puberty before start of breeding took longer to conceive than their pubertal counterparts in yr 2 ($P = 0.01$; 24 vs. 12 d) and yr 3 ($P = 0.01$; 26 vs. 18 d), but not in yr 1 ($P = 0.6$). Pubertal status did not account for variation in final pregnancy rate ($P = 0.5$). Recently, Martin et al. (2008) reported a 7-d later average calving date in heifers developed to 51% of mature BW when compared with heifers developed to 57% of mature BW at time of breeding. These researchers also reported that although there was no difference in final pregnancy rate between these 2 groups of heifers, a greater percentage of heifers developed to 51% of mature BW that failed to conceive were prepubertal before beginning of breeding when compared with open heifers that were developed to 57% of mature BW.

The main impetus behind developing heifers to the industry guidelines of 60 to 66% of mature BW at time of breeding (discussed above) was that pregnancy rates in heifers were shown to be dependent upon the proportion exhibiting puberty before or early in the breeding season (Short and Bellows, 1971; Byerley et al., 1987). In general, research reports published through the late 1980s have demonstrated negative associations of limited postweaning growth on age of puberty and subsequent pregnancy (Short and Bellows, 1971; Wiltbank et al., 1985; Patterson et al., 1989). Whereas studies completed more recently continued to observe inverse associations between postweaning growth and age of puberty, little or no influence of postweaning rate of growth has been observed on final pregnancy (Buskirk et al., 1995; Freetly and Cundiff., 1997; Lynch et al., 1997). Likewise, restricting development by restricting DMI, as in the present study, or feeding diets differing in quality (Funston and Deutscher, 2004; Martin et al., 2008) influenced puberty and, in some cases, AI pregnancy rate or average day of conception, but did not affect final pregnancy rate. Collectively, these studies demonstrate the potential for reducing development cost by feeding less or feeding lower quality feed without adversely affecting overall pregnancy rate. In addition to reducing cost of development, caloric restriction may also prolong lifespan, as has been shown in other species (reviewed in Speakman and Hambly, 2007). If this were found to be true in cattle, and increased lifespan was associated with increased duration of production, it could easily offset any negative effects on AI pregnancy rates or average days to conception in heifers.

Several factors likely contribute to the change in association of puberty and pregnancy that appear to have evolved over time (as discussed in previous paragraph). Small variations across studies in timing of the breeding season could markedly alter the outcomes. For example, studies where replacement heifers were managed to be bred to calve earlier than the cow herd would correspond to younger average age (i.e., average of 12 to 13 mo old at initiation of breeding) than studies where heifers were bred to calve with the cows (average age of 14 to 15 mo at initiation of breeding). Age at AI, shown in Table 1, may have also contributed to variation among years in timing of pregnancy in the present study. In addition, large changes in genetic factors controlling age of puberty have likely occurred over time. Initial research in this area corresponds to the industry shift from calving heifers at 3 yr of age to calving at 2 yr of age. Thus, selection pressure for age of puberty was probably minimal in the cattle population before the early studies cited above. Whereas selection intensity would have increased with reduction in calving age of heifers, genetic progress would take time due to the long generation interval in cattle. In the mid-1980s, producers began utilizing scrotal circumference as an indicator trait for age of puberty in response to the identification of the association between scrotal circumference in bulls and age of puberty in their female offspring (Brinks et al., 1978). An appraisal of breed association Web sites for changes in scrotal circumference EPD from 1985 to the present indicate substantial progress has been made and a similar response in age of puberty would be expected. Indeed, the inability of heifers to attain puberty before breeding may not be as problematic as heifers reaching puberty before weaning (Gasser et al., 2006a,b). An additional consideration for the present study is that heifers evaluated were from the CGC composite herd of cattle developed at Fort Keogh, and therefore the results may be affected by the high level of retained heterosis expected to exist in these and other crosses or composite cattle (Martin et al., 1992). This consideration is also pertinent to the interpretation of results of Funston and Deutscher (2004) and Martin et al. (2008) discussed above, as composite heifers were evaluated in these studies. Length of breeding season could also influence outcome of studies looking at association of pubertal status at onset of breeding and overall pregnancy rate, as longer breeding seasons would allow for a greater proportion of heifers to achieve puberty and become pregnant.

Economic Implications of Restricted Feeding

An estimate of the potential economic impact of rearing heifers on restricted feeding during the postweaning period is illustrated in Table 4. Although final pregnancy rates were not determined to be significantly influenced by feeding treatment in the present study, numbers of animals evaluated in the present study may not be sufficient to provide adequate power-of-the-test to draw the conclusion that pregnancy rates were similar for restricted and control heifers. Therefore, any consequent reduction in pregnancy rate was considered to be important when determining economic advantages of restricted feeding during the postweaning period, and economic impact is expressed on a per pregnant heifer basis. In addition to accounting for differences in numbers retained, market price differences for heifer calves vs. nonpregnant long-yearling heifers were considered. The outcome of the cost-benefit calculation indicated an approximate $33 advantage per pregnant heifer developed by restricted feeding during the postweaning

Table 4. Economic implications of developing heifers on a restricted level of feeding during a 140-d period between weaning and breeding[1]

Item	Control	Restricted	Savings due to restriction
Final pregnancy rate, %	91.90	87.40	
No. of calves retained/pregnant heifer	1.10	1.14	
BW of heifer calf at time of selection,[1] kg	208	208	
BW of retained/pregnant heifer, kg	229	238	
Value of calves retained/pregnant heifer ($2.33/kg),[2] $	533.16	554.51	−21.35
BW at 19.5 mo of age, kg	418	410	
Value of open heifer ($1.96/kg),[2] $	819.28	803.60	
Value of open females/pregnant heifer, $	82.02	115.85	33.83
Feed cost			
Daily cost per heifer during 140-d period,[3] $	0.70	0.51	
Total cost per heifer for 140-d period, $	98.00	71.54	
Total cost per pregnant heifer for 140-d period, $	107.81	81.85	25.96
Per pregnant heifer for 30 d before breeding ($0.70/d), $	23.10	24.03	−0.93
Per pregnant heifer for 6 mo grazing ($16/mo), $	105.61	109.84	−4.23
Savings/pregnant heifer developed under restriction,[4] $			33.28

[1]BW 1 mo after weaning.
[2]Average of September through November prices from Montana auction barns for 2000 to 2006.
[3]Twenty-seven percent less feed provided to restricted heifers.
[4]Minimum feed cost required for a saving under restricted feeding was $0.12/d.

period. Market prices from 2000 to 2006 that were used in this calculation were favorable for selling female offspring marketed as nonpregnant long-yearlings rather than heifer calves. Thus, approximately $12.5 of the $33 advantage was associated with a small difference in retention rate and price differential between heifer calves and open heifers (sum of first 2 values in last column of Table 4). Any change in price differential between these markets could have major impacts on the outcome, as was recently reported by Clark et al. (2005). Savings in feed cost associated with restricted feeding was approximately $21 on a per pregnant heifer basis. This cost savings is very similar to the $22 advantage reported when heifer development was restricted by feeding lower quality diets (Funston and Deutscher, 2004). Because feed costs can have large impacts on the outcome of this economic comparison, a minimum daily cost of feed that resulted in a savings due to restriction was determined. For this calculation, only the bottom portion of Table 4 was considered (i.e., summation of third, fourth, and fifth values in last column of Table 4 after decreasing value for daily feed cost for control heifers). The minimum daily feed cost for control heifers at which point there was no longer an economic advantage of restricted feeding was $0.12/d. Whereas the comparison summarized in Table 4 utilized actual mean BW of heifers from the 2 feeding protocols to determine difference in marketing prices in the present study, feeding costs per heifer assessed after the feeding trial were set to be the same for each treatment, and therefore accounted for differences in numbers, but not in DMI or efficiency that may result from differences in size. In addition, the comparison did not consider any potential differences due to changes in AI pregnancy rate or day of conception that could influence value of the calves derived from replacement heifers.

In summary, developing heifers on the restricted level of feeding resulted in a 27% reduction in harvested feeds needed per heifer over the 140-d period. Restriction resulted in lighter BW throughout the restriction period and in subsequent measurements made before breeding (17 kg difference) and after the grazing season (8 kg difference). When averaged over the 3-yr study, BW of heifers at initiation of breeding were equivalent to 55 and 58% of mature BW, which corresponded to 60 and 68% of heifers achieving puberty at the beginning of the breeding season for restricted- and control-fed heifers, respectively. The trend for restriction to reduce puberty at time of breeding carried over to result in a trend for reduced AI pregnancy rates, which was not as evident when estrus was synchronized using GnRH and a CIDR followed by a clean-up TAI. No effect of restriction was observed on final pregnancy rate. These results indicate a potential for reducing amount of harvested feed input when developing replacement heifers without adverse effects on final pregnancy rate. However, the potential for reduced pregnancy rate early in the breeding season should be considered, especially in situations where preweaning or early postweaning growth is limited. Ongoing research is evaluating the effect of feed restriction on subsequent duration and level of productivity.

LITERATURE CITED

Bellows, R. A., R. B. Staigmiller, J. M. Wilson, D. A. Phelps, and A. Darling. 1991. Use of bovine FSH for superovulation and embryo production in beef heifers. Theriogenology 35:1069–1082.

Brinks, J. S., M. J. McInerney, and P. J. Chenoweth. 1978. Relationship of age at puberty in heifers to reproductive traits in young bulls. Proc. West. Sect. Am. Soc. Anim. Sci. 29:28–30.

Buskirk, D. D., D. B. Faulkner, and F. A. Ireland. 1995. Increased postweaning gain of beef heifers enhances fertility and milk production. J. Anim. Sci. 73:937–946.

Byerley, D. J., R. B. Staigmiller, J. G. Berardinelli, and R. E. Short. 1987. Pregnancy rates of beef heifers bred either on puberal or third estrus. J. Anim. Sci. 65:645–650.

Clark, R. T., K. W. Creighton, H. H. Patterson, and T. N. Barrett. 2005. Symposium paper: Economic and tax implications for managing beef replacement heifers. Prof. Anim. Sci. 21:164–173.

Dickerson, G. E., and L. N. Hazel. 1944. Effectiveness of selection on progeny performance as a supplement to earlier culling in livestock. J. Agric. Res. 69:459–476.

Ferrell, C. L. 1982. Effects of postweaning rate of gain on onset of puberty and productive performance of heifers of different breeds. J. Anim. Sci. 55:1272–1283.

Freetly, H. C., and L. V. Cundiff. 1997. Postweaning growth and reproduction characteristics of heifers sired by bulls of seven breeds and raised on different levels of nutrition. J. Anim. Sci. 75:2841–2851.

Freetly, H. C., C. L. Ferrell, and T. G. Jenkins. 2001. Production performance of beef cows raised on three different nutritionally controlled heifer development programs. J. Anim. Sci. 79:819–826.

Funston, R. N., and G. H. Deutscher. 2004. Comparison of target breeding weight and breeding date for replacement beef heifers and effects on subsequent reproduction and calf performance. J. Anim. Sci. 82:3094–3099.

Gasser, C. L., E. J. Behlke, D. E. Grum, and M. L. Day. 2006b. Effect of timing of feeding a high-concentrate diet on growth and attainment of puberty in early-weaned heifers. J. Anim. Sci. 84:3118–3122.

Gasser, C. L., G. A. Bridges, M. L. Mussard, D. E. Grum, J. E. Kinder, and M. L. Day. 2006a. Induction of precocious puberty in heifers III: Hastened reduction of estradiol negative feedback on secretion of luteinizing hormone. J. Anim. Sci. 84:2050–2056.

Lamb, G. C., J. E. Larson, T. W. Geary, J. S. Stevenson, S. K. Johnson, M. L. Day, R. P. Ansotegui, D. J. Kesler, J. M. DeJarnette, and D. G. Landblom. 2006. Synchronization of estrus and artificial insemination in replacement beef heifers using gonadotropin-releasing hormone, prostaglandin F_2, and progesterone. J. Anim. Sci. 84:3000–3009.

Laster, D. B., H. A. Glimp, and K. E. Gregory. 1972. Age and weight at puberty and conception in different breeds and breed-crosses of beef heifers. J. Anim. Sci. 34:1031–1036.

Lynch, J. M., G. C. Lamb, B. L. Miller, R. T. Brandt Jr., R. C. Cochran, and J. E. Minton. 1997. Influence of timing of gain on growth and reproductive performance of beef replacement heifers. J. Anim. Sci. 75:1715–1722.

Martin, J. L., K. W. Creighton, J. A. Musgrave, T. J. Klopfenstein, R. T. Clark, D. C. Adams, and R. N. Funston. 2008. Effect of prebreeding body weight or progestin exposure before breeding on beef heifer performance through the second breeding season. J. Anim. Sci. 86:451–459.

Martin, L. C., J. S. Brinks, R. M. Bourdon, and L. V. Cundiff. 1992. Genetic effects on beef heifer puberty and subsequent reproduction. J. Anim. Sci. 70:4006–4017.

Montana Agricultural Statistics. 2007. USDA. National Agricultural Statistics Service. www.nass.usda.gov/Statistics_by_State/Montana/index.asp Accessed Dec. 10, 2007.

Notter, D. R., L. V. Cundiff, G. M. Smith, D. B. Laster, and K. E. Gregory. 1978. Characterization of biological types of cattle. VII. Milk production in young cows and transmitted and maternal effects on preweaning growth of cattle. J. Anim. Sci. 46:908–921.

Patterson, D. J., L. R. Corah, G. H. Kiracofe, J. S. Stevenson, and J. R. Brethour. 1989. Conception rate in *Bos taurus* and *Bos indicus* crossbred heifers after postweaning energy manipulation and synchronization of estrus with melengestrol acetate and fenprostalene. J. Anim. Sci. 67:1138–1147.

Patterson, D. J., R. C. Perry, G. H. Kiracofe, R. A. Bellows, R. B. Staigmiller, and L. R. Corah. 1992. Management considerations in heifer development and puberty. J. Anim. Sci. 70:4018–4035.

Roberts, A. J., S. I. Paisley, T. W. Geary, E. E. Grings, R. C. Waterman, and M. D. MacNeil. 2007. Effects of restricted feeding of beef heifers during the postweaning period on growth, efficiency and ultrasound carcass characteristics. J. Anim. Sci. 85:2740–2745.

Short, R. E., and R. A. Bellows. 1971. Relationships among weight gains, age at puberty and reproductive performance in heifers. J. Anim. Sci. 32:127–131.

Speakman, J. R., and C. Hambly. 2007. Starving for life: What animal studies can and cannot tell us about the use of caloric restriction to prolong human lifespan. J. Nutr. 137:1078–1086.

Wiltbank, J. N., K. E. Gregory, L. A. Swiger, J. E. Ingalls, J. A. Rothlisberger, and R. M. Koch. 1966. Effects of heterosis on age and weight at puberty in beef heifers. J. Anim. Sci. 25:744–751.

Wiltbank, J. N., S. Roberts, J. Nix, and L. Rowden. 1985. Reproductive performance and profitability of heifers fed to weigh 272 or 318 kg at the start of the first breeding season. J. Anim. Sci. 60:25–34.