MONTBELIARDE-SIRED CROSSBREDS COMPARED WITH PURE HOLSTEINS FOR FEED INTAKE, PRODUCTION, FERTILITY, SURVIVAL, AND BODY MEASUREMENTS

A THESIS
SUBMITTED TO THE FACULTY OF
UNIVERSITY OF MINNESOTA
BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

ADVISOR LESLIE B. HANSEN

MAY, 2013

Our deep respect for the land and its harvest
is the legacy of generations of farmers
who put food on our tables,
preserved our landscape,
and inspired us with a powerful work ethic.

−James H. Douglas

ACKNOWLEDGEMENTS

The support, guidance, and understanding of many colleagues and friends have made this research possible and made my time at the University of Minnesota enjoyable.

Thank you to my advisor, Dr. Les Hansen, for your guidance and patience with me throughout my Master's program and also my undergraduate years. I have learned so much from you about scientific method, crossbreeding, and dairy cattle breeding; but also, you have helped me grow in other ways, such as writing composition, public speaking, debating skills, and "seeing the forest for the trees". I feel lucky to have received many travel and conference opportunities during my program. Our chats about the dairy industry, workings of the University, and politics will always be memorable!

I also express appreciation to my committee members, Dr. Tony Seykora and Dr. Galin Jones, and the co-authors of my research projects: Dr. Brad Heins and Dr. Dennis Johnson. All of you have contributed valuable ideas and assistance to the design, collection of data, and analysis of this research. I also appreciate the opportunity that Dr. Seykora has given me to teach and interact with undergraduates.

A special thank you to my former officemates: Brad Heins, Stefan Blöttner, and Jennifer Becker for helping me with projects, data collection, the valuable discussions, and your comradeship! Many other current and former graduate students and friends have also assisted me with blood collection, blood processing, and measuring cows, and I wish to thank Greg Golombeski, Jamie Larson, Eb Ballinger, Karen Lobeck, Erika Shane, Bob Leuer, Elizabeth Bjorklund, Adam Husefeldt, and Amber Hazel for their time and effort. I also thank the numerous graduate students in the Department of Animal Science for their friendship.

The assistance of Bill Hansen and staff at the St. Paul dairy and Darin Huot and staff at the Morris dairy have provided much assistance with collection of data and care of animals, and I thank them for their role in my research projects.

My research would not have been possible without the supplemental financial support of Coopex Montbéliarde, and I especially thank Stéphane Fitamant for supporting our research efforts and for the invitations to visit Montbéliarde herds and shows in France. My international travel opportunities have been a highlight of my graduate program.

I wholeheartedly appreciate the never-ending love, support, and prayers from my parents, Brian and Judy, and my siblings, Amber and Adam. I especially thank my Dad for providing a dairy farmer's perspective on my research ideas. I praise the Lord God for the blessings he has provided me in life and worship Him eternally.

ABSTRACT

Crossbreeding was initiated in two institutional herds of the University of Minnesota in 2000. Montbeliarde (MO)-sired progeny of pure Holstein (HO) and Jersey × HO crossbred (JH) cows along with pure HO cows calved for the first time from 2005 to 2010 in both herds.

Montbeliarde (MO)-sired crossbred cows (n = 57) were compared with pure Holstein (HO) cows (n = 40) for dry matter intake (DMI), production, hip height, body condition score (BCS), and body weight (BW) during the first 150 d of first lactation. Also, production for 305 d was compared for first lactation. This subset of cows from the larger crossbreeding study were housed at the University of Minnesota St. Paul dairy and calved from 2005 to 2007. The MO-sired crossbred cows were composed of MO × HO cows (n = 33) and MO × Jersey/HO cows (n = 24). Cows were individually fed a total mixed ration twice daily. The DMI was measured for the first 150 d of lactation, except DMI was not recorded from d 1 to 3 postpartum to permit cows to acclimate to stalls in a confinement barn. Hip height was measured once between 20 and 172 d postpartum, and BCS and BW were recorded every other week. The MO-sired crossbred cows did not differ from the pure HO cows for 150-d DMI, 150-d fat plus protein production, or for 305-d fat plus protein production. Hip height was similar for MO × HO and pure HO cows, but MO × Jersey/HO cows had shorter hip height than the pure HO cows. Despite the lack of difference for DMI, the MO-sired crossbred cows had significantly greater BCS (3.30 vs. 2.74) and BW (551 kg vs. 528 kg) than the pure HO cows. The MO-sired crossbred cows (122 d) had fewer days open than the pure HO cows (150 d). The higher

BCS of the MO-sired crossbred cows, especially during early lactation, may have provided an advantage for fertility. Differences for DMI between breed groups were not studied for the latter half of first lactation or for multiparous cows.

Subsequently, Montbeliarde (MO)-sired crossbred cows (n = 150) were compared with pure Holstein (HO) cows (n = 163) for production, somatic cell score (SCS), fertility, survival to subsequent calving, mortality, and body measurements during their first five lactations. The MO-sired crossbreds cows consisted of MO × HO cows (n = 59) and MO × (Jersey/HO) cows (n = 91) and were housed in either a high-input, confinement herd (St. Paul) or a low-input, grazing herd (Morris). Body, hoof, and udder measurements of cows were objectively measured. The MO × HO crossbred cows were not different for fat plus protein production during any lactation and had significantly lower SCS during second lactation compared with the pure HO cows. However, the MO × (Jersey/HO) crossbred cows had 5% lower fat plus protein production with similar SCS compared with pure HO cows at St. Paul. On the other hand, the MO × (Jersey/HO) crossbred cows were not different for fat plus protein production and had lower SCS in third to fifth lactation compared with pure HO cows at Morris. Across herds, the MO-sired crossbred cows had 41 fewer days open and 12% higher pregnancy rate compared with the pure HO cows. Furthermore, the MO-sired crossbred cows (8%) had lower mortality rates than the pure HO cows (18%). Because of superior fertility and lower mortality rates, the MO-sired crossbred cows had greater survival to second (+13%), third (+24%), fourth (+25%), and fifth (+17%) calving in comparison to 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 than pure HO cows during first (+39 kg), second (+80 kg), and third to fifth (+39 kg) lactations. The MO × (Jersey/HO) had more body condition but shorter hip height than pure HO cows, and this resulted in less body weight across the first five lactations. The additional body condition of MO-sired crossbred cows may likely provide an advantage for fertility. Foot angle was steeper and hoof length was shorter for MO × HO cows, but MO × (Jersey/HO) cows were similar to pure HO cows for hoof measurements. The MO-sired crossbred cows had 3.6 cm less udder clearance and 2.6 cm greater front teat width than pure HO cows.

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INTRODUCTION

Greater input and labor costs, coupled with inflation-adjusted decreases in milk price, have caused dairy producers to seek dairy cows that have greater profitability. During most of the 20th century, dairy producers have been able to increase profit by increasing production per cow; therefore, the majority of the genetic advancement of dairy cattle was focused on within-breed selection for greater milk production.

Selection Indices in the United States

The United States Department of Agriculture (**USDA**) began collection of milk and fat records around 1885 (USDA-AIPL, 2013b). In 1971, USDA introduced the first genetic-economic index in the United States (**US**) called predicted difference dollars, and this index had 52% of selection emphasis on milk and 48% on fat (Cole et al., 2009b). The USDA has continued to calculate economic-based indices, later referred to as lifetime net merit (**NM$**), and NM$ has undergone 7 revisions since its inception. The most noteworthy additions included longevity and SCS in 1994; body size (negative emphasis), udder, and feet and leg composites in 2000; and fertility and calving traits in 2003 (Cole et al., 2009b).

The Total Performance Index (**TPI**) for the Holstein (**HO**) breed in the United States was first published by Holstein Association USA in 1976 and included only milk production and final score for conformation (VanRaden, 2002). The TPI has historically emphasized conformation to a greater extent than NM$, and final score for conformation has held between 10 and 40 percent of the emphasis in TPI over time. Furthermore, the conformation categories of body size, udder, and feet and leg composites have had varying degrees of emphasis, and some health and fertility traits were included in recent years (VanRaden, 2002; Holstein USA, 2013). Unlike NM$, which was an economic index calculated using revenue and expense assumptions for commercial dairy cows, TPI has traits of importance and their relative weights determined by a genetic advancement committee comprised of registered HO breeders. According to a 2010 resolution passed by the Holstein Association USA delegates, the committee was charged to "devise an index based on breeders' desires for a balance of type and production" (Holstein USA, 2013).

Results of Genetic Selection in Pure Holsteins

To document the impact of selection for milk production over time, the University of Minnesota initiated a selection experiment in 1964 (Hansen, 2000). The designed study established a control line of cows that were continuously mated to HO AI bulls. The AI sires for the control line were near the breed mean for PTA milk (kg) in 1964. The selection line was mated to the 4 highest bulls for PTA milk on an annual basis. In later years, selection criterion was altered to PTA protein production (kg). After 34 yr of the study, phenotypic milk production for the selection line increased dramatically compared with the control line (10,959 kg versus 6,454 kg, respectively). Furthermore, selection line cows had +282 kg greater fat plus protein production than control line cows with similar SCS. In the same study, changes in linear type scores (on a 50-point scale) were documented in 1986 and again in 1999. Among the traits measured, the increases in dairy form (+19 points), body size (+10 to +12 points), and rear udder traits (+10 to +13 points) were most profound. The health care costs for selection line cows were $25 greater in first lactation and $49 greater across the first five lactations compared with control line cows. Hansen (2000) concluded that emphasis on angularity in addition to production may result in greater predisposition to metabolic problems.

Holstein cows currently predominate in most temperate regions of the world because they have the greatest phenotypic production among the pure breeds. Genetic trends of pure HO cows were documented by USDA from national data (USDA-AIPL, 2013a), and USDA reported an increase in phenotypic milk production of 6,388 kg for cows in DHIA from 1960 to 2011. The increase in breeding value of cows for milk production was almost linear from 1970 to 2011 and averaged about +85 kg per year. Simultaneously, fertility declined, and phenotypic daughter pregnancy rates for pure HO cows dropped from 30% in the early 1960s to a low of 21% in 2000. Lucy (2001) also documented a decrease in reproductive efficiency over time, and cows with the greatest milk production also had the highest incidence of infertility.

Miglior et al. (2005) studied 17 national HO selection indices used in 15 countries in 2003, and they reported selection in most countries shifted from heavy emphasis on production toward greater emphasis on durability (longevity and conformation) and fertility and health. For example, the Danish S-Index had emphasis of 34% production, 29% durability, and 37% fertility and health, and authors cited reasons for the shift may include quota-based milk marketing, increase in labor costs, and producer and consumer concerns regarding the deterioration of health and fertility of cows (Miglior et al., 2005).

Inbreeding and Heterosis

Researchers at USDA-AIPL (2013c) reported the rate of increase of inbreeding coefficient among pure HO cows in the US has been steady at +0.1% annually for the past decade and currently is estimated at 5.99% for pure HO cows born in 2013 (USDA-AIPL, 2013c). Falconer and Mackay (1996) stated selection of any degree will inevitably lead to increased inbreeding, because most selection is carried out in a finite population. Inbreeding depression reduces the rate of response when selection is imposed, and it also increases the rate of deterioration for negatively correlated traits (Falconer and Mackay, 1996). Therefore, health and fertility may further deteriorate for pure HO cows, because genetic trends for milk production, angularity, and body size continue to increase.

Inbreeding depression tends to have largest impact on fitness traits, especially fertility and viability (Falconer and Mackay, 1996). A study by Wall et al. (2003) demonstrated increases in calving interval, and decreases in milk production and BCS when inbreeding levels surpassed 10%. Smith et al. (1998) estimated a 6-d decrease in longevity, a 177 kg lifetime milk loss, a 11.5 kg fat plus protein loss, and a $22 to $24 income loss for every 1% increase of inbreeding coefficient. Furthermore, lethal recessives such as complex vertebral malformation, brachyspina, and three lethal haplotypes that affect fertility (HH1, HH2, and HH3) may surface more frequently in cattle as inbreeding coefficient continues to rise. On a positive note, more deleterious recessives may be identified and purged from a breed with higher levels of inbreeding (Kearney et al., 2004b).

The equal and opposite effect of inbreeding depression is heterosis, which is expressed for matings of unrelated individuals. For dairy cattle, specifically, heterosis is meaningful when breeds are distantly related, and heterosis is highest for fertility, health, and survival (Young et al., 1969). Touchberry (1992) compared crosses of Guernsey and pure HO, and heterosis for income per cow per year was 11.4%. Crossbreds of Ayrshire and Holstein exhibited heterosis for lifetime milk production of 16.6% and 20.6% for annual net income (McAllister et al., 1994). Sørensen et al. (2008) reviewed multiple crossbreeding experiments from recent years and reported heterosis for fat and protein solids (1.5% to 8.4%), pregnancy rate (3.3% and 10.1%), survival (4.2% and 21.8%), and total merit (10% and 20%).

Systematic Crossbreeding for Commercial Dairy Production

A review by Touchberry (1992) stated the first documented studies of crossbreeding in dairy cattle were conducted because researchers observed variation for production between herds (and among cows within herds), but researchers disagreed whether inheritance of production was affected by only a few or many segregating loci. Furthermore, questions remained regarding the environmental and genotype × environment impacts (Touchberry, 1992). Subsequently, the first crossbreeding experiments were conducted beginning in the mid-20th century, mostly among HO, Jersey, Ayrshire, and Guernsey breeds, to answer questions about the viability of crossbreeding for commercial dairy production (McDowell, 1982; Touchberry, 1992; McAllister et al., 1994).

Dairy producer surveys. Fifty US dairy producers responded to a survey, that documented experiences and obtained producers' opinions regarding crossbreeding (Weigel and Barlass, 2003). Dairy producers who participated had been crossbreeding for an average of 8.9 yr, and the majority of dairy producers were milking crossbreds consisting of HO, Jersey, and Brown Swiss. The authors stated that producers sought (and many achieved) greater components in milk, improvement in fertility, lessened calving difficulty, and greater longevity above what purebreeding could provide. Many producers also had concern about inbreeding depression and had interest in utilizing heterosis to improve the traits formerly mentioned. Some producers cited disadvantages of crossbreeding that included difficulty marketing replacements, lack of uniform size among cows in the milking herd, and potentially lower milk volume for crosses of some breeds.

In Denmark, Sørensen et al. (2008) surveyed 282 randomly-selected dairy farmers about their attitudes toward crossbreeding, because approximately 2% of Danish dairy farmers were crossbreeding some or all of their cows in the early 2000s. Authors reported 40% of respondents had a positive attitude toward crossbreeding, and 25% indicated they would consider crossbreeding in their herds in the future.

The Montbeliarde Breed. The Montbeliarde (**MO**) breed is native to the East and Southeast of France in the Franche-Comté region and was first recognized in 1889 (O. S. Montbeliarde, 2013). Subsequently, the MO breed has grown to be the second largest breed in France with over 405,000 cows in milk recording in 2010, and over 80 progeny tested bulls sampled annually (Umotest, 2013). Despite global interest in the MO breed for use in crossbreeding schemes, few long-term studies exist that have documented results of MO-sired crossbred cows in comparison with pure HO or other crossbred cows.

Crossbreeding with MO in Ireland. A 5-yr Irish study commenced in 2001 to compare imported French pure MO, Normande, and Norwegian Red cows with pure HO cows and their resulting progeny, including MO × HO crossbred cows in a grass-based system (Buckley et al., 2007; Walsh et al., 2008). Cows were randomly assigned to either a high or low treatment for concentrate feeding in order to test potential interaction between genotype and feeding level. The study included a total of 749 lactations of 309 cows in first to fifth lactations, and the average breed group sizes in each of the five years for pure MO, MO × HO, and pure HO cows were 27, 28, and 33 cows, respectively (Walsh et al., 2008).

The MO × HO crossbreds had similar production of milk, protein and lactose compared with pure HO cows; however, fat production was significantly lower (−7 kg) during the complete lactation. For fertility, the MO × HO (91%) were more likely to be bred (odds ratio = 3.1) during the first 24-d of the breeding season than pure HO (76%) cows. At the end of the breeding season, MO × HO cows were 2.4 times more likely to be pregnant compared with pure HO cows; however, no differences for endocrine and metabolic hormones were observed between breed groups. Furthermore, MO × HO (1,385 d) had greater median longevity than pure HO (695 d) cows and also completed more lactations in the herd (3.8 lactations versus 1.9 lactations, respectively). The MO × HO (3.00) had greater BCS than pure HO (2.77) cows; however, BW was similar for the breed groups. No interaction of breed and feeding system interactions was observed for either production or fertility traits; however, Walsh et al. (2008) concluded pure HO cows are not optimal for grass-based dairying, because the poor fertility and compromised survival of pure HO cows in a seasonal production system would greatly reduce profitability.

Buckley et al. (2007) analyzed feed intake and feed efficiency for a subset of cows from the Irish study during 2003 and 2004, and feed intake was estimated using fecal alkane concentrations in lieu of actual feed intake because cows were on pasture. The MO × HO and pure HO cows had similar daily DMI (15.6 kg versus 15.8 kg), daily production of milk solids (2.14 kg versus 2.25 kg) and body weight (**BW**; 523 kg versus 526 kg), respectively; therefore, efficiency in terms of either milk solids over DMI or milk solids per 100 kg of BW were similar between breed groups (Buckley et al., 2007).

A California Field Study. A 7-yr study in California analyzed field data from 6 commercial dairy herds for cows that calved for the first time from 2002 to 2005 (Heins et al., 2006; Heins and Hansen, 2012; Heins et al., 2012a). Dams of cows were pure HO and were bred to AI bulls of MO, Normande, and Scandinavian Red breeds via imported frozen semen from France (for MO and Normande bulls) and Sweden and Norway (for Scandinavian Red bulls) to generate F_1 crossbred cows for comparison with pure HO contemporaries.

Heins et al (2006) compared calving difficulty and stillbirths for pure HO cows when bred to pure MO versus pure HO AI sires, and 158 MO × HO calves and 371 pure HO calves were born to first lactation pure HO dams. The MO AI sires and pure HO AI sires did not differ, respectively, for calving difficulty (11.6% versus 16.4%) or stillbirth (12.7% versus 15.1%), during first calvings. For second to fifth calvings, 2,373 MO × HO and 303 pure HO calvings were analyzed, and calving difficulty was similar (5.4% versus 8.4%), respectively, for MO and HO breed of sire; however, stillbirths were significantly lower for calves sired by MO bulls (5.0%) compared with calves sired by

HO bulls (12.7%). Subsequently, calving difficulty and stillbirth for first lactation cows was analyzed for 370 MO × HO and 676 pure HO cows. The majority of both MO × HO and pure HO cows gave birth to calves sired by Brown Swiss or Scandinavian Red AI bulls, and breed of service sire was included in the model used by Heins et al. (2006). Results for breed of dam showed MO × HO had less calving difficulty (7.2% versus 17.7%) and lower stillbirth (6.2% versus 14.0%) than pure HO cows during first calving; however, the calving difficulty and stillbirth for multiparous cows were similar among MO × HO and pure HO cows.

Heins and Hansen (2012) reported fertility, SCS, and production for 503 MO × HO and 416 pure HO cows during their first 5 lactations from the same study. The DO was lower (−26 d) and days to first breeding was less (−7 d) for MO × HO versus pure HO cows for all lactations; furthermore, pregnancy rate was also higher (+5.3%) for the MO × HO compared to the pure HO cows. The MO × HO had lower SCS in first, fourth, and fifth lactations and, across lactations, the SCS was −0.29 lower for MO × HO compared to pure HO cows. For 305-d fat plus protein production, the MO × HO were 3% to 5% lower in first, second, and third lactations compared with pure HO cows; however, fat plus protein was similar in fourth and fifth lactations. Heins and Hansen (2012) commented that within-breed rank of the MO AI bulls was lower for production in comparison to the ranking of pure HO bulls used in the study herds and, perhaps, this explained the slightly lower production of the MO × HO crossbred cows.

Subsequently, Heins et al. (2012a) analyzed survival and profitability for the same cows and MO × HO (2.0%) had significantly fewer death losses than pure HO (5.3%)

cows during first lactation. Survival to second, third, and fourth lactations also was greater for MO × HO than pure HO cows, and 14% to 26% more crossbred cows survived to subsequent calvings than pure HO cows. Furthermore, longevity was over 400 d longer for MO × HO than pure HO cows. Heins et al. (2012a) defined a profit function that considered revenues and expenses for production, SCS, fertility, feed intake, calf value, salvage value of cows, dead cow disposal, and a fixed overhead cost. The MO × HO cows had 50% more lifetime profit per cow than pure HO; however, greater lifetime profit for MO × HO was expected because of their much greater longevity. Most dairy producers have a fixed amount of housing for milking cows and profit per day in the herd may be a more appropriate gauge for comparing breed groups. Heins et al. (2012a) calculated profit per cow-day, and the MO × HO had +5.3% greater profit than pure HO cows. A sensitivity analysis adjusted costs and revenues for possible fluctuations in market prices, and MO × HO cows still maintained a significantly greater profit per day (+1% to +53%) compared to pure HO cows. Results for profit reported in the study were likely conservative because health costs were not available.

Chapter 1

Montbeliarde-sired crossbreds compared with pure Holsteins for dry matter intake, production, and body traits during the first 150 days of first lactation.

INTERPRETIVE SUMMARY

Dry matter intake and fat plus protein production of Montbeliarde-sired crossbred cows were not significantly different from pure Holstein cows during the first 150 days of first lactation. Montbeliarde × Holstein crossbred cows were similar to pure Holstein cows for hip height; however, Montbeliarde × (Jersey/Holstein) crossbred cows had significantly shorter hip height than both Montbeliarde × Holstein crossbred and pure Holstein cows. Because they carried more body condition, the Montbeliarde-sired crossbred cows had greater body weight than pure Holstein cows during early first lactation. For fertility, Montbeliarde-sired crossbred cows had significantly fewer days open than pure Holstein cows during first lactation.

INTRODUCTION

Some dairy producers have embraced crossbreeding to enhance the profitability of dairying by improving fertility, decreasing health costs, and enhancing the survival of cows (McAllister, 2002; Weigel and Barlass, 2003). Globally, the beef, pig, and poultry industries have used heterosis for commercial production for decades to capitalize on the documented gains for fertility, health, and profitability; however, heterosis can also be expressed as improved feed efficiency of animals (Rolfe et al., 2011). An important component of profitability of dairying is feed cost (Shalloo et al., 2004), and feed efficiency has a tremendous impact on profit from dairy cows.

Jersey × Holstein (**JH**) crossbred cows were more feed efficient than pure Holstein (**HO**) cows for Schwager-Suter et al. (2001), and they hypothesized heterosis may be responsible for lower energy requirements for one or more energy partitions of milk production, maintenance, and body tissue mobilization and deposition. In an Irish study, JH crossbred cows (16.2 kg) and pure HO cows (16.9 kg) had similar DMI; however, the JH crossbred cows had greater feed efficiency, which was measured as net energy intake over production of milk solids (Prendiville et al., 2009).

Olson et al. (2010) reported that JH reciprocal crossbred cows produced milk that contained the same amount of NE_L as pure HO cows during first lactation; however, the JH crossbred cows sired by HO bulls consumed less energy in feed than pure HO cows. However, Heins et al. (2008) reported that JH crossbred cows and pure HO cows had similar DMI and production during the first 150 d of first lactation and, because the JH crossbred cows were smaller for frame size, the authors concluded JH crossbred cows used DMI beyond their needs for production and maintenance to achieve greater BCS. Also, the feed efficiency of Ayrshire × HO, Brown Swiss × HO, and three-breed crossbred cows (Ayrshire, Brown Swiss, and HO) was similar to that of pure HO cows for McDowell (1982).

Little research has been conducted to compare crossbred cows sired by Montbeliarde (**MO**) bulls with pure HO cows, because MO semen has been marketed globally only during the past decade. Furthermore, actual DMI for individual cows is costly to collect and, therefore, direct measures of DMI have not been previously reported for MO-sired crossbred cows compared with pure HO contemporaries.

A long-term Irish study was initiated to compare Irish pure HO, imported French pure MO, and their resulting MO × HO progeny in a grass-based production system. Dillon et al. (2003) observed differences in estimated DMI, which was calculated from fecal alkane concentrations, for pure MO and pure HO cows in 3 periods during lactation. The pure MO cows had lower daily DMI (16.4 kg vs. 18.4 kg), but also had proportionally lower SCM (4,769 kg vs. 5,560 kg) than pure HO cows. Therefore, Dillon et al. (2003) reported equivalent feed efficiency for the two pure breeds. A follow-up study reported the imported French pure MO cows were more profitable than the Irish pure HO under several milk quota scenarios (Evans et al., 2004). Subsequently, pure MO, MO × HO, and pure HO cows, which were daughters of cows from Dillon et al. (2003) and Evans et al. (2004), were evaluated over several lactations in a 5-yr study by Walsh et al. (2008), who reported SCM was similar for MO × HO and pure HO cows but lower for pure MO cows. Furthermore, BCS was highest for pure MO cows (3.15), intermediate for MO × HO cows (3.00), and lowest for pure HO cows (2.77), but BW was similar for the three breed groups (Walsh et al., 2008). Notably, the MO × HO cows were 2.4 times more likely to be pregnant at the end of the breeding season compared with pure HO cows (Walsh et al., 2008). Buckley et al. (2007) also calculated DMI for cows from alkane concentrations for 2 fecal collection periods during early first through fourth lactations of pure MO, MO × HO, and pure HO cows. The MO × HO and pure HO cows were similar for both DMI and milk solids production; therefore, feed efficiency was likewise similar. However, pure MO cows had less DMI, lower milk solids production, and reduced feed efficiency than pure HO cows (Buckley et al., 2007).

An Israeli study (Aharoni et al., 2006) compared the heart rates and oxygen consumption of 7 multiparous MO × HO crossbred cows and 7 multiparous pure HO cows during two 10-d periods. Their equations predicted MO × HO cows had lower ME intake than pure HO cows; however, MO × HO cows also had less gross efficiency, because MO × HO cows were penalized for having greater BCS and BW.

A study of 6 commercial dairies in California reported MO × HO cows had somewhat lower fat plus protein production, but superior fertility, during 305-d first lactations compared with pure HO cows (Heins and Hansen, 2012). A subsequent economic analysis indicated MO × HO cows had 5.3% greater lifetime profit per day than pure HO cows (Heins et al., 2012a) when DMI was predicted from FCM equivalently across breed groups. Costs of health treatments were not available for Heins et al. (2012a), and inclusion of health costs might have increased the profitability of MO × HO cows versus pure HO cows.

For economic merit, VanRaden and Saunders (2003) reported both Brown Swiss × HO cows and JH crossbred cows were superior to pure HO cows for the Net Merit index in the United States. A review of crossbreeding by Sørensen et al. (2008) concluded heterosis of at least 10% can be expected for total economic merit of both F_1 and 3-breed crossbred cows.

The objectives of this study were to evaluate phenotypic differences for traits related to energy use for MO-sired crossbred and pure HO cows housed in a confinement system during the first 150 d of first lactation. Breed groups were compared for DMI and production during the first 150 d of first lactation; however, 305-d production was also compared to provide a broader assessment of total production performance during first lactation. Additionally, body traits were compared during the first 150 d of first lactation. A subsequent study using a larger number of MO-sired crossbred and pure HO cows in 2 institutional herds will evaluate the production, fertility, and survival, but not DMI, because of the high cost of data collection.

MATERIALS AND METHODS

Experimental Design

Cows in this study calved during 3 fall seasons: October to December 2005, October 2006 to January 2007, and October to December 2007, and cows were sired by MO or HO AI bulls selected on high rank for the ISU total merit index (O. S. Montbéliarde, 2012) in France for MO bulls or the Net Merit index (Cole et al., 2009b) in the United States for HO bulls. Three bulls were selected annually for each breed, and the MO bulls were among the top 10 proven AI bulls in France and the HO bulls were among the highest 1 percentile in the United States.

The 57 MO-sired crossbred cows were sired by 9 MO AI bulls and the 40 pure HO cows were sired by 16 HO AI bulls (Table 1). Dams of cows were either pure HO cows or JH crossbred cows, and dams of cows were sired by high-ranking AI bulls for the Net Merit index in the United States for both the Jersey and HO breeds at the time of sire selection. Cows in this study calved from 22 to 34 mo of age and were assigned to 3 classes of age at first calving: 22 to 23 mo (26 MO-sired crossbred and 17 pure HO cows), 24 to 26 mo (27 MO-sired crossbred and 16 pure HO cows), and 29 to 34 mo (4 MO-sired crossbred and 7 pure HO cows). The mean age of first calving was 24.3 ± 0.3 mo for the MO-sired crossbred cows and 24.9 ± 0.5 mo for the pure HO cows.

Table 1. Number of cows by year of fall calving by breed group.

Year	Pure Holstein	Montbeliarde × Holstein	Montbeliarde × Jersey/Holstein
2005	11	14	1
2006	13	12	11
2007	16	7	12
Total	40	33	24

Three cows were removed from the study within the first 90 d of first lactation. In the first year, one pure HO cow died from gangrene mastitis at 72 d postpartum. In the second year, one pure HO died from *Escherichia coli* mastitis at 90 d postpartum. In the third year, one MO × JH crossbred cow was culled for gangrene mastitis at 56 d postpartum.

DMI and Production

Cows were fed an ad libitum TMR diet consisting of 55% forage and 45% concentrate, and the diet was adjusted monthly to account for changes in DM of ingredients. Diets were composed of corn silage, chopped alfalfa hay, soybean meal, ground corn, concentrate supplements, vitamins, and minerals. Cows were fed twice daily with a Calan Data Ranger (American Calan, Northwood, NH), and feed refusals were collected once daily to determine daily DMI (kg) for each cow. Daily DMI was collected from d 4 to 150 postpartum. The DMI was not recorded for the first 3 d postpartum because cows were allowed to acclimate to tie stalls until d 3 of lactation. To analyze total 150-d DMI, the actual daily DMI observations were summed for each cow. Only 19 of the 14,259 daily observations for DMI were missing, and they were for 4 cows between 4 and 13 d postpartum. For 3 cows, data was missing because of computer recording errors, and 1 cow had difficulty acclimating to the tie stall. The 19 missing daily observations were estimated by extrapolation to determine the 150-d DMI for these 4 cows.

Independent variables for the statistical analysis of 150-d DMI included year of calving, age class at first calving, breed of sire, and MO × HO versus MO × JH nested within MO breed of sire. The GLM procedure of SAS (SAS Institute, 2008) was used to conduct the ANOVA and obtain solutions.

Test-day observations for twice-daily milking from DHI were used as inputs to estimate production. Standard edits used by the US Department of Agriculture for routine genetic evaluations were applied to all test-day observations. Each test-day was required to have an observation for milk, fat, and protein production. Fat percentage was required to be at least 1.0%, but no more than 9.9%, and protein percentage was required to be at least 1.0%, but no more than 6.0%. Test-day milk weights were required to be ≥ 4.54 kg. A first test-day was required by 90 DIM, and individual test-days from first lactation were used to predict 150-d milk (kg), fat (kg), and protein (kg) production and SCS with best prediction (Cole et al., 2009a). The 150-d fat plus protein (kg) was the sum of the 150-d production records of fat and protein. The 150-d SCS for each cow was the mean of predicted daily SCS.

The 305-d production was also estimated with best prediction using test days beyond 150 DIM. Lactations shorter than 305 d were projected to 305 d. The 305-d fat plus protein (kg) was the sum of the 305-d production records of fat and protein for each cow, and the 305-d SCS was the mean of predicted daily SCS.

Independent variables for the statistical analysis of both 150-d and 305-d milk, fat, and protein production, fat plus protein production, and SCS were year of calving, age class at first calving, breed of sire, and MO × HO versus MO × JH nested within MO breed of sire. The GLM procedure of SAS was used to conduct the ANOVA and obtain solutions for production and SCS.

Body Traits

Hip height (**HH**) was objectively measured from the ground to the sacrum once between 20 and 172 DIM while cows were in their tie stalls, and measurements were recorded in increments of 0.5 cm. Independent variables for the statistical analysis of HH were the fixed effects of year of calving, age class at first calving, breed of sire, and MO

× HO versus MO × JH nested within MO breed of sire. A preliminary model included a covariable for DIM at time of measurement, but DIM was not significant ($P = 0.85$) and was removed from the model. The GLM procedure of SAS was used to conduct the ANOVA and obtain solutions.

Body condition score and BW were recorded during the p.m. milking every other week during the first 150 d postpartum; therefore, most cows had 10 observations for BW and BCS at 14-d intervals (e.g., 1 to 15 d, 16 to 30 d, 31 to 45 d). The BCS was measured by the same person throughout the study on a 1 to 5 scale (1 = thin and 5 = obese) in increments of 0.25 (Ferguson et al., 1994), and BW was recorded for each cow using a digital scale as cows exited the milking parlor.

Statistical analysis of BCS and BW had fixed effects of year of calving, age class at first calving, breed of sire, MO × HO versus MO × JH nested within MO breed of sire, and 14-d period nested within breed of sire. The MIXED procedure of SAS was used for analysis, and cow nested within breed of sire and within MO × HO versus MO × JH was defined as a random variable with repeated measures for 14-d periods. The first order auto-regressive [**AR(1)**] covariance structure was used, because it resulted in the lowest Akaike's information criterion (Littell et al., 1998).

All phenotypic pairwise correlations of the 3 body traits were examined within each breed group, and the means of the repeated measures of BCS and BW of cows were analyzed. For each of the 3 body traits, adjustment factors for the fixed effects of year of calving and age class at first calving within breed groups were obtained using the least squares solutions from the GLM procedure of SAS, and the adjusted observations for each cow were used to calculate Pearson correlation coefficients. Statistical significance was declared when *P*-values were < 0.05; however, tendencies toward statistical significance (0.05 < *P* < 0.1) were also reported.

RESULTS AND DISCUSSION

DMI and Production

For total DMI, year of calving and age class at calving were the only independent variables that significantly explained variation. Cows calving in 2005 (3,109 kg) had significantly (*P* < 0.05) greater total DMI than cows calving in 2006 (2,916 kg) and 2007 (2,831 kg). Table 2 shows total DMI for cows calving from 22 to 23 mo, 24 to 26 mo, and 29 to 34 mo of age, and the least squares means for DMI were significantly greater for cows calving at 29 to 34 mo of age than at younger ages.

Table 2. Least squares means and standard errors of means for DMI, production, and SCS for age class at first calving across breed groups.

	22 to 23 mo (n = 43)		24 to 26 mo (n = 43)		29 to 34 mo (n = 11)	
	Mean	SEM	Mean	SEM	Mean	SEM
150 d						
DMI (kg)	2,802[a]	47.1	2,922[a]	45.3	3,132[b]	88.8
Milk (kg)	4,339[a]	61.1	4,660[b]	58.8	4,991[c]	115.2
Fat (kg)	154[a]	2.5	165[b]	2.4	184[c]	4.7
Protein (kg)	133[a]	1.8	141[b]	1.7	153[c]	3.4
Fat plus protein (kg)	287[a]	4.1	305[b]	3.9	336[c]	7.7
SCS	2.5[a]	0.2	2.4[a]	0.2	2.7[a]	0.3
305 d						
Milk (kg)	8,453[a]	110.9	8,972[b]	106.8	9,605[c]	209.2
Fat (kg)	303[a]	4.5	319[b]	4.3	353[c]	8.5
Protein (kg)	266[a]	3.5	278[b]	3.3	301[c]	6.5
Fat plus protein (kg)	569[a]	7.5	597[b]	7.2	654[c]	14.2
SCS	2.4[a]	0.2	2.3[a]	0.2	2.6[a]	0.3

[a-c] Means with different superscript letters within rows indicate *P* < 0.05.

Total DMI for the 150-d period was not different (P = 0.17) for MO × HO (2,904 kg), MO × JH (2,906 kg), and pure HO (2,999 kg) cows (Table 3); therefore, we found no evidence to suggest the MO-sired crossbred cows had greater DMI than the pure HO cows. Of course, because DMI was only collected for the first 150 DIM, conclusions cannot be made regarding DMI during the latter half of lactation and during subsequent lactations. Differences in nutrient requirements for cows may change after the first 150 d of first lactation because skeletal growth subsides for cows after first lactation and, additionally, fetal development requires a meaningful amount of nutrients during the final trimester of pregnancy (NRC, 2001).

Table 3. Least squares means and standard errors of means for DMI, production, and SCS for breed groups.

	Pure Holstein (n = 40)		Montbeliarde × Holstein (n = 33)		Montbeliarde × Jersey/Holstein (n = 24)	
	Mean	SEM	Mean	SEM	Mean	SEM
150 d						
DMI (kg)	2,999	48.2	2,904	55.0	2,906	69.6
Milk (kg)	4,764	62.6	4,573*	71.4	4,552*	90.3
Fat (kg)	168	2.6	166	2.9	168	3.7
Protein (kg)	143	1.8	140	2.1	142	2.6
Fat plus protein (kg)	311	4.2	306	4.8	310	6.1
SCS	2.4	0.2	2.4	0.2	2.7	0.2
305 d						
Milk (kg)	9,200	113.6	8,905†	129.6	8,735*	164.0
Fat (kg)	326	4.6	324	5.3	324	6.7
Protein (kg)	284	3.5	280	4.0	279	5.1
Fat plus protein (kg)	610	7.7	604	8.8	603	11.1
SCS	2.4	0.2	2.4	0.2	2.7	0.2

* $P < 0.05$ and † $P < 0.10$ for difference from pure Holstein cows.

For 150-d milk, fat, and protein production, only age class at calving significantly explained variation among the nonbreed effects in the stated model, and least squares means for production significantly increased with age at first calving (Table 2). For SCS, age at first calving was not significant ($P = 0.69$); however, cows calving in 2005 (2.95) had significantly ($P < 0.05$) higher SCS than cows calving in 2006 (2.34) and 2007 (2.25).

Least squares means of 150-d production and SCS for breed groups are in Table 3. The MO × HO and MH × JH crossbred cows had significantly ($P < 0.05$) lower 150-d milk volume than the pure HO cows; however, production of fat plus protein did not differ significantly ($P = 0.62$) and was very similar for the MO × HO (306 kg), MO × JH (310 kg), and pure HO (311 kg) cows (Table 3). Also, SCS was not significantly different ($P = 0.42$) for breed groups during the first 150-d of first lactation.

For lactational 305-d milk, fat, and protein production, only age class at calving significantly explained variation among the non-breed effects in the model. Least squares means for 305-d production (Table 2) increased with age at first calving, but SCS was not different ($P = 0.74$) for age class at first calving. For breed groups, the 305-d milk volume tended ($P = 0.07$) to be lower for the MO × HO crossbreds and was significantly ($P < 0.05$) lower for MO × JH crossbreds compared with pure HO cows. However, production of fat plus protein, again, did not differ ($P = 0.97$) and was essentially equivalent for MO × HO (604 kg), MO × JH (603 kg), and pure HO (610 kg) cows for 305-d lactations (Table 3). Also, SCS was not significantly different ($P = 0.29$) for the breed groups (Table 3). The results for fat plus protein production in this study differ somewhat from the results of Heins and Hansen (2012), who reported MO × HO crossbred cows had 3% lower fat plus protein production than pure HO cows during first lactation.

Fat plus protein production has the largest impact on the value of milk for approximately 93% of milk produced in the United States (US Department of Agriculture-Agricultural Marketing Service, 2012; US Department of Agriculture-National Agricultural Statistics Service, 2012). Therefore, the majority of dairy producers in the United States should not be alarmed by potentially lower milk volume of MO-sired crossbred cows compared with pure HO cows. The higher components in the milk of MO-sired crossbred cows may actually increase production efficiency, because the additional energy required by pure HO to synthesize greater milk volume is a loss of energy. Also, farming systems incur higher costs for equipment and electricity to cool and store additional fluid carrier (Cole et al., 2009b).

Measures of feed efficiency are often inherently problematic, and feed efficiency was not evaluated in this study. Most previous research has examined only DM or nutrients consumed versus energy in milk or solids produced without regard for changes in body composition or pregnancy status. A ratio trait of input (feed intake) divided by output (production) can be especially misleading, because analyzing the ratio of 2 traits often leads to spurious results that are highly correlated with the numerator or denominator. Emphasis during statistical analysis, especially ANOVA, is directed toward the numerator or denominator with the greatest variance (Sutherland, 1965). Additionally, Berry (2009) pointed out the disadvantages of including ratio traits in selection schemes because correlated traits are often undesirable, such as reduced appetite or other behavioral traits that influence DMI.

Residual feed intake (**RFI**) has become a popular method of gauging feed efficiency of dairy cattle during the past 5 yr (Berry, 2009), but RFI may not be appropriate for analyzing data that compare crossbred with pure HO cows. The RFI is calculated by subtracting actual DMI from expected DMI (NRC, 2001), and the expected DMI is defined as a function of BW, FCM, and week of lactation. By this definition, RFI does not consider the differences in BCS, proportion of adipose and muscular tissue, frame size, or heterosis for production or DMI. Furthermore, formulas used to predict DMI are based primarily on measurements from pure HO cows. Prendiville et al. (2009) argued that RFI poses problems for dairy cows, because cows mobilize energy reserves during early lactation but replenish these reserves later in lactation. The change in body composition during lactation complicates the calculation of profit from salvage value, because value of the carcass decreases during early lactation, but increases in value during later lactation.

Cows determined to be the most efficient by standard measures of feed efficiency may not be economically efficient if they have low DMI and low production (Prendiville et al., 2009), because these cows still incur direct and overhead costs at the same rate as higher-producing cows. Furthermore, low-producing cows have a higher risk of being culled (Pinedo et al., 2010), and these “poor doer” cows often have low BCS, which may be associated with impaired fertility, higher disease incidence, and lower salvage value.

For these reasons, measures of feed efficiency that only consider units of energy intake and output do not necessarily identify the most profitable cows.

Body Traits

Year of first calving, age class at first calving, and breed group significantly ($P < 0.01$) explained variation for HH. For year of calving, cows had HH of 137.8 cm, 142.9 cm, and 141.5 cm for 2005, 2006, and 2007, respectively. For age class at first calving, HH increased as expected (139.0 cm for 22 to 23 mo, 140.8 cm for 24 to 26 mo, and 142.5 cm for 29 to 34 mo). The MO × HO (141.4 cm) and pure HO (141.8 cm) cows did not differ ($P = 0.58$) for HH; however, MO × JH cows had significantly ($P < 0.01$) shorter HH than pure HO cows (Table 4). Pure Jersey cows have smaller frame size than pure HO cows, and the one-fourth Jersey content of the MO × JH cows in this study is the likely explanation for the shorter HH. Heins et al. (2011) reported that JH crossbred cows had 8.8 cm to 9.4 cm shorter HH than pure HO cows during their first 3 lactations.

Table 4. Least squares means and standard errors of means for hip height (cm), BCS, and BW (kg) of cows during the first 150 days of first lactation for breed groups.

	Pure Holstein (n = 40)		Montbeliarde × Holstein (n = 33)		Montbeliarde × Jersey/Holstein (n = 24)	
	Mean	SEM	Mean	SEM	Mean	SEM
Hip height (cm)	141.8	0.54	141.4	0.61	138.0**	0.78
BCS	2.74	0.03	3.32**	0.04	3.29**	0.05
BW (kg)	528	6.2	564**	7.1	537	8.9

** $P < 0.01$ for difference from pure Holstein cows.

Among the fixed effects in the statistical model for BCS, only breed group and 14-d period nested within breed of sire significantly ($P < 0.01$) explained any variation. For breed groups, the MO-sired crossbred cows had significantly greater BCS than pure HO cows throughout the study with least squares means of 3.32, 3.29, and 2.74 for MO × HO, MO × JH, and pure HO cows, respectively (Table 4). Least squares means for BCS in each of the 14-d periods were different ($P < 0.01$) for MO-sired crossbreds compared with pure HO cows, and differences for BCS between breed groups ranged from 0.47 to 0.64 and were greater for the first 100 d postpartum than for the subsequent 50 d postpartum.

The MO-sired crossbred and pure HO cows both mobilized body tissue during early lactation to meet the demands of production. Throughout the 150-d study period, the MO-sired crossbreds maintained greater BCS than the pure HO cows, and the greater BCS may explain the superior fertility (Dechow et al., 2001; Pryce et al., 2001) of the MO-sired crossbreds in this study and may also reduce occurrence of disease during early lactation (Hansen et al., 2002; Zwald et al., 2004). Similarly, a study comparing JH crossbred and pure HO cows in Australia (Auldist et al., 2007) concluded that JH crossbred cows had both greater BCS and superior fertility compared with pure HO cows.

The effects of age class at first calving, breed group, and 14-d period nested within breed of sire all explained variation for BW. The BW increased as age class at first calving increased (503, 533, and 581 kg for the 3 age classes, respectively), and all orthogonal contrasts for each of the 3 age classes were highly significant ($P < 0.01$). For breed groups (Table 4), the MO × HO crossbred cows had ($P < 0.01$) greater BW than pure HO cows across the first 150 d of first lactation (564 vs. 528 kg). The results presented here differed from Walsh et al. (2008), who found that BW was similar for MO × HO (572 kg), pure HO (570 kg), and pure MO cows (568 kg) from first through fifth lactations. For the current study, MO × JH cows (537 kg) were similar to pure HO cows for BW (Table 4).

Least squares means for BW for each 14-d period by breed of sire are in Table 5. The MO-sired crossbred cows (555 kg) had greater BW immediately after calving compared with pure HO cows (527 kg). Daughters of MO versus HO sires decreased similarly for BW between periods 1 and 2, had similar nadir BW between periods 2 and 4, and then BW rapidly increased starting in period 5. The largest difference in BW was immediately after calving and the difference tended to decrease as lactation progressed past the 12th week of lactation. Furthermore, the MO-sired crossbred cows gained less BW than the pure HO cows (+ 16 kg vs. + 28 kg) from first to last 14-d period.

Table 5. Least squares means and standard errors of means for BW (kg) of cows during the first 150 d, in 14-d intervals, of first lactation by breed group.

	Pure Holstein (n = 40)		Montbeliarde-sired crossbreds (n = 57)		
14-d period	Mean	SEM	Mean	SEM	Difference
1	527	6.8	555	6.5	+ 28**
2	511	6.8	536	6.5	+ 25**
3	509	6.8	536	6.5	+ 27**
4	511	6.8	535	6.5	+ 24**
5	518	6.8	542	6.5	+ 24**
6	525	6.8	549	6.5	+ 24**
7	535	6.8	556	6.5	+ 21*
8	540	6.8	561	6.5	+ 21*
9	546	6.8	565	6.5	+ 19*
10	555	6.9	571	6.6	+ 16[†]

** $P < 0.01$, * $P < 0.05$, † $P < 0.10$ for difference from pure Holstein cows.

The Pearson correlation coefficients between BW and BCS within breed groups ranged from + 0.47 to + 0.60 and were significantly ($P < 0.05$) different from zero within all 3 breed groups. The correlation between BW and HH was significantly different from zero within the MO × JH crossbred cows (+ 0.59) and pure HO cows (+ 0.41); on the other hand, the correlation between BW and HH within the MO × HO crossbred cows (+0.24) was not significantly different from zero. The correlation of BCS and HH was not significantly different from zero ($P > 0.23$) within any of the three breed groups.

Comparison of only HH, BCS, and BW does not provide a complete elucidation of the nutrient demands for depletion, accretion, or maintenance of adipose and muscle tissue; therefore, changes in body tissue composition of dairy cows during lactation warrant further study. More energy is required for adipose deposition compared with muscle tissue and water deposition (DiCostanzo et al., 1990); however, protein maintenance requires more energy than fat maintenance (Berry, 2009). Bewley and Schutz (2008) reviewed several studies that reported the DMI of cows is lower for cows carrying greater BCS, because body fat has a negative feedback effect on DMI.

Taylor et al. (1986) found differences in maintenance requirements for dairy and beef cattle with similar body composition, and De Campeneere et al. (2000) reported dual-purpose breeds had greater change in muscle content as BCS changed, in contrast to pure HO cows, which primarily had changes in fat content. Perhaps, MO-sired crossbred cows maintain BCS more efficiently than pure HO cows, because the MO breed was simultaneously selected over time for production, for higher BCS, and for feed conversion of progeny test bulls (Hansen, 2006) rather than against BCS as was done by the HO breed in the United States and Canada (Spahr and Opperman, 1995; Purebred Dairy Cattle Association, 2009). Apparently, the MO-sired crossbred cows in this study utilized energy in feed differently or mobilized body energy reserves differently than pure HO cows, such that the MO-sired crossbred cows maintained greater BCS while producing equivalent fat plus protein production without consuming additional DMI.

Poor health status and reduced reproductive efficiency are the 2 primary reasons cows die or are culled (Pinedo et al., 2010), and replacement costs have a large impact on herd profitability (Evans et al., 2004; Heins et al., 2012a). Incidences of health disorders were not available for the current study; however, MO-sired crossbred cows (122 d) had significantly fewer ($P < 0.05$) days open (**DO**) during first lactation than pure HO cows

(150 d). If the cost per additional DO is approximated at $1.50 (Cole et al., 2009b), the 28-d fewer DO for the MO-sired crossbred cows provides them with a $42 profit advantage over pure HO cows. Further research is warranted to compare the profitability of MO-sired crossbred cows and pure HO cows, and costs of health disorders should be included alongside other traits that are economically important for commercial dairies.

CONCLUSIONS

Because pure HO cows are predominant in the United States in the early 21st century, dairy producers are accustomed to managing cows with low to moderate BCS; therefore, dairy producers often assume cows with higher BCS are consuming more DMI and, consequently, are less efficient producers of milk. Our results suggest that MO-sired crossbred cows, which had greater BCS than pure HO cows, were competitive with pure HO cows in converting the energy from DMI to fat plus protein production. The MO-sired crossbred cows had higher BCS and greater BW at calving, but their greater BCS and BW did not result in additional DMI compared with pure HO cows during the first 150 d of first lactation. Furthermore, the MO-sired crossbred cows had a significant advantage of 28 d fewer DO. Potential advantages of MO-sired crossbred cows over pure HO cows for economic efficiency could result from heterosis, from simultaneous selection for production and BCS of cows and feed efficiency of bulls within the MO breed, or from a combination of both factors.

Chapter 2

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

INTERPRETIVE SUMMARY

Fat plus protein production and somatic cell score were similar for Montbeliarde-sired crossbred cows and pure Holstein cows. Montbeliarde-sired crossbred cows had superior fertility, lower death loss, and greater survival to subsequent calving than pure Holsteins. The Montbeliarde × Holstein crossbreds and pure Holsteins were not different for hip height; however, the Montbeliarde × Holstein crossbreds had more body weight and body condition than the pure Holsteins. On the other hand, the Montbeliarde × (Jersey/Holstein) crossbreds had significantly less hip height and body weight than pure Holsteins; however, the 3-breed crossbreds also had greater body condition compared with pure Holsteins.

INTRODUCTION

Sophisticated, long-term selection strategies have resulted in a rapid increase of milk production for the Holstein (**HO**) breed (Hansen, 2000; Miglior et al., 2005), and pure HO cows now predominate in most temperate regions of the world. However, simultaneous selection for reduced body condition and larger body size, alongside the selection for production, has been detrimental to fertility, health, and survival of pure HO cows (Lucy, 2001; Roche et al., 2009); therefore, dairy producers are exploring systems of crossbreeding to improve the robustness, efficiency, and profitability of dairy cows (Weigel and Barlass, 2003).

In recent years, performance of F_1 crossbred cows during multiple lactations has been reported for combinations of the familiar North American breeds of HO, Jersey, Brown Swiss (**BS**), and Ayrshire. Heins et al. (2011, 2012c) reported lower fat plus protein production for Jersey × Holstein (**JH**) crossbred cows during second and third lactations (−25 kg and −51 kg, respectively) compared with pure HO cows; however, JH cows also had fewer days open (**DO**) in first (−24 d), second (−42 d), and third (−42 d) lactations than pure HO cows. Moreover, a greater percentage of JH cows tended to calve a third time (63.8% versus 49.4%) than pure HO cows (Heins et al., 2012c). In a German study (Blöttner et al., 2011a,b), BS × HO crossbred cows and pure HO cows were similar for fat and protein production, SCS, and DO during their first three lactations. Dechow et al. (2007) observed similar fat plus protein production and SCS in first and second lactations for BS × HO crossbred and pure HO cows; however, BS × HO cows had greater daily fat plus protein production (2.54 kg and 2.25 kg, respectively) and lower SCS (2.19 and 2.59, respectively) than pure HO cows in third through fifth lactations. The DO were lower (−16.5 d) during first lactation for BS × HO compared with pure HO cows, but the BS × HO and pure HO cows had similar DO for multiparous cows in the 19 commercial dairies (Dechow et al., 2007). VanRaden and Saunders (2003) evaluated crosses among traditional United States (**US**) dairy breeds from national data and found both JH and BS × HO crossbred cows were equal or superior to pure HO cows for longevity and were also more profitable than pure HO cows using the Net Merit and Cheese Merit selection indices. In the same study, Ayrshire × HO crossbred cows were not as profitable as pure HO cows (VanRaden and Saunders, 2003). Their conclusions differed from those of McAllister et al. (1994), who reported crossbred cows of Ayrshire and HO had greater longevity and were competitive with pure HO cows for profitability.

Some dairy cattle breeds that are considered foreign to the US have had major impact for crossbreeding globally (Swalve, 2007; Sørensen et al., 2008). The Montbeliarde (**MO**) breed has generated substantial interest for crossbreeding internationally, and frozen semen from MO bulls has been marketed in the US since the early 2000s. A study of 6 commercial dairies in California (Heins and Hansen, 2012; Heins et al., 2012a) found MO × HO cows had slightly less (−3%) fat plus protein production for 305-d lactations than pure HO cows during the first five lactations; however, MO × HO cows were superior for SCS (2.98 versus 3.27), DO (122 d versus 148 d), pregnancy rate (**PR**; 20.0% versus 14.7%), longevity (1,358 d versus 946 d), and profit per day ($4.39 versus $4.17) when compared to pure HO cows. In Ireland, MO ×

HO and pure HO cows were studied over a 5-yr period during their first five lactations in a seasonal calving, grass-based system (Walsh et al., 2008). The MO × HO crossbred and pure HO cows had similar production of milk volume; however, total fat production was lower (−7 kg) for MO × HO cows. Furthermore, the MO × HO cows were 2.4 times more likely to be pregnant at the end of the breeding season then were pure HO cows, and longevity was significantly greater for MO × HO (1,385 d) compared with pure HO (695 d) cows for Walsh et al. (2008). A study by Heins et al. (2012b) reported less incidence of clinical mastitis during the first three lactations for MO × HO (37.9%) and MO × JH (26.3%) compared with pure HO (56.4%) cows in a low-input, grazing system. Mendonça et al. (2010, 2013) documented improved innate immune response for MO-sired crossbred versus pure HO cows, and the lower incidence of post-partum disease in MO-sired crossbred (35%) versus pure HO (57%) cows could have been the result.

Reports of body measurements for MO-sired crossbred cows are sparse; however, Walsh et al. (2008) reported greater BCS (3.00 versus 2.77) but similar BW (572 kg versus 570 kg) for MO × HO than pure HO cows across lactations. An analysis of hip height (**HH**), BCS, and BW during first lactation for a subset of cows in the present study was reported by Hazel et al. (2013), who found HH was similar for MO × HO and pure HO cows; however, MO × JH had shorter HH (−3.8 cm) than pure HO cows. In the same study, the MO-sired crossbred cows had significantly greater BCS (3.30 versus 2.74) and BW (551 kg versus 528 kg) than pure HO cows, despite a lack of difference for DMI.

Kargo et al. (2012) analyzed production data from 1,746 herds in Denmark and found no difference in heterosis for production across 5 levels of environment for strains of Jersey with varying U.S. and Danish Jersey composition. At an institutional herd in the United Kingdom, JH and pure HO cows were compared in high-input confinement versus low-input grazing systems and significant genotype × environment interaction existed only for milk production (Vance et al., 2012). In the same study, fat plus protein production and SCS were similar for breed groups irrespective of management system. Subsequently, Vance et al. (2013) compared JH and pure HO cows across 3 supplementation levels in a grazing environment, and genotype × environment interaction was not observed for fluid milk production, fat plus protein production, or SCS. In the Netherlands, de Haas et al. (2013) analyzed field data from organic herds that included both purebred and crossbred cows of the MO, Jersey, and HO breeds. Heterosis for production, SCS, and calving interval were similar to published estimates for confinement herds; therefore, de Haas et al. (2013) concluded expression of heterosis is likely independent of environment. Similarly, Walsh et al. (2008) did not observe genotype × environment interaction among pure MO, MO × HO, and pure HO cows supplemented at high and low concentrate levels within a grazing system.

The objectives of this study were to evaluate phenotypic differences of MO-sired crossbred and pure HO cows housed in both a high-input confinement herd and a low-input grazing herd. Breed groups were compared for production, SCS, DO, PR, mortality rate, survival (to second, third, fourth, and fifth calvings), and body measurements during their first 5 lactations.

MATERIALS AND METHODS

Experimental Design

A crossbreeding experiment was initiated in 2000 for two research dairy herds at the University of Minnesota, and the design of the experiment was thoroughly reviewed in Heins et al. (2010). The herd at the St. Paul campus of the University of Minnesota has 90 tie-stalls and a 40-head loose-housing barn with TMR feeding, and the herd at the West Central Research and Outreach Center, Morris, Minnesota, has 180 milking cows in a low-input grazing system.

Cows in this study were sired either by MO or HO AI bulls. Bull selection was based on high rank for the French ISU total merit index (O. S. Montbéliarde, 2013) for MO bulls and the U.S. Net Merit index (Cole et al., 2009b) for HO bulls. Three MO bulls were selected annually and they were always among the top 10 proven AI bulls in France, and some MO bulls had repeated use for multiple years. Likewise, 3 HO bulls were selected annually from the 95th percentile of proven bulls in the U.S., and 93% of the cows in this study are daughters of HO bulls selected in this manner. However, 7% of pure HO cows in this study were sired by progeny-test bulls, because a small number of pure HO cows that had difficulty in conception at Morris were bred to progeny-test AI bulls for 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 or JH crossbred cows, and dams of cows were sired by high-ranking AI bulls for the Net Merit index in the United States for both the HO and Jersey breeds at the time of selection.

Both herds calved seasonally, and cows at St. Paul began first lactation during fall seasons (October to January) for 5 years (2005 to 2009). Multiparous cows at St. Paul mostly calved in the fall and winter from October to February and were assigned to 7 subsequent years of calving (September to August) from 2006 to 2012. At Morris, cows calved for the first time during spring seasons (March to June) for 5 years (2006 to 2010). The majority of multiparous cows at Morris subsequently calved during spring, but a small number of fall-calving multiparous cows at Morris were combined with cows from the previous spring to create 6 years 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 1 has number of cows initiating first lactation at each location by calving year and breed group. The mean age of first calving at St. Paul for MO-sired crossbred and pure HO cows was 24.3 ± 0.3 mo and 24.4 ± 0.3 mo, respectively. At Morris, 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.

Table 1. Number of cows by herd, year, and breed group for first calving.

Year	Pure Holstein	Montbeliarde × Holstein	Montbeliarde × Jersey/Holstein
St. Paul			
2005	12	14	1
2006	14	12	11
2007	16	7	13
2008	14	0	14
2009	20	0	6
Morris			
2006	18	14	8
2007	17	7	16
2008	20	1	11
2009	13	3	7
2010	19	1	4
Total	163	59	91

Production and SCS

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

In order to estimate production and SCS, cows needed at least one test day, and 25 lactations without a test day were removed for analysis of production and SCS. Furthermore, 24 lactations were initiated by an abortion and were also excluded from analysis for production and SCS. Lactations were assigned to groups of first, second, or third to fifth. Within each lactation number and herd-year combination, at least 2 cows were required per breed of sire (MO-sired crossbred or pure HO), and this stipulation removed 1 pure HO in second lactation and 3 MO-sired and 1 pure HO 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, herd-year 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 three-way interaction of herd, lactation number, and breed group. Lactational records were also pre-adjusted for age at calving with best prediction. The MIXED procedure of SAS (SAS Institute, 2008) was used for the ANOVA and to obtain solutions, and cow nested within breed group was defined as a random variable.

Fertility

The DO was days from calving to pregnancy and was verified by subsequent calving or, when available, by palpation. Cows were required to have at least 250 DIM, and cows with DO greater than 250 d were set to 250 d (VanRaden et al., 2004). As with the production analysis, 2 cows were required per combination of lactation number, herd-year, and breed of sire, and 6 MO-sired crossbred and 1 pure HO cows 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 US and is defined as the number of cows that became pregnant per number of total days at risk during a 21-d period of time (de Vries et al., 2005). To be included in the PR analysis, cows must have reached the voluntary waiting period in their respective herd. Days at risk was defined as days from the voluntary waiting period for first breeding to 1) pregnancy, 2) assignment of “do not breed”, 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 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 numbers.

Mortality Rate and Survival

Mortality was recorded in a binomial 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 at one location. Nine of these 17 cows were transferred from Morris to St. Paul after completion of either first or second lactation, and the other 8 cows were in third and later lactation at Morris and were sold for dairy purposes. After exclusion of these 17 cows, 57 MO × HO, 86 MO ×JH, and 153 pure HO cows remained for analysis of mortality rate.

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 binomial 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 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 opportunity to calve a fifth time; 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. The GLM procedure of SAS was used to obtain least squares means; however, the LOGISTIC procedure of SAS was used to determine significance of contrasts for breed groups.

Body Measurements

Trait descriptions. The HH was objectively measured from the ground to the sacrum in increments of 0.5 cm and measurements were obtained while cows were standing either in their stalls or in a chute. Cows at St. Paul had HH measured once per lactation between 4 and 272 DIM; however, cows at Morris were measured monthly throughout lactation. Observations at Morris prior to 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 one HH observation per lactation for each cow. The BW was recorded for each cow using a digital scale as cows exited the milking parlor. The BCS was recorded by the same person within each herd-year of calving 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 at St. Paul between October 2005 and September 2008 and monthly thereafter. At Morris, BW and BCS were recorded monthly during the p.m. milking for the entire collection period. Measurements for BW and BCS between 90 and 225 DIM were averaged for each cow at Morris, and this resulted in a single observation per lactation. The heart girth (**HG**) was objectively measured using a tape measure. Measurements of HG were obtained once per lactation in both herds and were from 4 to 288 DIM.

Foot angle (**FA**) 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 FA and HL were both measured on the dorsal abaxial wall between the periople line and the point of toe (Hahn et al., 1984). The FA was the slope, and HL was the greatest distance between the periople line and the point of toe. A protractor was used to obtain FA in degrees relative to the floor, and a conventional divider was used to obtain HL in increments of 0.1 cm. Measurements for FA and HL were from 9 to 288 DIM, except for only 3 cows that calved late in the herd-year and were measured after 305 DIM.

Rear udder height (**RU**), udder clearance (**UC**), front teat width (**TW**), and front teat length (**TL**) were objectively measured once per lactation while cows were either standing in a stall, in a chute, or in the milking parlor. The RU was the distance between the vulva and the top of the rear udder. The UC was the distance between the lowest point of the udder floor and the ground, TW was the inner distance between the front teats, and TL was the length of the front teat; however, if TL appeared noticeably different between the two front teats, then length of both front teats were averaged to obtain a single TL measurement. All cows within each herd-year had udders measured within the same 3-hr period relative to previous milking. Udders were measured from 4 to 288 DIM, except for 1 MO × JH and 1 pure HO cow, which calved late in their respective herd-year 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 10 body measurements. Additionally, 1 MO-sired crossbred and 1 pure HO cow in first lactation had HG observations beyond 305 DIM, and those two observations for HG were removed from the data. Cows were assigned to herd-year of calving and at least 2 cows per lactation number, herd-year, and breed group combination were required, which resulted in the removal of a single pure HO cow in second lactation (for all 10 body measurements) and another 10 MO-sired crossbred and 1 pure HO cows from third to fifth lactation (only for HG, FA, HL, RU, UC, TW, and TL).

Statistical analysis for all 10 body measurements had the fixed effects of herd, lactation number, interaction of herd and lactation number, herd-year 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 three-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, but this effect was not significant ($P > 0.05$) for most of the body measurements. The MIXED procedure of SAS was used to conduct the ANOVA and obtain solutions.

RESULTS AND DISCUSSION

Production and SCS

As expected, large differences in 305-d milk, fat, protein, and fat plus protein production existed between the 2 herds because of the difference in energy content of feed for the herds. As expected, cows increased in production with increasing lactation number; therefore, the majority of effects including herd, lactation number, herd-year, and their interactions explained significant variation for the production traits.

For 305-d fluid volume of milk, the MO × HO and pure HO cows, respectively, were similar for first (7,561 kg versus 7,901 kg), second (9, 142 kg versus 9,179 kg) and third to fifth (9,949 kg versus 10,012 kg) lactation groups. The MO × 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 groups. However, production of fat plus protein across lactation groups did not differ ($P = 0.30$)

for MO × HO (585 kg), MO × JH (573 kg), and pure HO (585 kg) cows. Table 2 has fat plus protein production of breed groups by herd and lactation number. Across herds, MO × HO cows were never different from pure HO cows and MO × JH cows were different ($P < 0.05$) from pure HO cows only for first lactation fat plus protein production (495 kg and 518 kg, respectively). These results are consistent with Walsh et al. (2008), who observed similar production of milk, SCM, fat, and protein production for MO × HO and pure HO cows. Heins and Hansen (2012) observed 3% less fat plus protein production for MO × HO compared to pure HO cows; however, the authors commented that 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.

Table 2. Least squares means and standard errors for 305-d actual fat plus protein production (kg) for breed groups.

Lactation	Pure Holstein			Montbeliarde × Holstein			Montbeliarde × Jersey/Holstein		
number	n	Mean	SEM	n	Mean	SEM	n	Mean	SEM
Both herds									
1	162	518	6.1	59	509	10.9	90	495*	8.4
2	107	596	7.3	47	603	12.2	73	601	9.3
3 - 5	72	641	9.4	77	643	10.8	82	623	9.7
St. Paul									
1	76	622	8.8	33	606	14.7	45	580**	11.9
2	61	687	9.7	27	676	16.0	39	666	12.6
3 - 5	43	742	11.9	51	714	12.9	38	704*	13.9
Morris									
1	86	413	8.3	26	411	16.0	45	411	11.7
2	46	506	10.9	20	530	18.3	34	537†	13.5
3 - 5	29	540	14.2	26	571	17.0	44	542	13.3

** $P < 0.01$, * $P < 0.05$, † $P < 0.10$ for difference from pure Holstein cows.

The interaction of herd and breed group was significant for fat plus protein production (*P* = 0.02) in this study, and MO × JH cows were more similar to pure HO for fat plus protein production in the low-input, grazing herd at Morris than in the high-input, confinement herd at St. Paul. Heins et al. (2011) reported JH cows had numerous shortcomings in a high production herd due to lower fat plus protein production in second and third lactation and greater culling for udder conformation for JH compared with pure HO cows.

For SCS, MO-sired crossbred cows (2.80) tended (*P* = 0.08) to be lower than pure HO cows (3.02) during the first 5 lactations. 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 × HO, MO × JH, and pure HO cows, respectively; however, MO × HO cows (2.37) had lower (*P* < 0.05) SCS than MO × JH (2.57) and pure HO (2.87) during second lactation. The results are similar to Heins and Hansen (2012), who reported MO × HO had lower (*P* < 0.05) SCS during first, fourth, and fifth lactations compared with pure HO cows.

Fertility

Herd-year of calving was the only statistically significant effect among the non-breed effects for DO. The DO were not different (*P* = 0.10) for the 2 herds despite hormonal synchronization for almost all AI services at St. Paul but very few of the AI services at Morris. For breed groups, MO × HO and MO × JH cows had significantly (*P* < 0.01) fewer DO than pure HO cows (Table 3), and the magnitude of the advantage was 5 to 6 wk. The interaction of herd and breed group was not significant (*P* = 0.08), and

MO-sired crossbred cows had large advantages for DO in both herds. In agreement with the present study, Kearney et al. (2004a) reported heterosis for fertility was expressed similarly across various management systems.

Table 3. Least squares means and standard errors for days open for breed groups.

Lactation number	Pure Holstein n	Pure Holstein Mean	Pure Holstein SEM	Montbeliarde × Holstein n	Montbeliarde × Holstein Mean	Montbeliarde × Holstein SEM	Montbeliarde × Jersey/Holstein n	Montbeliarde × Jersey/Holstein Mean	Montbeliarde × Jersey/Holstein SEM
		--------- (d) ---------			-------- (d) ---------			--------- (d) ---------	
1	134	161	6.0	53	127**	10.4	78	115**	8.1
2	75	178	8.0	40	135**	12.6	50	132**	10.5
3 - 5	50	161	10.6	61	122**	10.5	58	125**	10.1
Combined	359	167	5.2	154	128**	7.1	186	124**	6.0

** $P < 0.01$ for difference from pure Holstein cows.

The MO-sired crossbreds had a pronounced advantage ($P < 0.01$) over the pure HO cows for PR (Table 4). 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 during the first 5 lactations. Across all lactation numbers, the MO-sired crossbreds had significantly greater ($P < 0.01$) PR (+10.8% and +12.8%, respectively) than pure HO cows, and the degree of the difference was almost double the PR for MO-sired crossbreds compared to pure HO cows in this study. An advantage of PR over DO as a measure of fertility is the ability to evaluate DIM at the time of assignment to a cow of “do not breed” or exited the herd. In this study, 17% of MO-sired crossbred and 32% of pure HO lactations ended without a pregnancy.

Table 4. Pregnancy rate for breed groups.[1]

Lactation number	Pure Holstein	Montbeliarde × Holstein	Montbeliarde × Jersey/Holstein
	(%)	(%)	(%)
1	12.0 (161)	21.7** (59)	28.3** (85)
2	10.9 (104)	19.6** (48)	21.2** (72)
3 - 5	13.4 (68)	27.3** (72)	24.9* (78)
Combined	12.1 (333)	22.9** (172)	24.9** (235)

[1] Number of lactations in parenthesis.
** $P < 0.01$, * $P < 0.05$ for difference from pure Holstein cows.

Differences of this magnitude for DO and PR greatly impacted the profitability of cows in both herds, because pure HO cows were more frequently culled for infertility and had longer calving intervals. A pure HO national data file (DRMS, 2013) reported DO (152.0 d) and PR (16.5%) of pure HO cows, and the pure HO cows in this study were more challenged for fertility than cows in that data.

Mortality Rate and Survival

St. Paul (14.8%) and Morris (11.2%) experienced similar ($P = 0.61$) mortality rates across breed groups; however, grazing dairies typically have reduced death loss compared with other housing systems (Burow et al., 2011). In the present study, breed of sire was the only significant effect for mortality rate. The odds ratios from logistic regression analysis revealed 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 5); however, MO × JH (−6%) were not statistically different from pure HO cows because standard errors for MO × JH were large. The analysis of mortality rate contained 7 MO-sired crossbred and 6 pure HO cows that were still in the herd at the time of final data collection, and all of these cows were in fourth lactation or greater. These 13 cows were credited as eventually being sold although their final status was unknown; consequently, mortality rate may have been slightly underestimated.

Table 5. Least squares means and standard errors for mortality rate and survival to subsequent calving for breed groups.

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

[†] ** $P < 0.01$, * $P < 0.05$, † $P < 0.10$ for difference from pure Holstein cows.

The 17.7% mortality rate for pure HO in this study are comparable to the 16.5% reported by Dechow and Goodling (2008) and the 20.6% found by Pinedo et al. (2010); however, death of cows is somewhat underreported in national US data because many herds in the US fail to report cows that died prior to their first test day (Heins et al., 2012a). Mortalities represent a significant loss of income for dairy producers because carcass disposal has a cost of at least US$125, and average cull values of healthy dairy cows in Minnesota recently surpassed US$1,000.

For survival to subsequent calving, significantly ($P < 0.04$) more cows survived to second, third, and fourth calving at St. Paul than at Morris. Perhaps, the difference in survival between herds was partially a result of differences in culling policy relative to fertility because 1) cows at Morris were permitted fewer services to become pregnant, 2) the Morris herd followed a more rigid breeding season compared with St. Paul, and 3) the St. Paul herd was more tolerant of cows remaining in the herd for an additional year if they did not conceive the first year after calving.

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 (Table 5) than pure HO (68%) cows. However, both groups of MO-sired crossbred cows had greater ($P < 0.01$) survival to all subsequent lactations than pure HO cows (Table 5). The statistical contrast for pure HO by herd revealed many more ($P < 0.01$) pure HO cows survived to second calving at St. Paul than at Morris (83% versus 53%), and a similar result was observed ($P = 0.03$) for survival of pure HO cows to third calving (40% versus 23%) for St. Paul and Morris, respectively. When MO × HO and pure HO cows were compared in a grazing environment by Walsh et al. (2008), the pure HO cows survived only 1.9 lactations, compared to 3.8 lactations for MO × HO cows. Washburn (2009) stated poor survival of pure HO cows in grazing environments may be the driving factor for the increased use of crossbreeding among grazing herds in the US.

Body Measurements

HH, BW, BCS, and HG. Herd-year of calving, lactation number, and breed group significantly ($P < 0.01$) explained variation for HH. For breed groups (Table 6), MO × HO did not differ from pure HO for HH during any lactation number; however, MO × JH cows had significantly ($P < 0.01$) shorter HH than 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 JH cows had 8.8 to 9.4 cm shorter HH than pure HO cows during their first 3 lactations.

Table 6. Least squares means and standard errors for hip height, body weight, body condition score, and heart girth for breed groups.

Lactation	Pure Holstein			Montbeliarde × Holstein			Montbeliarde × Jersey/Holstein		
number	n	Mean	SEM	n	Mean	SEM	n	Mean	SEM
Hip height (cm)									
1	162	142.4	0.3	59	142.2	0.5	90	137.9**	0.4
2	101	145.1	0.3	47	145.1	0.6	68	140.2**	0.4
3 - 5	63	146.0	0.4	72	145.7	0.5	75	140.3**	0.5
Combined	326	144.5	0.3	178	144.3	0.5	233	139.5**	0.4
Body weight (kg)									
1	156	516	4.3	58	555**	7.5	85	507	5.9
2	99	534	5.0	46	614**	8.2	68	559†	6.4
3 - 5	65	627	6.2	71	666**	7.6	72	597**	6.7
Combined	320	572	4.2	175	611**	6.6	225	544**	5.3
Body condition score									
1	156	2.87	0.03	58	3.34**	0.04	85	3.36**	0.03
2	99	2.85	0.03	47	3.36**	0.05	69	3.31**	0.04
3 - 5	65	2.89	0.04	71	3.39**	0.05	72	3.33**	0.04
Combined	320	2.87	0.02	176	3.36**	0.03	226	3.33**	0.03
Heart girth (cm)									
1	159	189.7	0.6	56	189.9	1.1	86	185.7**	0.8
2	95	198.1	0.7	47	199.5	1.1	68	191.7**	0.9
3 - 5	55	205.6	1.0	63	205.0	1.1	62	196.9**	1.0
Combined	309	197.9	0.6	166	198.2	0.9	216	191.4**	0.7

** $P < 0.01$, † $P < 0.10$ for difference from pure Holstein cows.

All effects of herd, herd-year of calving, lactation number, and their interactions significantly explained variation for BW. Across breed groups, cows at St. Paul had greater BW in first (+66 kg), second (+44 kg) and third through fifth (+66 kg) lactation than cows at Morris. The MO × HO had significantly greater ($P < 0.01$) BW in all lactations compared with pure HO cows (Table 6); 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. Least squares means of BW for breed groups by lactation number revealed MO × HO and MO × JH had similar gains from first to second lactation (+59 kg and +52 kg, respectively) and also from second lactation to third through fifth lactations (+52 and +38 kg, respectively). On the other hand, the pure HO cows increased only 18 kg for BW from first to second lactation, but the pure HO cows had a much larger increase of BW from second to third through fifth lactations (+93 kg). Pure HO cows often experience more calving difficulty at first calving compared to crossbred cows (Heins et al., 2006) and, perhaps, this is an explanation for the reduced fertility, survival, and increase in BW of pure HO cows during first lactation compared to crossbreds in the present study.

Among the fixed effects for BCS, only herd, interaction of herd and lactation number, herd-year of calving, and breed group significantly ($P < 0.01$) explained variation. Cows at Morris (3.00) had lower BCS than cows at St. Paul (3.21) across lactations and breed groups. The MO-sired crossbred cows (3.35) had greater BCS than pure HO cows (2.87) across herds and lactations, and the MO × HO and MO × JH cows had significantly greater ($P < 0.01$) BCS than pure HO cows during every lactation (Table 6). The greater BCS of MO-sired crossbred cows may explain the large advantages for fertility and survival of MO-sired crossbred cows over pure HO cows, because the relationships of BCS with both fertility and health have been well-documented (Banos et al., 2004; Zwald et al., 2004). 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 to pure HO cows could also be a contributing factor to the improved health and fertility of MO-sired crossbreds.

For HG, the fixed effects of herd, lactation number, herd-year of calving, breed group, and interaction of lactation number and breed group all significantly ($P < 0.01$) explained variation. Least squares means of HG for cows at St. Paul (198.9 cm) were significantly ($P < 0.01$) larger than for cows at Morris (193.6 cm), and HG of cows increased with lactation number as expected. Across lactations, MO × HO and pure HO cows did not differ for HG ($P > 0.31$) despite the significantly ($P < 0.01$) greater BW of MO × HO cows during all lactations. On the other hand, HG of MO × JH was smaller ($P < 0.01$) than pure HO cows (Table 6) during first (−3.7 cm), second (−6.4 cm), and third to fifth (−8.9 cm) lactations.

Pearson correlation coefficients were calculated between BW and HG by breed group for cows with both BW and HG observations during the same lactations. The 165 MO × HO (0.79) and 215 MO × JH (0.83) had numerically lower correlations between BW and HG than the 300 pure HO (0.87) lactational observations. Dairy herd consultants and extension specialists routinely recommend using HG as a proxy for BW when assessing growth and size of dairy cattle, especially for growing heifers. Collectively, the HH, BW, BCS, and HG measurements suggest body shape and BW distribution are different for MO-sired crossbreds compared with pure HO cows, because

MO × HO have similar HH and HG but significantly greater BW and BCS compared with pure HO cows. Association of HG and BW should be further investigated with larger numbers of MO-sired crossbred and pure HO heifers and cows.

Foot Angle and Hoof Length. For FA and HL, almost all fixed effects in the model significantly ($P < 0.05$) explained variation. Time on pasture is beneficial for hoof conformation and health (Haskell et al., 2006); therefore, as expected, cows at Morris had both steeper FA (+ 1.4 degrees) and shorter HL (−0.11 cm) than cows at St. Paul. The MO × HO had significantly ($P < 0.01$) steeper FA (+1.8 degrees) and significantly ($P < 0.01$) shorter HL (−0.2 cm) across lactations (Table 7); however, MO × JH were not different ($P > 0.16$) for either FA or HL compared with pure HO cows. Correlations between hoof disorders and feet and leg conformation are generally 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.

Table 7. Least squares means and standard errors for foot angle and hoof length for breed groups.

Lactation	Pure Holstein			Montbeliarde × Holstein			Montbeliarde × Jersey/Holstein		
number	n	Mean	SEM	n	Mean	SEM	n	Mean	SEM
Foot angle, (degrees)									
1	160	45.3	0.4	58	47.5**	0.7	86	45.9	0.5
2	95	43.2	0.5	47	44.8†	0.7	69	41.9†	0.6
3 - 5	57	42.3	0.7	59	44.0	0.7	60	43.3	0.6
Combined	312	43.6	0.3	164	45.4**	0.5	215	43.7	0.4
Hoof length (cm)									
1	160	7.4	0.05	50	7.2†	0.09	86	7.4	0.07
2	94	8.2	0.07	47	7.9*	0.10	69	8.3	0.08
3 - 5	57	8.4	0.09	59	8.2	0.10	60	8.0**	0.09
Combined	311	8.0	0.05	156	7.8**	0.07	215	7.9	0.05

** $P < 0.01$, * $P < 0.05$, † $P < 0.10$ for difference from pure Holstein cows.

Udder. For the analysis of RU, UC, TW, and TL, the fixed effect of herd was significant only for TW, and cows at St. Paul had greater distance for TW (+2.1 cm) compared with cows at Morris. The effects of lactation number, interaction of herd and lactation number, and herd-year of calving were significant for all udder measurements, except interaction of herd and lactation number was not significant for TL.

The MO × HO and MO × JH cows had a significantly (P <0.01) lower RU (more distance from the vulva) in first lactation (+2.0 cm, +1.2 cm, respectively) and the MO × HO also had a lower RU in second lactation (+1.4 cm) compared to pure HO cows (Table 8). No significant differences existed (P > 0.59) for RU among cows in lactations 3 to 5. For UC, MO-sired crossbreds had significantly (P < 0.01) less udder clearance for each lactation (Table 8). Across lactations, the MO × HO (−2.6 cm) had significantly (P < 0.01) less UC than pure HO cows. The MO × JH had significantly (P < 0.03) less UC than both the MO × HO and pure HO breed groups (−2.1 cm, −4.7 cm, respectively) across lactations. Heins et al. (2011) reported less UC for JH compared with pure HO cows in first (−7.0 cm), second (−9.0 cm), and third (−8.5 cm) 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. One cow from each of the three breed groups was culled for udder conformation in this study; however, more MO × HO and MO × JH cows survived to third, fourth, and fifth calvings than pure HO cows. Consequently, no evidence exists to suggest the −3.8 cm udder clearance of MO-sired crossbreds was a primary reason for culling.

Table 8. Least squares means and standard errors for rear udder height, udder clearance, front teat width, and front teat length for breed groups.

Lactation number	Preference for trait	Pure Holstein			Montbeliarde × Holstein			Montbeliarde × Jersey/Holstein		
		n	Mean	SEM	n	Mean	SEM	n	Mean	SEM
Rear udder height (cm)	Less distance									
1		159	12.4	0.2	58	14.4**	0.4	87	13.6**	0.3
2		95	15.0	0.3	45	16.4**	0.5	63	15.1	0.4
3 – 5		55	17.5	0.4	63	17.6	0.4	61	17.8	0.4
Udder clearance (cm)	More distance									
1		159	57.2	0.4	58	54.7**	0.7	87	52.9**	0.5
2		95	51.6	0.4	47	49.1**	0.7	68	46.5**	0.6
3 – 5		55	46.0	0.6	62	43.2**	0.7	62	41.3**	0.6
Front teat width (cm)	Less distance									
1		159	13.7	0.3	58	15.8**	0.5	87	16.3**	0.4
2		95	14.4	0.4	47	16.4**	0.6	68	17.6**	0.5
3 – 5		55	15.6	0.5	62	18.5**	0.6	62	18.7**	0.5
Front teat length (cm)	Intermediate									
1		159	4.5	0.07	58	4.7	0.12	87	4.7	0.10
2		95	4.9	0.09	47	5.2	0.14	68	5.2†	0.11
3 – 5		55	5.2	0.12	62	5.4	0.14	62	5.4	0.12

** $P < 0.01$, * $P < 0.05$, † $P < 0.10$ for difference from pure Holstein cows.

The TW was significantly wider for both MO × HO (+2.1 cm, +2.0 cm, and +1.9 cm) and MO × JH (+2.6 cm, +3.2 cm, and +3.1 cm) in first, second, and third to fifth lactations, respectively, than the pure HO cows (Table 8). However, TL was not significantly different for MO × HO and MO × JH versus pure HO. Traditionally, dairy producers have selected cows with greater UC and less TW, and significant selection for udder conformation in pure HO cows has resulted in shallower udders and closer front and rear teat placement for first lactation cows. However, close rear teats are a concern for milking ability, and especially for the increasing numbers of producers who use automated milking systems. Miller et al. (1995) reported 12% of first-lactation pure HO cows had failure of cluster attachment due to close rear teat placement.

APPLICATIONS

The economic benefit of crossbreeding is now well documented in a variety of production environments. Globally, the use of the MO breed for rotational crossbreeding has grown in interest. Results from this study provide further evidence that MO-sired crossbred cows have similar fat plus protein production to pure HO cows. However, MO-sired crossbreds likely generate greater profit than pure HO cows. In the present study, the MO-sired crossbreds were superior to pure HO cows for fertility (−41 d for DO and +12% PR), survival (+13% to +25% survival to subsequent calving), and mortality rate (−6% to −12%).

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 1,106 d of longevity compared with 787 d of longevity for pure HO cows when a 4-yr maximum for survival after first calving was enforced. For the 4-yr interval, MO × HO cows had significantly greater ($P < 0.01$) lifetime fat plus protein production than the pure HO cows (1,608 kg versus 1,201 kg), and this included the impact of more days at peak production due to more frequent calving for the MO × HO cows than the pure HO cows. The MO × JH also had greater longevity (+174 d) and greater fat plus protein (+188 kg) during the same 4-yr period after first calving. The MO-sired crossbreds had a greater number of calves because they calved more frequently than pure HO cows.

Feed efficiency is of growing concern to dairy producers and to environmentalists. Despite the greater BCS of MO × HO compared to pure HO cows, MO-sired crossbreds consume no more feed to achieve greater BCS (Buckley et al., 2007; Hazel et al., 2013). A sensitivity analysis by Heins et al. (2012a) adjusted for feed consumption based on the greater BW of MO × HO cows; however, daily profit for MO × HO ($4.53) was still greater ($P < 0.01$) compared with pure HO ($4.46) cows, because other income in the profit equation swamped the potentially greater feed cost. Because health, fertility, and survival traits are often difficult to record and summarize, some dairy producers may incorrectly assume pure HO cows with high milk volume are always more profitable than crossbred cows. Consequently, some may believe crossbreeding is a mating practice applicable only to low-input herds or herds with suboptimal management.

Many of the alternative dairy breed combinations for crossbreeding have not yet been thoroughly vetted across production environments. Expression of heterosis for various breed combinations may differ in divergent environmental scenarios.

Furthermore, previous recommendations for crossbreeding may be outdated because of highly effective selection programs within the major dairy breeds.

In countries where grazing is predominant, JH cows have been preferred for their greater content of fat and protein, enhanced fertility, and superior profitability over pure HO cows (Lopez-Villalobos et al., 2000; Dillon et al., 2007; Pyman, 2007). For these low-input systems, Jersey AI bulls have been successfully incorporated into crossbreeding schemes. Results from this study suggest MO × HO cows had economic advantages over pure HO cows in both a high-input herd and a low-input herd; therefore, use of MO AI bulls for crossbreeding should not be eliminated from consideration in either type of environment.

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