Impact of Age at Calving on Lactation, Reproduction, Health, and Income in First-Parity Holsteins on Commercial Farms

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ABSTRACT

The objective was to examine milk production, health, and economic performance among Holstein heifers during first lactation on 3 commercial dairy farms in California. Heifers ($n = 1905$) were moved to the breeding group between 360 and 390 d of age and grouped retrospectively according to age at first calving (AFC) as low (≤ 700 d), medium (701 to 750 d), and high (≥ 751 d). Within farm, growing heifers were managed similarly, as were lactating primiparous cows, for the first 310 d in lactation. Heifers were fed to gain 0.70 to 0.80 kg/d from 4 mo of age to breeding, and 0.8 to 0.9 kg/d from breeding to 252 to 258 d of pregnancy. First calving at < 700 d was associated with reduced yields of milk and milk components. Cows in the high age group produced more milk fat and true protein than medium and low cows. Incidence of stillbirths was highest for cows in the low group (19.8%), but stillbirths were also a concern for those calving at medium (16.1%) or high age groups (13.5%). Both low and high cows had lower conception rates at first postpartum AI, and abortions averaged 9.8% across groups. Days open and number of inseminations were lower for medium than low cows. Incidence of mastitis and lameness was lowest for cows in the medium group. Culling and mortality rates were not affected by AFC, but among those that died, cows in the low group tended to die earlier postpartum than cows in the high group. Heifers in the medium group had an adjusted income value numerically higher by \$138.33 and \$98.81 compared with those in the low and high groups, respectively. First calving at < 700 d compromised first lactation yields of milk and milk components and impaired reproductive performance. However, extending AFC beyond 750 d did not improve lactation, reproduction, or health of primiparous cows. Although not preassigned to age groups before start of

breeding, Holstein heifers managed as in this study had the highest economic return when calving between 23 and 24.5 mo of age.

(Key words: heifer, age at first calving, milk production, reproduction)

Abbreviation key: AFC = age at first calving, LDA = left displacement of abomasum.

INTRODUCTION

Age at first calving (AFC) is an important factor in the cost of rearing replacements in dairy herds. The net costs of rearing dairy replacements for a 100-cow herd using Pennsylvania and US information were estimated at \$32,344 (Tozer and Heinrichs, 2001). There was an estimated decrease in rearing costs of 18% when calving age was reduced from 25 to 21 mo (Tozer and Heinrichs, 2001). However, these calculations did not consider changes in reproduction, lactation, and survivability of primiparous cows when calving at different ages. Heinrichs (1993) suggested that optimum AFC for Holsteins for maximum profit should be 23 to 24 mo of age.

Age at first calving can be manipulated by altering growth rates (Van Amburgh et al., 1998). However, even when heifers are managed and fed similarly to achieve similar growth rates, variability in AFC is observed, which is dictated by the reproductive efficiency during breeding. Herds can minimize the variability in AFC by obtaining high pregnancy rates, but poor reproduction increases variability in AFC, although nutrition and growth rates may be adequate.

To maximize lactation performance and reduce rearing costs, average AFC in Holsteins was recommended to be ≤ 24 mo with BW > 560 kg after calving at 24 mo (Heinrichs, 1993; Tozer and Heinrichs, 2001). However, analyses of age and BW at first calving for Holsteins in the United States show that only 2.7% of dairy farms actually achieve the recommended targets (Losinger and Heinrichs, 1997). Heinrichs and Vazquez-Anon (1993) found that heifers calving at ≥ 26 mo of age produced similar amounts of 305-d milk, as did heifers calving at 24 mo of age. Van Amburgh et al. (1998)

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reduced AFC to 21.3 mo, with a prepubertal growth rate of 1.0 kg/d, and observed a 5% reduction in yields of milk and 4% FCM compared with heifers fed to gain 0.6 kg/d, but indicated that reductions were associated with lower BW at calving for heifers calving at 21.3 mo. Reduced performance during first lactation in heifers under accelerated growth during the prepubertal period might also be associated with reduced mammary secretory tissue (Sejrsen et al., 2000).

Insemination at 350 d compared with 462 d of age did not result in significant differences in reproductive performance during first lactation (Lin et al., 1988). Yields of milk during first lactation were significantly lower for early-bred heifers (Lin et al., 1986, 1988), and for every 1 mo of reduction in AFC, a decrease in 308-d milk, protein, and fat of 96, 3.1, and 4.3 kg, respectively, was observed during first lactation (Lin et al., 1988). However, lifetime production evaluated through the first 61-mo herd life was improved for early-bred heifers.

Dystocia is detrimental to reproduction and health, and BW of heifers at first calving impacts dystocia (Erb et al., 1985; Hoffman and Funk, 1992). Thompson et al. (1983) and Erb et al. (1985) found a negative correlation between BW at first calving and dystocia. Younger, smaller heifers, as well as older and overconditioned heifers might experience more dystocia. Thompson et al. (1983) did not observe an increase in calving difficulty for heifers calving as early as 22 mo of age. Hoffman et al. (1996) found no differences in dystocia for heifers under different postpubertal feeding regimens with AFC of 20.6 or 23.6 mo. In the same study, delaying breeding to increase AFC by about 2 mo resulted in a higher incidence ($P < 0.01$) of dystocia, and the higher BCS was suggested as the main reason.

The objectives of this study were to determine the impact of AFC in Holstein heifers fed similar diets and achieving similar growth rates on lactation, reproduction, health, and income at first lactation on large commercial dairy farms in California.

MATERIALS AND METHODS

Animals, Housing, and Feeding

Nulliparous Holstein heifers ($n = 1933$) from 3 commercial dairy farms in the Central Valley of California were moved to a breeding group at 2-wk intervals as heifers reached 360 to 390 d of age. After calving, primiparous cows were retrospectively assigned to 1 of 3 groups based on AFC. The experiment was conducted from January 2001 to December 2002, and only heifers calving between January and December of 2001 were used. Lactating herd sizes and rolling herd averages of 3.5% FCM per cow in 2002 for the 3 herds were 810

cows, 11,640 kg; 1450 cows, 12,140 kg; and 1480 cows, 11,910 kg. Nulliparous heifers were housed in open corrals in all 3 sites. After calving and during the entire 310-d lactations, primiparous cows were housed separately from multiparous cows in free-stall barns at all 3 sites.

Within each site, nulliparous heifers were fed 2 diets, one for the period between weaning and 12 mo of age, and a second diet for the period between breeding (13 mo) and 255 d pregnant. The TMR were formulated for a Holstein heifer to gain 0.70 to 0.80 kg/d from 4 mo of age to breeding, and 0.8 to 0.9 kg/d from breeding to 252 to 258 d pregnant. Diets in all 3 sites had a ratio of calculated metabolizable protein to metabolizable energy of 39 to 42 g/Mcal for the period between weaning but before breeding, and of 36.5 to 39 g/Mcal for after breeding (NRC, 2001). When heifers were 252 to 258 d pregnant, they were moved to a prepartum pen where they were fed a TMR higher in energy and protein. After calving, within each site, all primiparous cows received the same TMR throughout the entire lactation formulated to meet the nutrient requirements for lactating Holstein cows weighing 650 kg, consuming 24 kg of DM, and producing 45 kg of 3.5% FCM (NRC, 2001). Throughout the study, lactating diets contained at least 17.2% CP, 5.5% ether extract, 28.5% NDF based on chemical analyses of TMR, and an NE_L of 1.65 Mcal/kg after adjusting for a 24 kg of DM intake. At sites 1 and 3, diets were offered twice daily, and at site 2, once daily, for an expected 3% refusal of the total amount offered daily. Cows were milked twice starting at 0400 and 1600 h at sites 1 and 3, and 3 times daily starting at 0530, 1330, and 2130 h at site 2. At site 2, all cows received an injection of recombinant bST (Posilac, 500 mg, Monsanto Co., St. Louis, MO) at 14-d intervals starting at 63 ± 6 DIM.

Milk yields were recorded for individual cows once monthly during the official California DHIA test. Individual milk samples were also collected from consecutive milkings (A.M. and P.M.), composited, and analyzed for SCC, fat, and true protein concentrations (Foss 303 Milk-O-Scan, Foss Foods, Inc., Eden Prairie, MN) at the DHIA Laboratory in Hanford (sites 1 and 2) and Fresno (site 3), California.

Growth Rates Before Calving

Subsets of 120 to 200 heifers of 4 to 27 mo of age were measured for wither height and heart girth at each of the 3 sites during the years of 2000 and 2001, which corresponded to the period when nulliparous heifers were growing before calving. Body weights of heifers were estimated using the heart girth measurement with a measuring tape for Holsteins, and wither

Figure 1. Regression analysis of height (cm) and age (mo) for 566 heifers between the ages of 4 and 27 mo. Height (cm) = $89.7973 + 3.26860 X - 0.0557941 X^2$, where X = age in months. Adjusted $r^2 = 86.5$ ($P < 0.0001$).

height was measured using the procedure described by Heinrichs and Losinger (1998). A total of 566 heifers were evaluated at the 3 sites. Because growth rates at all 3 sites followed similar patterns according to age of animals, the data were merged and regression analyses were performed to estimate growth curves for height and BW in the first 27 mo of age (Figures 1 and 2).

Age of Calving Groups

Heifers were not randomly preassigned to be inseminated at differing ages but were divided into 3 age groups based on actual AFC. The average ($\pm$ SD) age at calving of all 1933 heifers was 726.2 ($\pm$ 50.2) d. Calving

age was ranked as low (≤ 700 d), medium (701 to 750 d), and high (≥ 751 d). This grouping strategy was used because AFC is usually considered economically optimum when heifers calve at 23 to 24 mo of age (Heinrichs, 1993). Calving at ages younger than 23 is considered economically advantageous, as long as future lactation is not compromised. Because heifers were moved to the breeding group at a similar age and, within each site, fed the same diet, AFC was determined only by when they became pregnant. The mean ages ($\pm$ SEM) at first AI were 396.6 ± 1.23 , 433.6 ± 0.95 , and 476.6 ± 1.24 d for low, medium, and high, respectively ($P < 0.001$). The retrospective differences in AFC among low, medium, and high were caused by differences in age at first breeding associated either with delayed cyclicity or unobserved estrus, as well as delays associated with failure to conceive at first AI.

Reproductive Management of Nulliparous Heifers

Within sites 2 and 3, AI was performed by the same technician except for one day a week when a relief technician inseminated the heifers. At site 1, 3 technicians inseminated the heifers. At site 1, heifers not found in estrus within 14 to 28 d of introduction to the breeding group were palpated per rectum and received an injection of 25 mg of PGF_{2 α} i.m. (Lutalyse, Dinoprost Tromethamine; Pharmacia Animal Health, Kalamazoo, MI) upon diagnosis of a CL in one of the ovaries. At the other 2 sites, no hormonal treatment was used to induce estrus in noninseminated heifers. Heifers were inseminated upon detected estrus based on visual observation and by removal of paint (All-weather Paintstik, LA-CO Industries, Chicago, IL) from the tail-head area (Macmillan et al., 1988). Pregnancy was diagnosed by palpation per rectum in all animals between 35 and 48 d after AI. Nonpregnant heifers at palpation per rectum received an injection of PGF_{2 α} upon detection of a CL, otherwise they received no further treatment.

Reproductive Management of Postpartum Primiparous Cows

At all 3 sites, lactating cows received 2 (site 1) or 3 (sites 2 and 3) injections of PGF_{2 α} i.m., given 14 d apart, starting after 30 ± 3 DIM. Estrus was detected once daily by visual observation and by tail chalking using paintsticks. Any cow observed in estrus following the second PGF_{2 α} treatment was inseminated. At site 1, 3 technicians inseminated lactating cows. Within sites 2 and 3, AI was performed by the same technician except for one day a week, when a relief technician inseminated the cows. Cows not observed in estrus by 14 d of the second (site 1) or third (sites 2 and 3) PGF_{2 α} treat-

Figure 2. Regression analysis of BW (kg) and age (mo) for 566 heifers between the ages of 4 and 27 mo old. BW (kg) = $95.9016 + 21.0186 X$, where X = age in months. Adjusted $r^2 = 90.9\%$ ($P < 0.0001$).

ment were enrolled in a timed AI protocol (Pursley et al., 1995).

Pregnancy diagnosis was performed by rectal palpation between 35 and 48 d after AI, and pregnant cows had their pregnancy reconfirmed immediately before completing the 310-d study period, or at 160 to 180 d pregnant. Cows not diagnosed as pregnant during the rectal exam were enrolled in a timed AI protocol for reinsemination. Reproductive measures evaluated were interval from calving to first postpartum AI, conception rate at the first postpartum AI, percentage of animals pregnant by 310 DIM, mean and median days from calving to conception for all cows (days open), proportion of cows aborting during the study, and number of AI per cow. Days open were defined as the number of days from calving to conception for those cows diagnosed as pregnant, in addition to the DIM when a cow left or completed the study (310 DIM) for any nonpregnant cow at the end of the study. Conception rate was defined as the proportion of pregnant animals relative to the number of artificially inseminated cows in each group.

Abortion Before First Lactation, Calf Gender, Twins, Calving Difficulty, and Stillbirths

Twenty-eight heifers aborted during first gestation and were excluded from the statistical analyses. Heifers that aborted started their first lactation at 669 d compared to 730 d for the 1905 heifers that did not experience abortion. Because of that, 22 of the 28 heifers that aborted would have been included in the low group, 4 in the medium, and 2 in the high. Heifers that abort are more likely to produce less milk during lactation and more likely to be culled. In fact, of the 28 heifers that aborted before first lactation, 14 were culled within 60 DIM.

Gender of calf and incidence of twin births were evaluated because of possible relationships to dystocia and stillbirths. Calving difficulty was scored based on a 0 to 3 scale: 0 = no assistance with normal delivery of a live calf, 1 = no assistance with delivery of a stillborn calf; 2 = some assistance required for extraction of the calf; and 3 = difficult calving with forced extraction of the calf. Cows requiring fetotomy and cesarean section surgery were not included in the data set. Stillbirths were calves born at term, but that died during or immediately after delivery before receiving colostrum and moved to individual hutches.

Monitoring Health Events in Postpartum Cows

Health was monitored daily during the first 2 to 3 wk postpartum at all 3 sites. Cows with signs of illness

had rectal temperatures taken, and the presence of ketones was determined in the urine (Ketostix, Bayer Co., Pittsburgh, PA). Cows with rectal temperature above 39.5°C were considered as febrile and treated according to protocols established by the herd veterinarian.

Fetal membranes retained >24 h were diagnosed by farm personnel. Cows with retained fetal membranes usually received an injection of 2 mL containing 4 mg of estradiol cypionate (ECP, Pharmacia Animal Health, Kalamazoo, MI) 36 to 48 h after calving, plus 3 d of antibiotic treatment. Diagnosis of left displacement of abomasum (**LDA**) was based on clinical signs: reduced milk production, rumen atony, ketonuria, diarrhea, and presence of an acute ping sound at auscultation and percussion on the left side of the abdomen. Cows diagnosed with LDA were treated by the toggle pin suture procedure at sites 2 and 3 and by surgical correction at site 1. Supportive therapy with propylene glycol or calcium propionate and antibiotics was used as needed.

All cows were examined for clinical mastitis by herd personnel during milking twice daily at sites 1 and 3, and 3 times daily at site 2. Clinical mastitis cases were characterized by the presence of abnormal milk or by signs of inflammation in one or more quarters, and were treated by intramammary infusion of antibiotics according to treatment protocols established by the herd veterinarian. A new case of mastitis was defined for the same cow when a different quarter was affected or a period of 21 d had passed since the previous diagnosis.

Incidence of lameness during the 310-d lactation was determined based on diagnosis performed by visual observation during weekly or twice-monthly visits by the herd veterinarian, as well as detection of abnormal gait by herd personnel.

Primiparous cows that died or were sold, as well as DIM when the event occurred, were recorded and evaluated. Health data evaluated were general incidence of mastitis (number of affected cows/number of cows at risk), DIM at diagnosis of mastitis, clinical mastitis cases as a proportion of cows at risk up to 310 DIM, incidence of retained fetal membranes, incidence of LDA and DIM when LDA was diagnosed, incidence of lameness and DIM when first diagnosed, mortality rate, DIM when a cow died, percentage of cows sold during the study period, DIM when a cow was sold, percentage of cows leaving the study (sold or dead), and DIM when cows left the study. Incidences of lameness at site 3 and retained placenta at site 1 were omitted from the data set for statistical analyses because of incomplete records.

Cost Analysis of Income at First Lactation

Additional costs to raise heifers beyond the mean AFC for low heifers of 680 d was calculated, considering

feed and labor costs from each farm. Heifers in the low group conceived at an average of 401 d of age, whereas heifers in the medium and high groups conceived 43 and 112 d later, respectively. At sites 1, 2, and 3, respectively, the average DM offered per heifer and daily feed cost in the breeding group was 9.8 kg/d and \$0.90, 9.1 kg/d and \$0.81, and 9.6 kg/d and \$1.01. Additional labor cost was computed at actual local cost of \$7.50/h, with 15 s/d for individual observation of animals, detection of estrus, and AI based on actual time spent by herd personnel for such activities on the study farms. In all age groups during lactation, an additional expense of \$0.67/cow per day was included to cover labor costs, with the assumptions that the average employee salary and benefits is \$24,000/yr and a ratio of 1 employee per 100 lactating cows.

Gross income was calculated per heifer based on total milk produced and average milk price (\$0.26/kg) for 2002 in California. The cost of days open beyond 85 DIM was computed as follows: \$0.42/d, 86 to 115 DIM; \$1.14/d, 116 to 130 DIM; \$1.98/d, 131 to 145 DIM; \$3.12/d, 146 to 160 DIM; and \$4.95/d, 161 to 175 DIM (French and Nebel, 2003). Cost of treatment computed was \$9.00 and \$40.00 for each case of retained fetal membrane and lameness, respectively. The cost for treatment of LDA including correction and postcorrection care was \$40.00 for sites 2 and 3 based on toggle pin suture, and \$170.00 for site 1 based on surgical correction. The cost for each mastitis case was \$50.80, which consisted of antibiotic treatment, labor, and 5 d of discarded milk. The average milk production for the study (34.1 kg/d) was used to calculate the cost of discarded milk. The value of a newborn calf or cost of a stillbirth was \$60.00 for males and \$250.00 for females based on prices in California for 2002. The value of a culled cow was the market price for a cow sold to slaughter (\$450.00), and equivalent to the value lost for each dead cow. The value of the surviving cow at the end of the 310-d study was set at \$1300.00 if pregnant or \$550.00 if not pregnant. Opportunity cost for calving heifers at younger ages was not considered in our calculations.

Experimental Design and Statistical Analyses

A retrospective cohort study design was used. A total of 1905 heifers were included in the data analyses. Data from cows that remained in the herd after the voluntary waiting period of 44 d were included in the analyses for the reproductive data. Only cows that had been diagnosed as pregnant were included in the analysis of abortion incidence.

Lactation performance was analyzed by ANOVA for repeated measures by the MIXED procedure of SAS (Littell et al., 1998) with a mathematical model that

included the effects of group, month postpartum, the interaction between group and month postpartum, dairy, season of calving (spring, March 21 to June 20; summer, June 21 to September 20; fall, September 21 to December 20; or winter, December 21 to March 20), the interaction between group and dairy, the interaction between group and season of calving, and cow nested within group as the random error. The covariance structure (unstructured, compound symmetry, toeplitz, and autoregressive order 1) for the repeated measures model was tested (Littell et al., 2000), and the autoregressive order 1 structure was chosen based on the Schwarz's Bayesian criterion.

Count data, such as number of mastitis cases per cow, number of AI per cow, and calving difficulty, were all analyzed by the GENMOD procedure using a Poisson distribution and log transformation function (Allison, 1999) with the SAS (2001) program. Least square means were calculated, but statistical values for count data are from the Poisson distribution.

Binomially distributed data, such as conception rate at first AI, proportion pregnant at 310 DIM, incidence of diseases and abortion, were analyzed by logistic regression (Allison, 1999) by the LOGISTIC procedure of SAS (2001) using a model that included the effects of group, dairy, season of calving, interaction between group and dairy, and interaction between group and season of calving. Because male calves and twin pregnancies increased the incidence of stillbirths and difficult calving, gender and twins were included in the model for analysis of stillbirths and calving difficulty.

Interval from calving to the first postpartum AI was analyzed by ANOVA using the GLM procedure (SAS, 2001) with a model that included the effects of group, dairy, season of calving, interaction between group and dairy, and interaction between group and season of calving.

Interval from calving to pregnancy or diagnosis of a disease event was calculated for cows that experienced the event and for all cows. When only cows that experienced an event (pregnancy, disease, and so on) were used in the analyses, the interval from calving to the event was analyzed by ANOVA using the GLM procedure of SAS (2001) with a model that included group, dairy, season of calving, interaction between group and dairy, and interaction between group and season of calving. When all cows were included in the analyses, the product limit method of the Kaplan-Meier model (Kaplan and Meier, 1958) for the survival analysis procedure LIFETEST (Allison, 1995) of the SAS (2001) program was used to assess the effect of group on days postpartum when a cow became pregnant, and when a cow left the study either by culling or death. Cows that did not experience the event at the end of the study

were censored at 310 d postpartum. Additionally, the LIFEREG (Allison, 1995) procedure of SAS (2001) was used to determine the effects of age group, dairy, season of calving, and interactions on interval from calving to conception and to leave the study.

Among heifers that became pregnant at first AI when nulliparous, additional analyses of reproductive measures during first lactation were done to reduce prior fertility bias. Those analyses were done as described previously.

Additional rearing costs and income at first lactation for the 3 groups were analyzed by ANOVA using the GLM procedure SAS (2001) with a model that included the effects of group, dairy, season of calving, interaction between group and dairy, and interaction between group and season of calving.

Data are presented as least square means and proportions. Group differences with $P \leq 0.05$ were considered significant and those where $0.05 < P \leq 0.10$ were considered a tendency.

RESULTS AND DISCUSSION

Conception rates at first AI in nulliparous differed for low, medium, and high heifers and were 76.9, 64.4, and 44.9% ($P < 0.001$), respectively. Conception rates at first AI in nulliparous cows were similar for low and medium cows, but higher than high cows. It is not clear why conception rates differed for older heifers, but clearly that resulted in a longer interval from initiation of breeding to pregnancy, which likely influenced AFC. Donovan et al. (2003) evaluated factors associated with conception rates in nulliparous Holstein heifers in Florida. They determined that BW, BCS, average daily gain between 6 mo and first AI, and age at first AI were not risk factors affecting conception rates. However, pelvimetry, type of estrus (either natural or induced by PGF_{2α}), and vaccination with a modified live viral vaccine affected conception rates. In the current study, all heifers had been vaccinated at least twice with a modified live viral vaccine before first AI.

Distribution of AFC for all 1905 heifers is presented in Figure 3. Most heifers had AFC of 650 to 800 d, with a small proportion calving between 800 and 1077 d of age. After grouping cows based on AFC, a total of 514, 917, and 474 cows were in the low, medium, and high groups, respectively. The mean AFC were 680, 724, and 791 d for low, medium, and high, respectively.

Based on regression analysis of height and age of a subgroup of 566 heifers between ages 4 and 27 mo (Figure 1), low, medium, and high heifers calved with estimated heights and BW of 135.2 cm and 570.9 kg, 136.2 cm and 603.3 kg, and 137.2 cm and 650.4 kg, respectively. Evaluation of growth of Holstein heifers in 659

Figure 3. Histogram of frequency of age at first calving in days (d) for all 1905 heifers in the study. Ages at calving were grouped as: Low = <700 d, $n = 514$, mean = 679.8 ± 0.7 d, median = 682 d; medium = 701 to 750 d, $n = 917$, mean = 724.2 ± 0.4 d, median = 723 d; and high = > 750 d, $n = 474$, mean = 791.4 ± 2.2 d, median = 781 d.

dairy farms (Heinrichs and Losinger, 1998) revealed that US Holstein heifers at 22.5 mo of age averaged 523 ± 99.4 kg BW and measured 134.7 ± 7.0 cm at the withers. Low heifers in the current study were slightly heavier and of similar height compared with the average US Holstein heifer. Therefore, growth rates for the heifers in the current study were within the expected range for large-frame Holsteins.

Calving Difficulty and Stillbirths

The proportion of cows delivering female calves differed among farms, and site 1 had a lower proportion of females (43.0%) than sites 2 and 3 (48.7 and 49.5%, respectively) ($P = 0.02$). However, among groups of AFC, the proportion of female calves was similar ($P = 0.62$) and averaged 47.4%. Calving difficulty was lower ($P < 0.001$) in cows delivering females than males (1.36 vs. 1.81). Similarly, cows delivering single calves had lower calving difficulty than those with twins (1.57 vs. 2.19; $P = 0.03$). Although numerically higher with decreasing AFC (low = 1.94; medium = 1.84; high = 1.66), calving difficulty was not associated with AFC ($P = 0.69$). Incidence of stillborn calves was lower for high (13.5%) compared with low (16.1%) and medium (19.8%) heifers ($P < 0.05$). Similar to calving difficulty, cows calving male or twin calves had higher incidence of stillbirths than those calving female (20.6 vs. 11.9%; $P < 0.001$) or single calves (37.5 vs. 16.2; $P < 0.01$), respectively.

The successful delivery of a live calf in primiparous cows is dependent, among other factors, on size and BW of the dam (Hoffman and Funk, 1992). Male calves are more likely to result in dystocia because of larger size. Proportions of female calves born were similar for all age groups, and gender of calf was included in the

Figure 4. Least square means of milk yield (kg/d) in the first 310 DIM among primiparous Holstein cows that calved at different ages. Low: solid circle (●; LSM = 33.4, SEM = 0.23 kg); medium: solid square (■; LSM = 34.4, SEM = 0.18); high: solid triangle (▲; LSM = 34.7, SEM = 0.24 kg). Significant effects: age group ($P < 0.001$); month postpartum ($P < 0.001$); age group by month postpartum ($P = 0.08$); and season ($P < 0.005$).

statistical model to analyze stillbirths and calving difficulty. Lin et al. (1988) subjected nulliparous cows to first AI either at 350 d or 462 d of age and observed no effect of age at first AI on the proportion of cows having calving difficulty, but their data did not indicate whether gender of calf was evaluated.

Increased calving difficulty results in more stillborns, as observed for heifers in the low group. Furthermore, increased calving difficulty puts at risk the life of the dam, and heifers with calving difficulty scores 2 and 3 had higher mortality rates than those with calving difficulty scores 0 and 1 (4.9 vs. 2.7%; $P = 0.02$). Erb et al. (1985) found that heifers with dystocia were 2.9 to 4 times more likely to have retained placenta and metritis or to be culled involuntarily, and they had an additional 7.4 d to first service. Similarly, retained placenta, dystocia, metritis, and stillbirth lowered milk production by 239, 173, 98, and 181 kg, respectively, in primiparous cows (Simerl et al., 1992).

Lactation Performance

Milk production was similar for all 3 groups early in lactation (Figure 4), but heifers in the low group produced less milk than those in the medium and high groups after 50 DIM. This resulted in lower milk production for low (33.4 ± 0.23 kg/d) than medium (34.4 ± 0.18 kg/d) and high (34.7 ± 0.24 kg/d) heifers during the entire study ($P < 0.001$). Changes in milk production for low heifers after 50 DIM represents a total lactation loss of more than 310 kg of milk and 3.5% FCM when

compared with heifers in the medium and high groups. Similar to milk yield, production of 3.5% FCM was also reduced in low (33.8 ± 0.22 kg/d) than medium (34.9 ± 0.18 kg/d) and high (35.6 ± 0.23 kg/d) heifers ($P < 0.001$). Total lactation production in the first 310 DIM was 10,354 (± 71), 10,664 (± 56), and 10,757 (± 74) kg for low, medium, and high heifers ($P < 0.001$). Interestingly, increasing the average AFC from 724 to 791 d resulted in no advantages in yields of milk and 3.5% FCM. The effects of AFC on yields of milk were observed regardless of site, because no interaction of herd by age group was observed ($P = 0.14$).

Reducing AFC is one of the many factors that affect costs of raising replacement heifers (Tozer and Heinrichs, 2001). Van Amburgh et al. (1998) suggested that calving at <24 mo might present economic advantages with minimal impacts on lactation performance, as long as heifers are fed properly before puberty and achieve adequate BW at calving. Efforts to reduce AFC below 23 mo have generally resulted in reduced milk yield during first lactation (Hoffman and Funk, 1992; Hoffman et al., 1996). However, response to AFC can differ between first lactation and lifetime production. Delaying insemination of heifers by 112 d to achieve AFC of 26.5 mo of age resulted in a first lactation milk production increase of 275 kg compared with heifers calving at 23.3 mo of age, although early calving heifers yielded 1475 more kilograms of milk during a 61-mo productive period because of more days of productive life (Lin et al., 1988). Delaying age at first breeding from 350 to 462 d increased daily milk yield during first lactation by approximately 7% (14.3 vs. 15.3 kg/d) (Lin et al., 1986).

Because AFC and BW can be confounded, differences in lactation performance might also be related to BW at calving. When Hoffman et al. (1996) fed postpubertal heifers to achieve different growth rates reaching AFC at 21.7 and 24.6, heifers with lower AFC had reduced lactation performance in spite of the similar BW at calving.

Lower milk yield due to reduced AFC may be related to accelerated growth rates during the prepubertal period, which has been shown to reduce parenchymal DNA in the mammary gland (Sejrsen et al., 2000). Also, size and BW at first calving, which are influenced by age, are significant factors affecting dystocia and the successful delivery of a live calf (Hoffman and Funk, 1992), and complications at calving can affect lactation performance of dairy cows (Thompson et al., 1983; Erb et al., 1985; Simerl et al., 1992). Although somewhat interrelated, BW seems to be important in determining lactation performance of primiparous cows (Clark and Touchberry, 1962). These authors demonstrated that BW at calving influenced first-lactation milk production

4 times more than AFC. Therefore, postpubertal feeding should be such that younger heifers achieve similar BW to those heifers calving at a later age, as long as excessive body condition at calving does not compromise DMI and subsequent health.

Van Amburgh et al. (1998) evaluated the effects of BW gain and different protein sources in the diet of prepubertal heifers on lactation performance during first lactation on commercial farm conditions. Heifers fed to gain 0.94 kg/d during the prepubertal period calved at a younger age, had reduced BW at calving, and produced less milk over an entire lactation than those fed to gain 0.68 kg/d. The authors indicated that the negative effect of growth rate on lactation performance was caused by reduced AFC, with associated reduced BW at calving. In that study, adjustment for BW removed the treatment effect on fat-corrected milk yields; heifers calving at 21.3 mo of age weighed 520 kg at the day of calving, lower than the estimated 570 kg BW of heifers calving at 22.6 mo in the current study.

Heifers in the current study were fed a similar diet during the entire growth period. Therefore, it is unlikely that reduced milk yield for younger cows was caused by accelerated growth during the prepubertal period. It is possible that the lower AFC with reduced BW and height might be the reason for the compromised lactation performance during first lactation in heifers in the low group. Smaller heifers are more likely to experience dystocia, and animals with dystocia are more likely to develop health problems that affect lactation (Erb et al., 1985). Furthermore, smaller heifers may be less able to compete for feed at the feedbunk and stalls to rest because dominance in dairy cattle is determined in part by body size and weight (Grant and Albright, 1995). Also, the fact that low heifers had similar milk production to medium and high heifers in early lactation, but not after 50 DIM, might suggest that the lactating ration may have been of insufficient nutrient density for the low heifers to grow and lactate.

Based on growth rates, low heifers calved with an estimated height and BW of 135.2 cm and 570 kg, which is similar to, or higher than, those observed for a recent survey on growth of Holstein heifers in 659 dairy farms (Heinrichs and Losinger, 1998). However, it has been indicated that optimum body size of Holstein replacement heifers at calving, as evaluated by BW, should be between 590 to 635 kg (Hoffman, 1997). Hoffman (1997) cited several studies in which first lactation performance was improved when heifers calved with a BW greater than that observed in the current study for the low group. If heifers in the low group were indeed of lower BW and of smaller skeletal size as indicated by the growth charts for the population evaluated, then it is possible that the smaller animals were unable to

Figure 5. A. Least square means of milk fat content (%) in primiparous Holstein cows that calved at different ages in the first 310 DIM. Low: solid circle (●; LSM = 3.61, SEM = 0.02); medium: solid square (■; LSM = 3.64, SEM = 0.01); high: solid triangle (▲; LSM = 3.69, SEM = 0.02). Significant effects: age group ($P < 0.01$); month postpartum ($P < 0.001$); age group by month postpartum ($P < 0.01$); and season ($P = 0.05$). B. Least square means of milk true protein content in the first 310 DIM among primiparous Holstein cows that calved at different ages. Low: solid circle (●; LSM = 3.01, SEM = 0.01); medium: solid square (■; LSM = 2.99, SEM = 0.01); high: solid triangle (▲; LSM = 3.01, SEM = 0.01). Significant effects: age group ($P = 0.07$); month postpartum ($P < 0.001$); age group by month postpartum ($P = 0.03$); season ($P < 0.001$); and age group by dairy ($P < 0.05$).

consume enough nutrients to achieve their lactation potential. Also, because they were of smaller size, partitioning of nutrients could be more toward growth for younger heifers compared to older heifers. These 2 confounding circumstances might account for lower production of heifers calving at less than 700 d.

Concentrations of fat in milk were similar for low and medium heifers but lower than high heifers ($P = 0.02$). An interaction between group and month postpartum was observed ($P < 0.01$; Figure 5A), and the increase in milk fat content for high compared with medium heifers was observed only in early lactation.

Table 1. Reproductive performance of primiparous Holstein cows through 310 DIM according to age at first calving (LSM $\pm$ SEM).

Item	Group ¹		
	Low	Medium	High
All heifers	N = 514	N = 917	N = 474
DIM at first AI, d	65.4 $\pm$ 0.8	65.9 $\pm$ 0.6	66.3 $\pm$ 0.8
CR ² at first AI, %	27.9 ^a	36.9 ^b	30.8 ^a
Pregnant at 310 DIM, %	77.9 ^d	83.4 ^e	80.5 ^{de}
Number of AI/cow, n	3.27 ^a	2.85 ^b	3.23 ^a
Abortion, %	9.8	9.8	10.3
Number of abortions per cow, n	0.09	0.10	0.10
Days open for pregnant cows, d	121.6 $\pm$ 3.5	118.6 $\pm$ 2.6	123.3 $\pm$ 3.5
Days open for all cows, d	160.9 ^b $\pm$ 4.5	148.6 ^a $\pm$ 3.1	154.5 ^{ab} $\pm$ 4.2
Heifers pregnant at first AI when nulliparous	N = 395	N = 590	N = 212
DIM at first AI, d	64.9 ($\pm$ 0.90)	65.6 ($\pm$ 0.77)	65.8 ($\pm$ 1.41)
CR at first AI, %	27.0 ^{de}	36.4 ^d	24.1 ^e
Pregnant at 310 DIM, %	79.3	83.9	84.7
Number of AI/cow, n	3.20 ^a	2.87 ^b	3.23 ^a
Abortion, %	8.4	9.7	9.5
Number of abortions per cow, n	0.09	0.11	0.08
Days open for pregnant cows, d	123.2 ($\pm$ 4.1)	120.0 ($\pm$ 3.3)	121.7 ($\pm$ 6.3)
Days open for all cows, d	158.1 ($\pm$ 5.1)	146.7 ($\pm$ 3.8)	147.1 ($\pm$ 6.9)

^{a,b,c}Superscripts in the same row differ ($P < 0.05$).

^{d,e}Superscripts in the same row differ ($P \leq 0.10$).

¹Low = Age at first calving $\leq$ 700 d; medium = age at first calving = 701 – 750 d; high = age at first calving $>$ 750 d.

²CR = Conception rate.

After 50 DIM, milk fat content was similar for medium and high heifers. It is possible that heifers calving at a higher age might have higher BCS at calving (Van Amburgh et al., 1998). Although not directly measured, a greater degree of fatness at calving could suppress DMI (Hayirli et al., 2002), increase postpartum BW loss, increase mobilization of fat and circulating fatty acids, and thereby increase milk fat (Palmquist et al., 1993).

Tendencies were observed for concentrations of true protein in milk ($P = 0.07$), and low heifers had higher milk true protein than medium heifers ($P < 0.02$), but they did not differ from high heifers (Figure 5B). Yields of milk fat and true protein followed similar patterns, with high $>$ medium $>$ low for both fat (1255 ± 8.8 , 1226 ± 6.7 , and 1183 ± 8.5 g/d, respectively) and true protein (1028 ± 6.4 , 1011 ± 4.9 , and 991 ± 6.2 g/d, respectively) associated with higher yields of milk for heifers calving at older ages. An interaction between group and month postpartum was observed for yields of milk fat ($P = 0.03$) and true protein ($P < 0.01$). The linear SCS was similar for all groups throughout the lactation and averaged $2.23 (\pm 0.05)$ across groups ($P = 0.45$).

Reproductive Performance

Interval to first postpartum AI was similar for all age groups (Table 1) ($P = 0.70$), and no interaction between age group and dairy or season of calving was

observed ($P > 0.20$). Because all sites used synchronization of estrus with PGF_{2 α} followed by a regimen for fixed-time AI (Pursley et al., 1995), differences in cyclicity and detection of estrus among groups were not expected.

Conception rate at first postpartum AI was affected by age of calving ($P = 0.02$), season of calving ($P < 0.001$), and by an interaction between age group and season of calving ($P = 0.02$). For all cows in the medium AFC group, there was a higher conception rate at first postpartum AI than those in the low and high groups ($P < 0.05$) (Table 1). Numerically, group means for postpartum conception and pregnancy rates and the number of inseminations per cow followed a similar pattern when a subsample of heifers that became pregnant at first AI as nulliparous was evaluated compared with data from the 3 calving-age groups including all heifers (Table 1). Therefore, postpartum reproductive differences across age groups do not seem directly related to reproductive efficiency of nulliparous heifers.

Cows calving in the summer had the lowest fertility at first AI (25.9%) and those calving in the winter had the highest (42.5%), with intermediary values for cows calving in the spring (30.2%) and fall (34.8%). Cows calving during spring and summer received first AI during periods of high ambient temperature, which compromises fertilization and embryonic survival. Interestingly, no age group by dairy interaction was observed for conception rate at first AI ($P = 0.76$), indicat-

Figure 6. Survival curves for proportion of primiparous Holstein cows that calved at different ages remaining nonpregnant. Cows not conceiving were censored at 310 DIM or when left the study because of culling or death. Low: dashed line with solid circle (●; median = 131); medium: solid line with solid square (■; median = 119); and high: dashed thin line with empty triangles (△; median = 129). Significant effects: age group ($P < 0.02$); season ($P < 0.003$); and age group by season ($P < 0.01$).

ing similar reproductive responses in all 3 sites for different AFC.

Energy status, BCS, cyclicity, and level of milk production are some of the factors that can affect conception in lactating dairy cows. Excessive condition can negatively affect energy status because of lower DMI prepartum and postpartum (Hayirli et al., 2002), resulting in weight loss. Also, smaller heifers might not be able to compete for food (Grant and Albright, 1995), leading to greater BW losses. Excessive BW loss postpartum affects energy balance and delays resumption of cyclicity, which in turn affects fertility (Butler and Smith, 1989). Lower AFC associated with reduced BW and frame size might affect conception rates at first AI because of inadequate energy intake to support lactation and growth. Older heifers likely calved with higher BW and may have had more body condition that could exacerbate negative energy balance early postpartum and thereby affect conception.

Although age group had no effect on the proportion of cows pregnant at 310 DIM ($P < 0.20$), the number of days open was influenced by AFC (Figure 6) ($P < 0.02$), and medium cows had lower median (Figure 6) and mean days open (Table 1) than low and high cows. Similar to conception rates at first AI, the proportion of pregnant cows at 310 DIM and days open were affected by season ($P < 0.01$), with cows calving in winter having the best reproductive performance. The higher pregnancy rate for cows in the medium group as detected by reduced days open resulted in a lower number of AI than those in the low and high groups ($P < 0.05$).

Approximately 10% of the primiparous cows that became pregnant aborted at least once, but AFC did not affect abortion incidence ($P < 0.88$). Similarly, number of abortions during first lactation was not affected by AFC ($P < 0.84$).

Lin et al. (1998) inseminated nulliparous cows either at 350 or 462 d of age to result in different AFC. Although age at first insemination in nulliparous cows affected respective ages at calving at first, second, and third lactation, the authors observed no effect on first-lactation reproductive performance. However, cows in that study were of low production, approximately 35 to 40% of the milk production for the primiparous cows in the current study. Such magnitude of difference in milk production is anticipated to alter nutrient requirements and impact reproductive responses to AFC. When physiological maturity or body size is not adequate in first-lactation animals, those of greater genetic potential for milk production are expected to experience more metabolic consequences, which might affect reproduction.

Holsteins calving at younger ages in the current study had reduced reproductive efficiency in the first lactation compared with heifers calving near 24 mo of age, but no advantage in reproduction was observed among heifers first calving at older ages. Therefore, for Holstein heifers managed as in the present study, optimal reproduction was for calving near 24 mo.

Incidence of Health Problems

An overall low incidence of retained fetal membranes was observed in the current study (3.0%). Age group had no effect on retained placenta and incidences in low, medium, and high heifers were 3.5, 2.6, and 3.7%, respectively ($P = 0.61$). Neither season of calving nor interaction between group and dairy or season of calving was significant for retained placenta. Similarly, incidence of LDA was low and unaffected by age group ($P = 0.54$), with 2.5, 2.8, and 3.4% of the low, medium, and high heifers affected, respectively. However, season of calving had a major impact on LDA, and in cows calving during the spring, summer, fall, and winter, the incidences of LDA were 3.4, 1.2, 2.5, and 4.9%, respectively ($P < 0.01$), independent of AFC. The interval from calving to diagnosis of LDA in low, medium, and high AFC heifers did not differ (21.5 ± 4.5 , 20.8 ± 2.9 , and 18.0 ± 3.8 d, respectively; $P = 0.79$), and no interactions between age group and season or dairy were observed for the interval from calving to diagnosis of LDA.

Cases of lameness were observed in 15% of the animals, and medium cows tended to have a lower incidence than high cows (13.6 vs. 16.6%; $P = 0.09$). Interval

to the diagnosis of lameness tended to be shorter for medium than low cows (129 vs. 147 d; $P = 0.06$). Season of calving affected incidence of lameness ($P < 0.001$), and more cows calving during the fall months were diagnosed lame than any other season of the year (23.2 vs. 13.0 vs. 10.5 vs. 14.0% for fall, spring, summer, and winter, respectively). Nevertheless, no interaction between age group and season was observed.

Incidences of mastitis were 20.6, 18.7, and 19.0% for low, medium, and high cows, and medium tended to be less affected than low cows ($P = 0.08$), but interval to first clinical case was 85.5 ± 9.1 , 104.6 ± 8.0 , and 103.7 ± 10.1 d for low, medium, and high, respectively ($P = 0.24$), and number of clinical cases per cow (0.29, 0.25, and 0.24 for low, medium, and high, respectively; $P = 0.30$) were unaffected by AFC. Season of calving affected incidence of mastitis and number of clinical cases per cow, and cows calving during the summer (21.2%) and fall (22.5%) tended ($P = 0.08$) to have a higher incidence of mastitis than those calving in the winter (16.0%) and spring (16.6%) months. Similarly, number of clinical mastitis cases per cow differed with season ($P < 0.001$), and these averaged 0.36, 0.24, 0.29, and 0.22 for cows calving in the fall, spring, summer, and winter months, respectively. In contrast, an increase in AFC was associated with increased risk of mastitis (Waage et al., 1998), although heifers calving at an extraordinarily high age were at decreased risk. Waner et al. (1999) also showed that older heifers were 13% more likely develop clinical mastitis, and they associated the higher risk with a longer period of exposure. It is possible in the current study that herd exposure to pathogens before first calving was not a high risk for mastitis postpartum, minimizing possible effects of AFC on mastitis.

Culling and Mortality of Dairy Cows

Culling after calving was similar for all 3 age groups and averaged 17.6% ($P = 0.32$). Neither season of calving nor interactions between group and dairy or group and season of calving were observed ($P > 0.10$). Furthermore, DIM when a cow was sold was not affected by AFC ($P = 0.85$), but season affected the interval from calving to culling ($P = 0.07$). Cows calving in the summer were sold earlier in lactation than cows calving in the fall (78.3 ± 9.9 vs. 112.7 ± 8.8 DIM; $P < 0.01$) and tended ($P = 0.10$) to be earlier than cows calving in the winter (102.6 DIM), but similar to those calving in spring (96.2 DIM). Cows calving during summer are more likely to experience heat stress leading to problems that might exacerbate losses of milk, increasing the risk for culling.

Mortality was similar for all 3 groups (4.9% for low, 4.2% for medium, and 2.5% for high; $P = 0.23$), but low cows tended to die earlier in lactation than high cows (20.3 ± 27.3 vs. 77.7 ± 22.2 d; $P = 0.10$). Cows with calving difficulty scores 2 and 3, requiring extraction of the calf, had higher ($P = 0.02$) mortality (4.9%) than those with calving difficulty scores 0 and 1 (2.7%). Cows that died had a higher calving difficulty score than those that survived (1.98 vs. 1.59; $P = 0.04$), indicating that complications associated with dystocia likely contributed to mortality. Reasons for death of cows in the first 30 DIM were ruptured mammary vein (1 high), fractured cervical vertebrae (1 medium), and complications associated with ketosis (4 low, 4 medium, and 2 high), severe lameness and arthritis (1 low), LDA (2 low, 2 medium, and 4 high), mastitis (1 medium), pneumonia (2 medium), and acute metritis and postpartum fever (10 low, 14 medium, and 2 high), and unknown cause (4 medium).

When both dead and sold cows were combined to determine the proportion of cows leaving the study before 310 DIM (21.8% for low, 21.1% for medium, and 22.2% for high; $P = 0.66$), no effects of age group, season of calving, or interaction between age group and season or dairy were observed. Survival analysis of interval from calving to date leaving the herd indicated no effect of AFC (mean = 255 ± 3.9 d; $P = 0.67$). Simerl et al. (1992) observed no effects of AFC on survival of primiparous cows to second parturition. Therefore, AFC had only subtle effects of survivability of cows during first lactation and only the interval from calving to death tended to be affected.

Rearing Costs and Income at First Lactation

Increasing AFC resulted in an increase in rearing costs of heifers ($P < 0.001$) (Table 2). The resulting additional rearing costs for each medium and high heifer were \$40.34 and \$107.89, respectively. After considering income from milk, newborn calves, cows sold to slaughter, value of the cow at the end of the 310-d study, and costs associated with stillbirths, diseases, days open, mortality of cows, and labor, the gross income at the end of the 310-d study tended ($P < 0.10$) to be higher for medium than high cows, and it was \$178.58 higher for medium than low cows ($P = 0.03$). Although herd had an effect on gross income at the end of 310 DIM ($P < 0.001$), no interaction between age group and herd was observed ($P = 0.76$). When considering both additional rearing costs and gross income from first lactation, the overall gross income at 310 DIM did not differ statistically, but was approximately \$138.33 and \$98.81 higher for medium compared with low and high cows, respectively. Results from these analyses also in-

Table 2. Economic analysis at 310 d postpartum for groups at different ages at first calving (means in US \$ $\pm$ SEM).

Item	Group ¹		
	Low	Medium	High
Additional rearing costs ² US \$	0.12 ^a $\pm$ 1.21	40.46 ^b $\pm$ 0.93	108.01 ^c $\pm$ 1.23
Value of income at 310 d of lactation, ³ US \$	3085.56 ^d $\pm$ 65.70	3264.24 ^e $\pm$ 50.61	3232.97 ^{de} $\pm$ 66.22
Adjusted value of income at 310-d lactation, ⁴ US \$	3085.44 ^f $\pm$ 65.71	3223.77 ^g $\pm$ 50.62	3124.96 ^{fg} $\pm$ 66.22
Estimated feed cost to increase milk yield, ⁵ US \$	—	18.60	30.44

^{a,b,c}Superscripts in the same row differ ($P < 0.001$).

^{d,e}Superscripts in the same row differ ($P = 0.03$).

^{f,g}Superscripts in the same row differ ($P < 0.10$).

¹Low = Age at first calving $\leq$ 700 d; medium = age at first calving = 701 to 750 d; high = age at first calving $>$ 750 d.

²Additional rearing costs in the breeding group for heifers that calved after 680 d of age.

³Income value considering milk production, stillbirths, live calf value, diseases, days open, culling, mortality, labor cost during lactation, and the value of a cow at the end of the 310-d study.

⁴Difference between value of income and additional rearing costs.

⁵Estimated cost of additional feed to produce the increased 3.5% fat-corrected milk in medium (1.1 kg/d) and high (1.8 kg/d), considering the average cost of US \$150/tonne of ration DM and an additional 0.4 kg of DM/kg of milk (0.66 Mcal NE_L).

licated no interaction between age group and dairy ($P = 0.77$), demonstrating that the numerical economic advantage for heifers with mean AFC of 24 mo was observed in all sites. The additional 1.1 kg/d of 3.5% FCM produced by medium compared with low heifers would require approximately 0.68 Mcal of NE_L (NRC, 2001). That was equivalent to 0.4 kg of DM (1.65 Mcal/kg of DM). The estimated increase in DMI for the medium cows would be 124 kg/cow for the 310-d study, which resulted in an additional expense of \$18.60, considering the average cost of \$150/tonne of diet DM for all 3 sites. The overall gross income would still be \$119.73 higher for medium than low cows when considering the additional feed costs.

The net costs of rearing replacements for a 100-cow herd using Pennsylvania and US information was estimated at \$32,344 with 25% culling 10% calf mortality (Tozer and Heinrichs, 2001). Decreasing AFC from 25 to 21 mo resulted in a marked decrease in rearing costs. However, the model developed by Tozer and Heinrichs (2001) did not consider changes in milk yield, reproductive performance, and survivability of cows when calving at different ages.

The opportunity cost of reducing AFC and having primiparous cows producing milk at an earlier age was not considered in our calculations. Therefore, it is likely that these values for overall gross income at the end of the 310-d study might be overestimated. Even so, the opportunity cost for reducing AFC from 724 to 680 d of age would have to be greater than \$138.33 to offset the lower overall gross income for heifers in the low group, or \$119.73 considering the increased feed cost to support the additional milk yield for medium cows.

In the current study, we evaluated productivity only through the first lactation to determine profitability, which might not necessarily reflect lifetime productiv-

ity of the animals in different groups (Lin et al., 1988). It is possible that heifers in the low group might achieve lactational, reproductive, and health performances similar to older groups in subsequent lactations, which might offset some differences observed during the first year of production.

CONCLUSIONS

Heifers in the low group, with an average AFC of 22.6 mo and with a lower estimated BW, produced less milk and 3.5% fat-corrected milk, had lower first service conception rate and lower pregnancy rate, and a smaller proportion of them were pregnant at the end of the study when compared to heifers in the medium group during first lactation. Increasing AFC, as observed for heifers in the high group, was associated with no benefits in lactation, reproduction, and health, compared with heifers in the medium group. Heifers in the medium group tended to be less affected by mastitis and lameness than heifers in the low and high groups, respectively. When considering both additional rearing costs and income from first lactation, the overall gross income at the end of the 310-d study was not statistically different, but numerically \$138.33 and \$98.81 higher for primiparous cows in the medium group, compared with those in the low and high groups, respectively. In general, medium heifers had better performance than low and high heifers when considering only results through the first lactation. For heifers reared as in the current study, reproductive programs should be managed such that all animals become pregnant to calve between 23 and 24.5 mo of age. This can be achieved by aggressive breeding programs resulting in high pregnancy rates, which is expected to improve

lactation, reproduction, health, and economic return during the first lactation.

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