Production, fertility, survival, and body measurements of Montbéliarde-sired crossbreds compared with pure Holsteins during their first 5 lactations

A. R. Hazel,¹ B. J. Heins, A. J. Seykora, and L. B. Hansen

Department of Animal Science, University of Minnesota, St. Paul 55108

ABSTRACT

Two-breed crossbreds of Montbéliarde and Holstein (MO × HO) as well as 3-breed crossbreds of Montbéliarde and Jersey/Holstein (MO × JH) were compared with pure Holstein (HO) cows for production, somatic cell score (SCS), fertility, survival to subsequent calving, mortality, and body measurements during their first 5 lactations. Cows calved for the first time between 2005 and 2010 and were housed in either a confinement herd or a herd that had access to pasture for 165 d of the year in the north central region of the United States. Body, hoof, and udder measurements of cows were also objectively measured. The MO × HO crossbred cows were not different from pure HO cows for fat-plus-protein production during any lactation. However, the MO × JH crossbred cows had 5% lower fat-plus-protein production compared with pure HO cows in the confinement herd. On the other hand, the MO × JH crossbred cows were not different for fat-plus-protein production in the third to fifth lactation compared with pure HO cows in the seasonal pasture herd. Across the 2 herds, the MO × HO and MO × JH crossbred cows had 21% higher first-service conception rate, 41 fewer days open, and 12% higher pregnancy rate compared with the pure HO cows. Furthermore, the MO × HO (5%) and MO × JH (12%) crossbred cows had lower mortality rates than the pure HO cows (18%). Because of superior fertility and lower mortality rates, the MO × HO and MO × JH crossbred cows, combined, had greater survival to second (+13%), third (+24%), fourth (+25%), and fifth (+17%) lactation compared with pure HO cows. For body measurements, MO × HO were similar to pure HO cows for hip height and heart girth, but MO × HO cows had more body condition and greater body weight (+39 kg) across the first 5 lactations. The MO × JH cows had more body condition but 5 cm shorter hip height and 28 kg less body weight than pure HO cows across the first 5 lactations. Foot angle was steeper and hoof

length was shorter for MO × HO cows, but MO × JH cows were similar to pure HO cows for hoof measurements.

Key words: crossbreeding, Montbéliarde, fertility, survival

INTRODUCTION

Through modern history, milk has traditionally been produced by purebred dairy cows from localized breeds in most places of the world. In recent decades, sophisticated, long-term selection strategies have resulted in a rapid increase of milk production for the Holstein (HO) breed (Miglior et al., 2005), and pure HO cows now predominate in most temperate regions of the world. A genetic monoculture of only pure HO cows has the potential of becoming detrimental to the fitness and viability of cows as increased genetic relationships within the breed result from highly effective selection programs.

Simultaneous selection for increased angularity and larger body size (Leitch, 1994; Hansen, 2000; Shook, 2006; Henderson et al., 2011), in conjunction with selection for production, has exacerbated a decline in fertility, health, and survival of pure HO cows (Lucy, 2001; Roche et al., 2009). Deterioration of health traits may also result from continuous increases of inbreeding (Sørensen et al., 2005; Bjelland et al., 2013), which is about 6.1% for US Holstein cows born in 2013 (Council on Dairy Cattle Breeding, 2013). As a consequence, dairy producers are exploring systems of crossbreeding to improve the robustness, efficiency, and profitability of dairy cows (Weigel and Barlass, 2003).

Heterosis results from the interaction of heterozygous genes at loci, so the performance of offspring is greater than the average of parents, and heterosis has a major effect on health and fertility traits (Falconer and Mackay, 1996). The largest amount of heterosis is achieved when mating individuals from unrelated breeds (Hansen, 2006). Most producers of beef cattle, pig, sheep, and poultry have embraced the routine use of heterosis for their commercial production systems for at least 50 yr, and the desire to boost animal performance via heterosis has necessitated the ongoing stewardship

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¹Corresponding author: haze0025@umn.edu

of multiple breeds or inbred lines for those types of farm animals. Dependence on the routine crossing of breeds or inbred lines eliminates the concern regarding negative consequences of inbreeding depression for the commercial sector. In contrast, the majority of dairy producers have instead chosen to invest in labor-intensive and costly management inputs rather than relying on heterosis to mitigate health problems and impaired fertility of dairy cows.

The economic benefit of crossbreeding has been documented over the past 15 yr in a variety of management systems for commercial milk production (VanRaden and Sanders, 2003; Dillon et al., 2007; Pyman, 2007; Sørensen et al., 2008; Heins et al., 2012a). Specifically, the performance and profitability of 2-breed crossbred cows during multiple lactations have been reported for combinations of HO, Jersey, and Brown Swiss, which are familiar breeds in North America (VanRaden and Sanders, 2003; Heins et al., 2011, 2012b). Inevitably, producers must decide how to mate 2-breed crossbred cows, and a backcross to 1 of the 2 parental breeds results in a 50% reduction of heterosis compared with that of 2-breed crossbreds. Lopez-Villalobos et al. (2000) observed that 3-breed rotational crossbreeding systems could increase profitability for commercial milk production in New Zealand. The use of 3 breeds is necessary to maintain high average levels of heterosis across generations, and the 3 breeds should be used in a rotational mating pattern (Hansen, 2006). Assessing the performance of 3-breed crossbred cows is a high priority for research into the future, because few crossbreeding studies have assessed performance of the second generation of a rotational crossbreeding system across various management systems.

Some dairy cattle breeds that have been regarded as foreign to the United States are being used for crossbreeding (Swalve, 2007; Sørensen et al., 2008), because some of these breeds offer strength for traits that are lacking in the traditional US dairy breeds. In particular, the Montbéliarde (MO) breed has generated substantial interest for crossbreeding in recent years, and research has documented that milk, fat, and protein production of MO $\times$ HO cows is similar to or slightly lower (ranging from 0 to -3%) than that of pure HO cows (Walsh et al., 2008; Heins and Hansen, 2012; Heins et al., 2012a). Furthermore, the superiority of MO $\times$ HO cows for SCS, fertility, and longevity may contribute to the greater profitability of MO-sired crossbreds (+5%; Heins et al., 2012a) compared with pure HO cows. Mendonça et al. (2010, 2013) documented greater innate immune response for MO-sired crossbred versus pure HO cows as well as a lower incidence of postpartum disease for MO-sired (35%) crossbreds versus pure HO (57%) cows.

Reports of body measurements for MO-sired crossbred cows are sparse, yet some dairy producers focus attention on conformation when evaluating crossbred cows. Walsh et al. (2008) and Hazel et al. (2013) both reported greater BCS for MO $\times$ HO versus pure HO cows across lactations. Differences for BW were nonexistent according to Walsh et al. (2008) and greater for MO $\times$ HO cows compared with pure HO cows (+36 kg) according to Hazel et al. (2013). Neither of these studies included measurements of udders or feet and legs of cows.

The objectives of this study were to compare the phenotypic performance of MO-sired crossbred and pure HO cows. The phenotypic traits compared were production, SCS, first-service conception rate (CR), days open (DO), pregnancy rate (PR), mortality rate, survival (to second, third, fourth, and fifth calvings), longevity, and body measurements during the first 5 lactations.

MATERIALS AND METHODS

Experimental Design

A crossbreeding experiment was initiated in 2000 for 2 research dairy herds at the University of Minnesota, and the 2 herds had historically used the same service sires to breed cows for many generations. The design of the experiment was thoroughly reviewed in Heins et al. (2010). The confinement herd at the St. Paul campus of the University of Minnesota had 90 tie-stalls and a 40-head loose-housing barn with TMR feeding (Table 1). The seasonal pasture herd was located at the West Central Research and Outreach Center (Morris, MN) and had 180 milking cows. The seasonal pasture herd was fed a TMR diet during the entire year; however, the summer TMR diet contained less forage because cows consumed approximately 35% of their diet from pasture for the 165-d pasture period, which spanned from May to October (Table 1). Winters are extremely harsh in Minnesota, without potential for access to pasture for 6 mo of each year (November to April). Cows in the seasonal pasture herd were stocked at a rate of 3.1 cows/ha and were rotated to other paddocks as availability of grass was depleted.

Cows in this study were sired either by MO or HO AI bulls. Bull selection was based on high rank for the French total merit index [Index de Synthèse UPRA (ISU); O. S. Montbéliarde, 2013] for MO bulls and the US net merit index (Cole et al., 2009b) for HO bulls. The same 3 MO bulls were selected annually for use in both herds, and they were always among the top 10 proven AI bulls in France for the ISU index. Likewise, 3 HO bulls were selected annually for use in both herds

Table 1. Constituents of diets for the confinement herd (St. Paul, MN) and the seasonal pasture herd (Morris, MN) on a DM basis

Constituent (%, unless otherwise noted)	Confinement herd (TMR diet)	Seasonal pasture herd	
		Winter diet (TMR only)	Summer diet (TMR plus pasture)
NE _L (Mcal/kg of DM)	1.70	1.59	1.59
CP (% of DM)	18.0	16.4	19.6
Corn silage	39.7	37.0	20.2
Alfalfa silage	—	16.4	—
Chopped alfalfa hay	15.6	—	—
Pasture	—	—	34.9
Chopped straw	—	4.2	4.5
Ground corn	12.6	25.3	22.4
Distillers grains	—	9.6	9.1
Soybean meal	11.4	5.5	7.2
Protein by-products ¹	11.7	—	—

¹Protein by-products included soybean hulls, bypass protein, corn gluten meal, and blood meal.

that ranked among the top 5% of proven bulls in the US for the net merit index, and 93% of the cows in this study were daughters of HO bulls selected in this manner. However, 7% of pure HO cows in this study were sired by unproven AI bulls without daughters contributing to their PTA, because a small number of pure HO cows that had difficulty in conception in the seasonal pasture herd were bred to unproven AI bulls for fourth-or-later AI services. In total, the 150 MO-sired crossbred cows were sired by 12 MO AI bulls and the 163 pure HO cows were sired by 27 HO AI bulls. Dams of cows were either pure HO cows or Jersey × HO crossbred (**JH**) cows, and dams of cows were sired by high-ranking (top 5%) AI bulls for the net merit index in the United States for both the HO and Jersey breeds at the time of selection.

All cows in the confinement herd began first lactation during fall seasons (October to January) for 5 years (2005 to 2009). Most cows in the confinement herd (84% of lactations) calved for subsequent lactations during fall seasons from October to February and were assigned to 7 yr of calving from 2006 to 2012. In the seasonal pasture herd, all cows calved for the first time during spring seasons (March to June) for 5 yr (2006 to 2010). The majority of multiparous cows in the seasonal pasture herd subsequently calved during spring (68% of lactations), but fall-calving multiparous cows (32% of lactations) were combined with cows from the previous spring to create 6 yr of calving (March to December) from 2007 to 2012. Data collection spanned the period from October 2005 to February 2013, except body measurements ended in February 2012.

Table 2 has number of cows initiating first lactation in each herd by calving year and breed group. The mean age of first calving in the confinement herd for MO-sired crossbred and pure HO cows was 24.3 ± 0.3

mo and 24.4 ± 0.3 mo, respectively. In the seasonal pasture herd, mean age of first calving was 23.8 ± 0.2 mo for MO-sired crossbred cows and 24.7 ± 0.3 mo for pure HO cows.

Cows in the confinement herd were synchronized with a timed AI protocol for both first and later services during a 6-mo concentrated breeding season. Despite efforts to calve seasonally, some cows calved outside of target calving periods because managers in the confinement herd bred some cows from standing heats after the designated breeding period in years when fertility was particularly poor. Cows in the seasonal pasture herd were synchronized with prostaglandin, and 90% of cows were bred as a result of standing heat following either a first or second prostaglandin injection. The 10% of cows not bred from prostaglandin were enrolled in a timed synchronization protocol. Subsequent AI services in the seasonal pasture herd were also synchronized, and breeding seasons consisted of two 3-mo periods in late winter and late summer.

Managers of the 2 herds culled cows only involuntarily, except 8 cows were voluntarily sold in the seasonal pasture herd during third lactation or greater during the final year of the study. Cows in the confinement herd were allowed at least 6 mo of opportunity to become pregnant before a decision to cull was made. On the other hand, cows in the seasonal pasture herd were strictly culled if they did not become pregnant within 2 breeding seasons (6 mo of opportunity).

Production and SCS

Monthly test-day observations for twice-daily milking from milk recording (DHI) were used to estimate production. Standard edits used by the US Department of Agriculture for routine genetic evaluations were ap-

Table 2. Number of cows by herd, year, and breed group for first calving

Item	Breed		
	Pure Holstein	Montbéliarde × Holstein	Montbéliarde × Jersey/Holstein
Confinement herd (St. Paul, MN)			
2005	12	14	1
2006	14	12	11
2007	16	7	13
2008	14	0	14
2009	20	0	6
Seasonal pasture herd (Morris, MN)			
2006	18	14	8
2007	17	7	16
2008	20	1	11
2009	13	3	7
2010	19	1	4
Total	163	59	91

plied to test-day observations and were discussed in Hazel et al. (2013). The 305-d production and SCS was calculated with best prediction (Cole et al., 2009a), using all available individual test-day records for milk (kg), fat (kg), and protein (kg) production and SCS. Records less than 305 d were projected to 305 d, including records of cows with completed lactations of less than 305 d.

To estimate production and SCS, cows were required to have at least 1 test day, and 25 lactations of cows (11 MO-sired crossbred and 14 pure HO) without a test day were removed for analysis of production and SCS. Furthermore, 23 cows experienced spontaneous abortion, and the affected lactations (13 MO-sired crossbred and 10 pure HO) were also excluded from analysis for production and SCS. Lactations were assigned to groups of first, second, or third to fifth. At least 2 cows were required per breed of sire (MO-sired crossbred or pure HO) within each combination of herd, lactation number, year of calving, and breed of sire, and this stipulation removed 1 pure HO in second lactation and 3 MO-sired and 1 pure HO cow from third to fifth lactation.

Independent variables for the statistical analysis of 305-d milk, fat, and protein production, fat-plus-protein production, and SCS were the fixed effects of herd, lactation number, interaction of herd and lactation number, year of calving nested within interaction of herd and lactation number, breed of sire, MO × HO versus MO × JH nested within MO breed of sire (henceforth referred to as breed group), interaction of herd and breed group, interaction of lactation number and breed group, and 3-way interaction of herd, lactation number, and breed group. Lactational records were preadjusted for age at calving with best prediction. The MIXED procedure of SAS (SAS Institute, 2008) was

used to conduct the ANOVA and to obtain solutions, and cow nested within breed group was defined as a random variable.

Fertility

The CR was defined as the proportion of cows that became pregnant divided by the cows that were inseminated for the first time during each of their first 5 lactations. The result of first breeding was determined by (1) subsequent breeding, (2) palpation, or (3) subsequent calving. Cows that did not remain in the herd to be either rebred or palpated after first breeding were excluded from the analysis ($n = 8$). Similar to the production analysis, 2 cows were required per combination of herd, lactation number, year of calving, and breed of sire, and 1 MO-sired crossbred in third-to-fifth lactation and 1 pure HO cow in second lactation were removed, which resulted in 707 observations for CR available for analysis. Independent variables for the statistical analysis of CR were the same as those for analysis of production and SCS. A preliminary model included DIM at first breeding; however, the linear effect was not significant ($P = 0.96$) and, therefore, DIM was removed from the final analysis. The MIXED procedure of SAS was used to obtain the least squares means and the LOGISTIC procedure was used to determine significance of contrasts because CR was a binary trait.

The 599 observations for DO consisted of days from calving to pregnancy and all pregnancies were verified by palpation and, when possible, by subsequent calving ($n = 487$). Cows with DO greater than 250 d ($n = 131$) were set to 250 d (VanRaden et al., 2004), which is the method used for genetic evaluation in the United States. This maximum of 250 d favored the pure HO cows, because 34% of pure HO cows surpassed 250

DO whereas only 12% of MO-sired crossbred cows surpassed 250 DO. Cows were required to complete at least 250 DIM (VanRaden et al., 2004), and the number of observations for DO was less than observations for CR because 103 cows were bred at least once but did not remain in the herd for 250 d. Two cows were required per combination of herd, lactation number, year of calving, and breed of sire, and 6 MO-sired crossbred and 1 pure HO cow in second lactation were removed. Independent variables and methods for the statistical analysis of DO were the same as those used for analysis of production and SCS.

The PR is a group statistic used heavily in the United States for herd management and is defined as the number of cows that became pregnant divided by the number of cows eligible to become pregnant, where the denominator equals the cumulative days at risk for pregnancy divided by 21 (the length of an average estrous cycle; de Vries et al., 2005). To be included in the analysis of PR, cows were required to reach the end of the voluntary waiting period in their respective herd (57 DIM for the confinement herd and 60 DIM for the seasonal pasture herd). Days at risk was defined as days from the end of the voluntary waiting period for first breeding to (1) pregnancy, (2) decision to cull, or (3) exiting the herd. The numbers of lactational records analyzed for PR are different from DO, because PR includes cows that were culled or died between the end of the voluntary waiting period and 250 DIM. The PR was calculated independently for each combination of lactation number and breed group, and the PR for breed groups across lactations was also computed independently. The LIFETEST procedure of SAS was used to determine statistical significance of PR for breed groups within and across lactation number.

Mortality Rate and Survival

Mortality rate was defined as the number of cows that died or were euthanized divided by the total number of cows. Mortality was recorded in a binary manner as died (1) or sold (0), and cows coded as died also included cows that were euthanized. Seven MO-sired crossbreds and 10 pure HO cows were removed from the survival analysis because they did not spend their entire lives in 1 herd. Nine of these 17 cows were transferred from the seasonal pasture herd to the confinement herd after completion of either first or second lactation, and the other 8 cows were in third-or-later lactation in the seasonal pasture herd and were sold for dairy purposes. After exclusion of these 17 cows, 57 MO $\times$ HO, 86 MO $\times$ JH, and 153 pure HO cows remained for analysis of mortality rate. The analysis of mortality rate included 7 MO-sired crossbred and 6 pure HO cows that were

still in the herds at the cutoff of data for this study, and all of these cows were in fourth lactation or greater. These 13 cows were credited as eventually being sold alive, although their final status was unknown.

Independent variables for mortality rate included the effects of herd, breed of sire, breed group, and interaction of herd and breed group. The GLM procedure of SAS was used to obtain least squares means, and the LOGISTIC procedure of SAS was used to determine significance of contrasts because mortality rate was a binary trait.

Data for survival were recorded in a binary manner as calved (1) or did not calve (0) for a second, third, fourth, or fifth time. The 17 cows removed from the mortality analysis were also removed from the survival analysis. All cows were provided an opportunity to calve a third time, but some cows did not have an opportunity to calve a fourth or fifth time because data collection ceased in February 2013. Four MO-sired crossbreds and 17 pure HO did not have an opportunity to calve a fourth time. Additionally, 15 MO-sired crossbreds and 33 pure HO cows did not have an opportunity to calve a fifth time and, therefore, those cows were removed from the analysis for survival to fourth or fifth calving.

Independent variables for survival to subsequent calving included the effects of herd, breed of sire, breed group, and interaction of herd and breed group, and the GLM procedure of SAS was used to obtain least squares means. The LOGISTIC procedure of SAS was used to determine significance of contrasts for breed groups.

Longevity and Lifetime Production

The 17 cows removed from the mortality and survival analyses were also removed from the longevity and lifetime production analysis because they did not complete their entire lives in a single herd. Longevity during the first 4 yr (1,461 d) in the herd was defined as the total number of days in the herd from first calving to either (1) exiting the herd or (2) remaining in the herd at 1,461 d after first calving. Nineteen MO-sired crossbreds and 50 pure HO cows were removed from the analysis of longevity and lifetime production because data collection ceased in February 2013, and these cows did not have an opportunity to remain in the herds for 4 yr. A 4-yr maximum was imposed because almost all cows in this study had the opportunity to remain in the herd for 4 yr, and cows surviving beyond 4 yr (28% of MO $\times$ HO, 23% of MO $\times$ JH, and 16% of pure HO cows) were assigned a maximum of 1,461 d of longevity. The exclusions resulted in 53 MO $\times$ HO, 71 MO $\times$ JH, and 103 pure HO cows available for analysis of longevity and lifetime production across both herds.

For lifetime production, daily fat and protein production was calculated from best prediction for complete lactations (up to 999 DIM) using all available test days from milk recording. Cows with lactations shorter than 305 d were not projected to 305 d, and all production beyond 305 d was included. Daily production of fat and protein was summed across lactations, and days in the dry period were assigned 0 kg of production. Daily production of fat and protein beyond 1,461 d was excluded from the summed lifetime production.

The statistical analysis of longevity and lifetime fat-protein production had independent variables of herd, breed of sire, breed group, and interaction of herd and breed group as fixed effects. The GLM procedure of SAS was used to conduct the ANOVA and obtain least squares means.

Body Measurements

Trait Descriptions. The hip height (HH) was objectively measured from the ground to the sacrum, and measurements were obtained while cows were standing either in their stalls or in a chute. Cows in the confinement herd had HH measured once per lactation between 4 and 272 DIM. However, cows in the seasonal pasture herd were measured monthly throughout lactation. Observations in the seasonal pasture herd before 4 DIM and after 272 DIM were discarded, and the remainder of HH observations (up to 10 per cow) was averaged for each cow, resulting in 1 HH observation per lactation for each cow. The BCS was recorded by the same person within each combination of year of calving and herd on a 1-to-5 scale (1 = thin and 5 = obese) in increments of 0.25 (Ferguson et al., 1994). The BW and BCS were recorded during the p.m. milking every other week in the confinement herd between October 2005 and September 2008 and monthly thereafter. In the seasonal pasture herd, BW and BCS were recorded monthly during the a.m. milking for the entire collection period. Measurements for BW and BCS between 90 and 225 DIM were averaged for each cow, and this resulted in a single observation per lactation. To assess change in BW and BCS during lactations for breed groups, all available BW and BCS measurements from day of calving to 300 DIM were assigned to 30-d intervals (1 to 30 d, 31 to 60 d, 61 to 90 d, and so on), which resulted in up to 10 observations per cow that spanned the first 300 d of lactation. Measurements of heart girth (HG) were obtained once per lactation in both herds and were from 4 to 288 DIM.

Foot angle (FANGL) and hoof length (HL) were collected from the lateral claw of the rear hoof once per lactation while cows were standing on a level, concrete surface. The FANGL and HL were both measured on

the dorsal abaxial wall between the periople line and the point of toe (Hahn et al., 1984). The FANGL was the slope, and HL was the greatest distance between the periople line and the point of toe. Measurements for FANGL and HL were from 9 to 288 DIM, except for only 3 cows that calved late in the year of calving and were measured after 305 DIM.

Udder clearance (UC), front teat width (TW), and front teat length (TL) were objectively measured once per lactation. The UC was the distance between the lowest point of the udder floor and the ground, and TW was the inner distance between the front teats. The TL was the length of the front teat, unless TL appeared noticeably different between the 2 front teats. In that case, the length of both front teats was averaged to obtain a single TL measurement. All cows within each year of calving had udders measured within the same 3-h period relative to previous milking. Udders were measured from 4 to 288 DIM, except for 1 MO × JH and 1 pure HO cow that calved late in their respective year of calving and were measured after 305 DIM.

Editing and Analysis. Lactations from 3 to 5 were combined into a single lactation group for analysis, and observations in sixth-and-greater lactations were excluded for the analysis of all 9 body measurements. Additionally, 1 MO-sired crossbred and 1 pure HO cow in first lactation had HG observations beyond 305 DIM, and those 2 observations for HG were removed from the data. Cows were assigned to years of calving, and at least 2 cows per combination of herd, lactation number, year of calving, and breed of sire were required. Therefore, 1 pure HO cow in second lactation (for all 9 body measurements) and another 10 MO-sired crossbred and 1 pure HO cows from third-to-fifth lactation (only for HG, FANGL, HL, UC, TW, and TL) were removed from the data.

Statistical analysis for all 9 body measurements had the fixed effects of herd, lactation number, interaction of herd and lactation number, year of calving nested within interaction of herd and lactation number, breed of sire, breed group, interaction of herd and breed group, interaction of lactation number and breed group, and 3-way interaction of herd, lactation number, and breed group. Cow nested within breed group was defined as a random variable. A preliminary model considered the linear effect of DIM at time of measurement; however, this effect was not significant ($P > 0.05$) for HH, BW, BCS, HG, HL, and TL and was removed from all models so that a consistent model could be used for all 9 body measurement analyses. The MIXED procedure of SAS was used to conduct the ANOVA and obtain solutions.

For the independent analysis of each 30-d interval of BW and BCS, multiparous cows were combined into a

single lactation group. Cows were assigned to years of calving, and 2 cows were required for each combination of herd, lactation group, year of calving, and breed of sire. This edit resulted in the removal of 1 pure HO cow in first lactation during interval 7, and an average of 4 MO-sired cows and 1 pure HO cow in second-through-fifth lactations across 6 other intervals. Numbers of cows analyzed for BW and BCS intervals decreased throughout lactation because some cows left the herd before 300 DIM. The total number of observations analyzed in interval 1 were 175 for MO $\times$ HO, 223 for MO $\times$ JH, and 315 for pure HO, and the total number of observations in interval 10 were 110 for MO $\times$ HO, 150 for MO $\times$ JH, and 208 for pure HO. Statistical analysis for the intervals of BW and BCS had the fixed effects of herd, lactation group (primiparous or multiparous), interaction of herd and lactation group, year of calving nested within interaction of herd and lactation group, breed of sire, breed group, and interaction of lactation group and breed group. Cow nested within breed group was defined as a random variable. The MIXED procedure of SAS was used to conduct the ANOVA and obtain solutions.

RESULTS AND DISCUSSION

Production and SCS

The 305-d milk, fat, protein, and fat-plus-protein production differed for the 2 herds because of a difference in the energy content of the feed consumed by cows. Cows increased production with increasing lactation number in both herds, and most effects, including herd, lactation number, interaction of herd and lactation number year of calving nested within interaction of herd and lactation number, and interaction of herd and breed group, differed significantly for the production traits.

For 305-d fluid volume of milk, the 2-breed MO $\times$ HO crossbreds and the pure HO cows, respectively, were not significantly different for first (7,561 vs. 7,901 kg), second (9,142 vs. 9,179 kg), and third-to-fifth (9,949 vs. 10,012 kg) lactation across both herds. The MO $\times$ JH cows had significantly less ($P < 0.05$) fluid milk production than the pure HO cows during first (−781 kg), second (−420 kg), and third-through-fifth (−913 kg) lactation, and they also had significantly less ($P < 0.05$) milk volume than MO $\times$ HO cows during third-through-fifth lactation (−850 kg). Milk payment for both herds was based on kilograms of solids in the milk (Hazel et al., 2013), and milk with higher water content may result in a penalty after hauling charges are assessed (Cole et al., 2009b). Therefore, the potentially lower fluid volume of MO $\times$ JH crossbred cows

should not disqualify the Jersey breed for consideration for crossbreeding.

Production of fat plus protein across herds and lactation groups did not differ ($P = 0.30$) for MO $\times$ HO (585 kg), MO $\times$ JH (573 kg), and pure HO (585 kg) cows. Table 3 has fat-plus-protein production of breed groups by herd and lactation number. Across herds, MO $\times$ HO cows were never different from pure HO cows, and MO $\times$ JH cows were different ($P < 0.05$) from pure HO cows only for fat-plus-protein production during first lactation (495 and 518 kg, respectively). These results are consistent with Walsh et al. (2008), who observed that production of milk, SCM, fat, and protein did not significantly differ for MO $\times$ HO and pure HO cows. Heins and Hansen (2012) observed 3% less fat-plus-protein production for MO $\times$ HO compared with pure HO cows. However, they pointed out the MO-sired cows were disadvantaged because the mean rank of sires within breed for production EBV was lower for MO bulls compared with pure HO bulls in that study.

The interaction of herd and breed group was significant for fat-plus-protein production ($P = 0.02$) in this study, and MO $\times$ JH cows were more similar to pure HO for fat-plus-protein production in the seasonal pasture herd than in the confinement herd. Crossbreds containing Jersey are often viewed favorably in environments that permit use of pasture because JH crossbred cows have greater fat content of their milk, enhanced fertility and calving ability, and superior profitability compared with pure HO cows (Lopez-Villalobos et al., 2000; Dillon et al., 2007; Pyman, 2007). However, Heins et al. (2011) reported that JH cows had shortcomings in a high-production herd due to lower kilograms of fat-plus-protein production during second and third lactation and greater culling for udder conformation for JH compared with pure HO cows. Vance et al. (2012) compared JH and pure HO cows in a confinement versus a pasture-based system, and interaction of breed group and management system was significant only for milk production. Other studies, which investigated milk, fat, and protein production, SCS, and calving interval, concluded that expression of heterosis is usually similar across levels of nutritional or management intensity (Walsh et al., 2008; Kargo et al., 2012; de Haas et al., 2013; Vance et al., 2013).

The MO-sired crossbred cows (2.80) tended ($P = 0.08$) to have lower SCS than pure HO cows (3.02) across the first 5 lactations and across herds. Interaction of herd and breed group was not significant ($P = 0.27$). Breed groups were similar for SCS during first (2.85, 2.83, and 2.78), and third-through-fifth (3.05, 3.13, and 3.42) lactations for MO $\times$ HO, MO $\times$ JH, and pure HO cows, respectively. In second lactation,

Table 3. Least squares means and SE for 305-d fat-plus-protein production (kg) for breed groups

Herd and lactation number	Pure Holstein			Montbéliarde × Holstein			Montbéliarde × Jersey/Holstein		
	n	LSM	SEM	n	LSM	SEM	n	LSM	SEM
Both herds									
1	162	518 ^a	6.1	59	509 ^{ab}	10.9	90	495 ^b	8.4
2	107	596 ^a	7.3	47	603 ^a	12.2	73	601 ^a	9.3
3–5	72	641 ^a	9.4	77	643 ^a	10.8	82	623 ^a	9.7
Across lactations	341	585 ^a	5.5	183	585 ^a	8.6	245	573 ^a	6.8
Confinement herd (St. Paul, MN)									
1	76	622 ^a	8.8	33	606 ^{ab}	14.7	45	580 ^b	11.9
2	61	687 ^a	9.7	27	676 ^a	16.0	39	666 ^a	12.6
3–5	43	742 ^a	11.9	51	714 ^{ab}	12.9	38	704 ^b	13.9
Across lactations	180	684 ^a	7.4	111	665 ^{ab}	11.0	122	650 ^b	9.5
Seasonal pasture herd (Morris, MN)									
1	86	413 ^a	8.3	26	411 ^a	16.0	45	411 ^a	11.7
2	46	506 ^a	10.9	20	530 ^a	18.3	34	537 ^a	13.5
3–5	29	540 ^a	14.2	26	571 ^a	17.0	44	542 ^a	13.3
Across lactations	161	486 ^a	8.0	72	504 ^a	12.9	123	497 ^a	9.6

^{a,b}Means within a row with different superscript letters differ ($P < 0.05$).

however, MO × HO cows (2.37) had lower ($P < 0.05$) SCS than MO × JH (2.57) and pure HO (2.87) cows. The results are similar to those of Heins and Hansen (2012), who reported that MO × HO had lower ($P < 0.05$) SCS during first, fourth, and fifth lactations compared with pure HO cows.

Fertility

Year of calving nested within herd and lactation number was the only statistically significant effect among the non-breed effects for both CR and DO. The CR and DO were not different ($P = 0.09$ and 0.10 , respectively) between the 2 herds, which was not surprising because timed AI synchronization was used for all AI services in the confinement herd and most cows were AI bred from synchronized standing heats in the seasonal pasture herd. For breed groups, MO × HO and MO × JH cows had significantly ($P < 0.01$) higher CR and fewer DO (Table 4) than pure HO cows, and the magnitude of the advantage was about 20% higher CR and 5 to 6 wk fewer DO. Kearney et al. (2004) reported heterosis for fertility was expressed similarly across various management systems. Results from the current study support

Kearney et al. (2004), because the interaction of herd and breed group was not significant for either CR or DO ($P > 0.08$) and MO-sired crossbred cows had large advantages for CR and DO in both herds.

The MO-sired crossbreds also had a pronounced advantage ($P < 0.01$) over the pure HO cows for PR across herds (Table 5). The MO × HO had an advantage of +8.7% to +13.9% greater PR, and MO × JH cows had +10.3% to +16.3% greater PR versus pure HO cows across lactation groups. Across all lactations of cows, the MO × HO (2-breed) and the MO × JH (3-breed) crossbreds had significantly ($P < 0.01$) greater PR (+10.8 and +12.8%, respectively) than pure HO cows, and the PR of the MO-sired crossbreds was almost double the PR of the pure HO cows in this study.

An advantage of PR as a measure of fertility is its ability to capture the pregnancy status of cows as they complete lactations. In this study, 17% of MO-sired crossbred and 32% of pure HO lactations ended without a pregnancy because they either left the herd without a confirmed pregnancy or were involuntarily culled for fertility. Differences of this magnitude for CR, DO, or PR of cows in both herds could contribute to improved profitability, because MO-sired crossbred cows were less

Table 4. Least squares means and SE for first-service conception rate (CR) and days open (DO) across lactations and herds for breed groups

Trait	Pure Holstein			Montbéliarde × Holstein			Montbéliarde × Jersey/Holstein		
	n	LSM	SEM	n	LSM	SEM	n	LSM	SEM
CR (%)	312	26.9 ^a	4.20	172	45.1 ^b	4.43	223	49.9 ^b	3.68
DO (d)	259	167 ^a	5.2	154	128 ^b	7.1	186	124 ^b	6.0

^{a,b}Means within a row with different superscript letters differ ($P < 0.05$).

Table 5. Pregnancy rate¹ (% , with number of lactations in parentheses) for breed groups

Lactation number	Breed		
	Pure Holstein	Montbéliarde × Holstein	Montbéliarde × Jersey/Holstein
1	12.0 ^a (161)	21.7 ^b (59)	28.3 ^b (85)
2	10.9 ^a (104)	19.6 ^b (48)	21.2 ^b (72)
3–5	13.4 ^a (68)	27.3 ^b (72)	24.9 ^b (78)
Combined	12.1 ^a (333)	22.9 ^b (172)	24.9 ^b (235)

^{a,b}Means within a row with different superscript letters differ ($P < 0.05$).

¹Pregnancy rate = the number of cows that became pregnant divided by the number of cows eligible to become pregnant during a 21-d estrous cycle.

frequently culled for infertility and had shorter calving intervals than pure HO cows. If each additional DO is assigned a loss of \$1.50 (Cole et al., 2009b), the 39-d fewer DO of MO × HO and the 43-d fewer DO of MO × JH cows provides a profit advantage of \$58.50 and \$64.50, respectively, per lactation from fertility.

Mortality Rate and Survival

The confinement herd (14.8%) and the seasonal pasture herd (11.2%) experienced a similar ($P = 0.61$) mortality rate across breed groups; however, seasonal pasture herds typically have reduced death loss compared with other housing systems (Burow et al., 2011; Dechow et al., 2012; Mee, 2012), and this may be because exercise improves the general health of cows (Gustafson, 1993). Mortality rate for the seasonal pasture herd in this study may have been greater than expected because (1) mortalities due to injury may have been higher than for most seasonal pasture herds and (2) some cows were likely euthanized that may have otherwise been acceptable for slaughter because of high hauling cost to the nearest cattle market.

Breed of sire was the only significant effect for mortality rate in the present study. The odds ratios from logistic regression analysis revealed that pure HO cows were 2.1 times more likely to die on farm than MO-sired crossbred cows during their lifetimes. The MO × HO (5.1%) had significantly lower ($P < 0.05$) mortality rate than pure HO (17.7%) cows (Table 6). However, MO × JH (11.7%) were not statistically different from pure HO cows because standard errors for MO × JH were large.

The 17.7% mortality rate for pure HO in this study is comparable to the 16.5% reported by Dechow and Goodling (2008) and the 20.6% found by Pinedo et al. (2010). For national US data, death of cows are likely underreported because some herds fail to report cows that die before their first test day (Heins et al., 2012a). Mortality represents a significant loss of income for dairy producers because salvage value is lost, carcass disposal is costly, future production is lost, and heifer replacement costs may not be recovered (Heins et al., 2012a; Pritchard et al., 2013).

For survival to subsequent calving, significantly ($P < 0.04$) more cows survived to second, third, and fourth calving for the confinement herd than for the seasonal pasture herd. The difference in survival was likely due to the more stringent culling for fertility of the seasonal pasture herd compared with the confinement herd. For statistical contrasts of the breed groups, MO × HO (81%) and MO × JH (81%) cows tended ($P < 0.09$) to have greater survival to second calving than pure HO (68%) cows (Table 6). However, both groups of MO-sired crossbred cows had greater ($P < 0.01$) survival to all of the subsequent lactations than pure HO cows (Table 6). Significantly ($P < 0.01$) more pure HO cows survived to second calving in the confinement herd than in the seasonal pasture herd (83 vs. 53%, respectively), and a similar result was observed ($P = 0.03$) for survival of pure HO cows to third calving

Table 6. Least squares means and SE for mortality rate¹ and survival to subsequent calving² for breed groups

Trait	Pure Holstein			Montbéliarde × Holstein			Montbéliarde × Jersey/Holstein		
	n	LSM (%)	SEM (%)	n	LSM (%)	SEM (%)	n	LSM (%)	SEM (%)
Mortality rate	153	17.7 ^a	2.8	57	5.1 ^b	4.6	86	11.7 ^{ab}	3.7
Survival to subsequent calving									
Second	153	68.1 ^a	3.4	57	81.4 ^a	5.6	86	81.2 ^a	4.5
Third	153	31.4 ^a	3.9	57	58.3 ^b	6.4	86	51.1 ^b	5.2
Fourth	136	14.2 ^a	3.7	56	42.5 ^b	5.8	83	34.7 ^b	4.7
Fifth	103	6.4 ^a	3.7	53	26.7 ^b	5.8	71	20.2 ^b	4.7

^{a,b}Means within a row with different superscript letters differ ($P < 0.05$).

¹Mortality rate = number of cows died or euthanized divided by total number of cows.

²Survival to subsequent calving = number of cows that calved divided by the number of cows with opportunity to calve for a subsequent lactation.

Table 7. Least squares means and SE for body measurements across lactations and herds for breed groups

Trait	Pure Holstein			Montbéliarde × Holstein			Montbéliarde × Jersey/Holstein		
	n ¹	LSM	SEM	n ¹	LSM	SEM	n ¹	LSM	SEM
Hip height (cm)	326	144.5 ^a	0.3	178	144.3 ^a	0.5	233	139.5 ^b	0.4
BW (kg)	320	572 ^a	4.2	176	611 ^b	6.6	226	554 ^c	5.3
BCS	320	2.87 ^a	0.02	176	3.36 ^b	0.03	226	3.33 ^b	0.03
Heart girth (cm)	309	197.7 ^a	0.6	166	198.2 ^a	0.9	216	191.4 ^b	0.7
Foot angle (°)	311	43.6 ^a	0.3	164	45.4 ^b	0.5	215	43.7 ^a	0.4
Hoof length (cm)	311	8.0 ^a	0.05	164	7.8 ^b	0.07	215	7.9 ^{ab}	0.05
Udder clearance ² (cm)	309	51.6 ^a	0.4	167	49.0 ^b	0.6	217	46.9 ^c	0.5
Front teat width (cm)	309	14.6 ^a	0.3	167	16.9 ^b	0.5	217	17.5 ^b	0.4
Front teat length (cm)	309	4.9 ^a	0.07	167	5.1 ^a	0.11	217	5.1 ^a	0.09

^{a-c}Means within a row with different superscript letters differ ($P < 0.05$).

¹n = number of lactations.

²Udder clearance = distance from ground to udder floor.

(40 vs. 23%, respectively) for the 2 herds. The reduced survival of pure HO cows in the seasonal pasture herd appeared to be heavily influenced by the poor fertility of pure HO cows. When MO × HO and pure HO cows were compared in a pasture environment by Walsh et al. (2008), the pure HO cows survived only 1.9 lactations, compared with 3.8 lactations for MO × HO cows. Washburn (2009) suggested that the poor survival of pure HO cows in pasture herds may be the driving factor for the increased use of crossbreeding among pasture herds in the United States.

Longevity and Lifetime Production

Longevity of cows is an important factor in profit calculations, because a large expense for dairy herds is growing replacement heifers. The MO × HO cows in the present study had longevity of 973 d compared with 747 d for pure HO cows across herds when a 4-yr maximum for survival after first calving was enforced. For that 4-yr interval, MO × HO cows had significantly greater ($P < 0.01$) lifetime fat-plus-protein production than the pure HO cows (1,609 vs. 1,201 kg), which was anticipated because the MO × HO cows calved more frequently during their lifetimes and, consequently, had more days at peak production. The MO × JH cows had greater ($P < 0.05$) longevity (884 d) than pure HO cows (746 d), but fat-plus-protein production (1,389 kg) was similar to pure HO cows (1,201 kg) during the same 4-yr period after first calving. The MO-sired crossbreds had a greater number of calves born, because they calved more frequently than pure HO cows. Results from this study emulate those of Heins et al. (2012a), who reported that MO × HO cows had +213 d greater longevity and +401 kg of fat plus protein when data was limited to the first 4 yr in the herd. Walsh et al. (2008) reported that median days of longevity were

+690 d greater and +1.9 lactations longer for MO × HO compared with pure HO cows.

Body Measurements

HH, BW, BCS, and HG. Lactation number, year of calving nested within herd and lactation number, and breed group differed significantly ($P < 0.01$) for HH. For breed groups across herds (Table 7), MO × HO did not differ from pure HO for HH during any lactation number or across lactations. However, MO × JH cows had significantly ($P < 0.01$) shorter HH than either MO × HO or pure HO cows for first, second, and third-through-fifth lactations. The shorter HH of MO × JH cows was expected because Heins et al. (2011) reported that JH cows had 8.8 to 9.4 cm shorter HH than pure HO cows during their first 3 lactations.

All effects of herd, lactation number, their interaction, year of calving nested within herd and lactation, and breed group differed significantly for BW. Across breed groups, cows in the confinement herd had greater BW in first (+66 kg), second (+44 kg), and third-through-fifth (+66 kg) lactation than cows in the seasonal pasture herd, and this was likely a result of the greater energy level of diets fed to cows in the confinement herd. The MO × HO had significantly greater ($P < 0.01$) BW across lactations compared with pure HO cows (Table 7) and also within each lactation number. However, the MO × JH cows were not different ($P = 0.25$) from pure HO cows for BW in first lactation, tended ($P = 0.08$) to be heavier in second lactation (+25 kg), and were significantly lighter (−30 kg) than pure HO in third-to-fifth lactations. Across lactations, the MO × JH cows had less BW than either MO × HO or pure HO cows. The interaction of lactation number and breed group was not significant ($P = 0.07$), and least squares means of BW for breed groups by lactation number revealed

that MO $\times$ HO, MO $\times$ JH, and pure HO cows all had similar increases from first to second lactation (+59, +52, and +58 kg, respectively) and also from second lactation to third-through-fifth lactations (+52, +38, and +53 kg, respectively). Therefore, breed groups appeared to increase in BW at similar rates during their lifetimes.

For the analysis of BW for the 10 intervals across lactation, MO $\times$ HO cows had significantly ($P < 0.01$) greater BW than MO $\times$ JH and pure HO cows in all 10 intervals for both primiparous and multiparous lactation groups. On the other hand, MO $\times$ JH cows were not different from pure HO in any interval for first lactation and, in second-and-later lactations, MO $\times$ JH cows had significantly ($P < 0.05$) less BW than pure HO cows during intervals 1, 3, 4, 5, 7, and 8. All contrasts for BW between breeds for each of the first 4 intervals were conducted within each lactation group (36 comparisons in total) to assess rate of loss in BW during early lactation, and 35 of those contrasts were nonsignificant ($P > 0.05$). Therefore, results from this study suggest that MO $\times$ HO cows carried greater BW throughout their lactations compared with both the MO $\times$ JH and pure HO cows. However, lactation curves for BW did not differ in shape for the breed groups.

Among the fixed effects for BCS, only herd, interaction of herd and lactation number, year of calving nested within herd and lactation number, and breed group differed significantly ($P < 0.01$). Cows in the seasonal pasture herd had lower BCS (3.00) than cows in the confinement herd (3.21) across lactations and breed groups, which was likely the cause of the lower BW for cows in the seasonal pasture herd. The MO $\times$ HO (3.36) and MO $\times$ JH crossbred cows (3.33) had greater BCS than pure HO cows (2.87) across herds and lactations (Table 7), and the MO $\times$ HO and MO $\times$ JH cows had significantly greater ($P < 0.01$) BCS than pure HO cows during each lactation. For the 10 intervals of BCS throughout lactation, the MO-sired crossbred cows had significantly ($P < 0.01$) greater BCS in every interval for both primiparous and multiparous lactation groups. The MO $\times$ HO in second-and-greater lactations had significantly ($P < 0.05$) greater BCS than MO $\times$ JH cows only during intervals 3, 8, and 10. Change in BCS during the first 4 intervals was compared between the 3 breed groups, but 34 of 36 contrasts were not significantly different ($P > 0.05$). Results from change in BCS during early lactation reveal that all cows lost BCS in early lactation, which agrees with results of Walsh et al. (2008). The rate of loss of BCS was similar for breed groups, and MO-sired crossbreds maintained greater BCS throughout lactation because they had greater precalving BCS.

Perhaps, the greater BCS of MO-sired crossbred cows partially explains the substantial advantages for fertility and survival of MO-sired crossbred cows over pure HO cows in this study, because the relationships of BCS with both fertility and health have been well documented within the HO breed (Zwald et al., 2004; Banos and Coffey, 2010). Mendonça et al. (2013) credited heterosis, breed differences, or both of these factors for the improved immunity and decreased incidence of health disorders of MO-sired crossbred versus pure HO cows. However, the greater BCS of MO-sired crossbreds compared with pure HO cows could also be a contributing factor to the improved health and fertility of MO-sired crossbreds because greater BCS is linked to enhanced health and fertility in observations of pure HO cows (Pryce et al., 2001; Loker et al., 2012).

For HG, the fixed effects of herd, lactation number, year of calving nested within herd and lactation, breed group, and interaction of lactation number and breed group were all significant ($P < 0.01$). Least squares means of HG for cows in the confinement herd (198.9 cm) were significantly ($P < 0.01$) larger than for cows in the seasonal pasture herd (193.6 cm), and HG of cows increased with lactation number, as expected. Across lactations, MO $\times$ HO and pure HO cows did not differ for HG ($P > 0.31$; Table 7) despite the significantly ($P < 0.01$) greater BW of MO $\times$ HO cows during all lactations. On the other hand, HG of MO $\times$ JH was smaller ($P < 0.01$) than both MO $\times$ HO and pure HO cows across lactations (Table 7). The lack of difference in HG of MO $\times$ HO and pure HO cows and the smaller HG of MO $\times$ JH cows was surprising because BW and HG often have high correlation within the HO breed. Perhaps, proportionality of body dimensions differ for MO-sired crossbred cows versus pure HO cows.

FANGL and HL. For FANGL and HL, almost all fixed effects in the model differed significantly ($P < 0.05$). Time on pasture is beneficial for hoof conformation and health (Haskell et al., 2006) and, as expected, cows in the seasonal pasture herd had both steeper FANGL (+1.4°) and shorter HL (−0.11 cm) than cows in the confinement herd. The MO $\times$ HO had significantly ($P < 0.01$) steeper FANGL (+1.8°) and significantly ($P < 0.01$) shorter HL (−0.2 cm) than the pure HO cows across lactations (Table 7). The MO $\times$ JH were not different ($P > 0.16$) for either FANGL or HL compared with pure HO cows. However, among the MO-sired crossbreds, MO $\times$ HO had significantly ($P < 0.05$) steeper FANGL (+1.7°) than MO $\times$ JH cows, which was not surprising because FANGL of the JH crossbred dams of cows in the current study was −1.3 to −1.8° lower than the pure HO cows (Heins et al., 2011). Dairy producers perceive cows with steeper FANGL to have fewer hoof disorders, but the correlation between

hoof disorders and feet and leg conformation is often nonsignificant (Häggman and Juga, 2013). Therefore, future comparisons of MO-sired crossbred and pure HO cows should focus on incidence of lameness and hoof disorders rather than hoof measurements.

Udder. The effects of lactation number, interaction of herd and lactation number, and year of calving nested within herd and lactation number were significant ($P < 0.05$) for all udder measurements, except interaction of herd and lactation number was not significant for TL. The fixed effect of herd was significant only for TW, and cows in the confinement herd had greater distance for TW (+2.1 cm) compared with cows in the seasonal pasture herd. The greater TW for cows in the confinement herd was likely a result of the higher production levels of those cows because they were fed a TMR diet year-round, whereas the cows in the seasonal pasture herd were on pasture during summer when udder measurements were collected.

The MO-sired crossbreds had significantly less UC than the pure HO cows during each lactation and, across lactations, the MO $\times$ HO (−2.6 cm) had significantly ($P < 0.01$) less UC than pure HO cows (Table 7). The MO $\times$ JH had significantly ($P < 0.03$) less UC than both the MO $\times$ HO and pure HO cows (−2.1 and −4.7 cm, respectively) across lactations. Interaction of lactation number and breed group was not significant ($P = 0.72$) for UC; therefore, regardless of breed group, udders became deeper with increasing lactation number at approximately the same rate. Only a single cow from each of the 3 breed groups was culled for udder conformation in this study, but more MO $\times$ HO and MO $\times$ JH cows survived to third, fourth, and fifth calvings than pure HO cows. Consequently, evidence did not exist to suggest that the −3.8-cm less UC of MO-sired crossbreds across lactations and breed groups resulted in increased culling of cows. Conversely, Heins et al. (2011) reported that the −8.5 to −9.0 cm less UC of JH cows during second and third lactations caused significantly more JH cows to be culled for udder conformation than pure HO cows in that study.

The TW was significantly greater for both MO $\times$ HO (+2.3 cm) and MO $\times$ JH (+2.9 cm) across lactations than the pure HO cows. However, TL was not significantly different for MO $\times$ HO and MO $\times$ JH versus pure HO cows (Table 7). Traditionally, dairy producers have selected cows with greater UC and less TW (Miglior et al., 2005; Shook, 2006), and significant selection for udder conformation of pure HO cows has resulted in shallower udders and closer front and rear teat placement for first-lactation cows (Shook, 2006; VanRaden et al., 2009). However, rear teats that are too close are a concern for milking ability, especially for the increasing number of cows milked with robotic sys-

tems. Miller et al. (1995) reported 12% of first-lactation pure HO cows that were milked by a robotic milking system had failure of cluster attachment due to close rear teat placement.

CONCLUSIONS

The MO-sired crossbred cows in this study did not significantly differ from pure HO cows for fat-plus-protein production across herds and lactations. The similar production for the breed groups may have resulted from genetic improvement within the HO and MO breeds, heterosis when breeds are crossed, or a combination of these 2 factors. More importantly, the MO-sired crossbreds were much superior to pure HO cows for fertility, mortality rate, survival to subsequent calving, and longevity. Some of the superiority for fertility and longevity of the MO-sired crossbreds compared with pure HO cows in this study may have resulted from the greater BCS of the MO-sired crossbreds. A breeding objective of the MO breed in France has continuously been to place emphasis on maintaining BCS, which is contrary to the breeding objective of the HO breed to increase angularity. Results of this study indicated that MO-sired crossbred cows had similar production to pure HO cows, but the MO-sired crossbred cows had advantages over pure HO cows for fertility, survival, and longevity in both a confinement and a seasonal pasture herd. Three-breed rotational crossbreeding using purebred bulls from distinct dairy breeds is the most common approach currently being recommended and used for commercial milk production. The 3 breeds must be complementary to each other, and they must be well suited to specific management systems. The alternative combinations of dairy breeds for crossbreeding have not yet been examined across management systems and warrant further research.

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