Survival, lifetime production, and profitability of Normande × Holstein, Montbéliarde × Holstein, and Scandinavian Red × Holstein crossbreds versus pure Holsteins

B. J. Heins,^{*1} L. B. Hansen,^{*} and A. De Vriest[†]

^{*}Department of Animal Science, University of Minnesota, St. Paul 55108

[†]Department of Animal Sciences, University of Florida, Gainesville 32611

ABSTRACT

Pure Holstein (HO) cows ($n = 416$) were compared with Normande (NO) × HO ($n = 251$), Montbéliarde (MO) × HO ($n = 503$), and Scandinavian Red (SR) × HO ($n = 321$) crossbred cows for survival, lifetime production, and profitability in 6 commercial herds in California. The SR crossbred cows were sired by both Swedish Red and Norwegian Red bulls. Cows calved from June 2002 to January 2009. For analysis of survival to subsequent calvings, lifetime production, and profitability, data were restricted to 3 of 6 herds because they had at least 20 cows in each of the breed groups. All cows had the opportunity to calve at least 4 times. Best prediction, which is used by USDA for national genetic evaluations in the United States, was used to determine lifetime production to 4 yr (1,461 d) in the herd after first calving from test-day observations. Production and survival were estimated after 4 yr to calculate lifetime profit. A profit function was defined to include revenues and expenses for milk, fat, protein, and other solids production; somatic cell count; reproduction; feed intake; calf value; salvage value; dead cow disposal; and fixed cost. The NO × HO (1.2%), MO × HO (2.0%), and SR × HO cows (1.6%) had significantly fewer deaths than did pure HO cows (5.3%) during the first 305 d of first lactation. All crossbred groups had significantly more cows that calved a second, third, and fourth time, and had mean survival that was 300 to 400 d longer than did pure HO cows. The NO × HO, MO × HO, and SR × HO cows had significantly higher lifetime fat plus protein production than did pure HO cows up to 1,461 d after first calving. For profitability (ignoring possible differences in health costs), NO × HO cows had 26% greater projected lifetime profit per cow, but 6.7% less profit per cow-day, than did pure HO cows. On the other hand, MO × HO and SR × HO cows had 50

to 44%, respectively, more projected lifetime profit per cow and 5.3 to 3.6%, respectively, more projected profit per cow-day than did pure HO cows.

Key words: crossbreeding, heterosis, survival, economics

INTRODUCTION

The Holstein (HO) breed has dominated global milk production for the past 25 yr, and the success of selection for milk production has contributed to the domination of the HO breed. However, dairy producers with HO cattle have observed a substantial decrease in survival of cows (Hare et al., 2006), increased death rate of cows (Miller et al., 2008), and a sharp decrease in cow fertility (Norman et al., 2009) in recent years. From an economic standpoint, high culling rates in pure HO cows are of great concern to dairy producers (Weigel et al., 2003); therefore, dairy producers around the world have turned to mating pure HO heifers and cows to AI bulls from breeds of dairy cattle other than HO to reduce these problems.

Touchberry (1992) reported survival of crossbred cows versus pure Guernsey and pure HO cows over a 20-yr period from 1949 to 1969, and 88% of HO and Guernsey crossbred heifers survived to first calving, whereas only 83% of pure HO heifers survived to first calving. Eighty-five percent of crossbred cows calved twice; however, only 77% of pure HO cows calved twice (Touchberry, 1992). Furthermore, Touchberry (1992) combined measures of survival, growth, production, and reproduction into an economic index to calculate the total income per cow for crossbreds and purebreds. Crossbreds had 11.4% greater income per lactation at \$1,497 for crossbreds and \$1,344 for purebreds.

At Agriculture Canada, Vesely et al. (1986) reported no difference between crossbred cows of Ayrshire × HO and pure HO cows for percentage leaving the herd from first to second lactation. However, from the same experiment, Hocking et al. (1988) used survival analysis and found crossbred cows of Ayrshire and HO had

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¹Corresponding author: hein0106@umn.edu

greater herd life than did pure HO cows. McAllister et al. (1994) used lifetime data for all animals until culling, death, or the end of the study, and lifetime survival and health, growth, reproduction, production, and salvage value were recorded. The result was that Ayrshire $\times$ HO cows had significantly greater annualized and discounted net return than did pure HO cows. From the same experiment, but with an alternative economic analysis using data from the first 3 lactations of cows, Gunjal et al. (1997) found that pure HO cows had the highest net present value, pure Ayrshire cows had the lowest net present value, and the crossbred cows were intermediate. The net present value indicated that pure HO cows were the most profitable compared with pure Ayrshire cows and crossbred cows.

McDowell and McDaniel (1968) reported that Ayrshire $\times$ HO and Brown Swiss $\times$ HO cows did not differ significantly from pure HO cows for milk revenue or income over feed cost during first lactation; however, the inclusion of health treatments and mortality in their study resulted in crossbred cows being more profitable than pure HO cows.

The Animal Improvement Program Laboratory of the USDA (VanRaden and Sanders, 2003) reported that the mean productive life for crossbred cows was 24.3 mo compared with 23.8 mo for pure HO cows. Furthermore, VanRaden and Sanders (2003) compared the Net Merit, Cheese Merit, and Fluid Merit economic indexes for crossbreds and purebreds. Brown Swiss $\times$ HO and Jersey $\times$ HO cows were more profitable than pure HO cows for Net Merit and Cheese Merit, although no crossbred group was superior to pure HO cows for Fluid Merit (VanRaden and Sanders, 2003).

In Denmark, Sørensen et al. (2008) reported substantial heterosis (+18%) for the productive life of crossbred cows compared with purebred cows. Furthermore, heterosis for traits of economic value for 3-breed rotational crossbreeding was greater than 21%, and the study concluded that crossbreeding may provide a substantial amount of heterosis for total economic merit.

During the past decade, the Normande (**NO**), Montbéliarde (**MO**), and Scandinavian Red (**SR**) breeds were introduced into the United States and many other countries in the world for crossbreeding. Each of the 3 breeds has more than 300,000 cows on milk recording in its home country and has a sophisticated progeny-testing program. No previous research has compared NO $\times$ HO, MO $\times$ HO, and SR $\times$ HO cows to pure HO cows for high-input dairying. Therefore, the objectives of this study were to compare NO $\times$ HO, MO $\times$ HO, and SR $\times$ HO cows with pure HO cows for 1) deaths and removals to first milk recording and to 305 d postpartum during first lactation, 2) survival to subsequent calving (up to fourth calving), 3) lifetime production,

and 4) profitability. A companion paper (Heins and Hansen, 2012) reported results for the same herds of cows for fertility, SCS, and 305-d projected production.

MATERIALS AND METHODS

Data

A detailed description of the study and number of daughters per sire is reported in Heins and Hansen (2012). In brief, all cows initiated their first lactations between June 2002 and January 2005. Also, data collection spanned the period of time from June 2002 to January 2009. Calving dates, number of calves, and sex of calves born alive, breeding dates, pregnancy diagnoses of cows, DHI production, and disposal dates, along with reasons for disposal were provided by 6 commercial herds in California.

Data for this study were originally edited on test-day records (Heins et al., 2006b). However, many cattle did not survive to first milk recording; therefore, they were excluded from previously published results (Heins et al., 2006a). Data from herd records allowed the addition of 64 cows (9 NO $\times$ HO, 12 MO $\times$ HO, 7 SR $\times$ HO, and 36 pure HO) that calved in these 6 herds in the same window of time as the previously reported cows, but died or were culled before first milk recording. Therefore, 251 NO $\times$ HO, 503 MO $\times$ HO, 321 SR $\times$ HO, and 416 pure HO cows that calved for the first time from June 2002 to January 2005 were compared. The distribution of cows by herd and breed group is in Table 1, and the 6 herds were variable in number of cows and in extent of use of breeds for crossbreeding.

However, for the analysis of survival to subsequent calving, lifetime production, and profitability, the data were restricted to 3 of the 6 herds because they had at least 20 cows in each of the breed groups to provide a meaningful comparison of cows for lifetime performance within herds. Those 3 herds were herds 2, 4, and 6 in Table 1 with 168 NO $\times$ HO, 369 MO $\times$ HO, 218 SR $\times$ HO, and 165 pure HO cows to analyze survival, lifetime production, and profitability. The data for this study included only crossbreds with HO dams and pure HO cows, and therefore, the mating system did not permit the separation of additive genetic and heterotic effects.

Deaths and Survival

Crossbreds and pure HO cows were compared for survival to the first test day for milk recording and to 305 d postpartum during first lactation. Cows that died or were removed before the first test day and up to 305 d postpartum were recorded in a binary manner as died or removed (1) or alive in the herd (0). Further-

Table 1. Distribution of Normande $\times$ Holstein, Montbéliarde $\times$ Holstein, and Scandinavian Red $\times$ Holstein crossbred cows and pure Holstein cows by herd and breed group

Herd	Pure Holstein	Normande $\times$ Holstein	Montbéliarde $\times$ Holstein	Scandinavian Red $\times$ Holstein
1	232	13	7	59
2	51	60	94	84
3	3	27	42	25
4	74	75	182	81
5	16	43	85	19
6	40	33	93	53
Total	416	251	503	321

more, crossbreds and pure HO cows were compared for percentage of cows calving a second, third, and fourth time, because all cows had the opportunity to calve at least 4 times. Data were recorded in a binary manner as calved (1) or did not calve (0) a second, third, or fourth time. A χ^2 test (SAS Institute, 2008) was used to compare each crossbred group to the pure HO cows for all measures of survival. Additionally, logistic regression (SAS Institute, 2008), with fixed effects of herd and breed group, was used to determine odds ratios and significance of contrasts between breed groups.

Lifetime Production

Edits were applied to test-day observations for lifetime production and were described in Heins and Hansen (2012). Best prediction provided daily production, adjusted for age at calving, from 1 to 999 DIM for any lactation of a cow with a maximum of 50 test days (Cole et al., 2009); therefore, best prediction was used to predict production each day of lactation, excluding the dry period, and daily production was summed across lactations to determine lifetime production. Every cow had the opportunity to survive at least 4 yr (1,461 d) after first calving in these herds; therefore, lifetime was defined as the time from the date of first calving to 4 yr (1,461 d) in the herd after first calving. For lifetime production to 1,461 d, cows with records shorter than 305 d were not projected to 305 d, and all production beyond 305 d in lactation was included. For statistical analysis of lifetime production (milk, fat, protein, and fat plus protein), the independent variables were fixed effects of herd and breed group. The general linear model procedure of SAS (SAS Institute, 2008) was used to obtain solutions and conduct the ANOVA. Cows that did not survive to the first test day for milk recording were not included in the analysis of lifetime production.

Profitability

Lifetime profit was estimated as a function of the revenue and expense of cows during the first 4 yr (1,461 d)

after first calving, because all cows had the opportunity to survive to at least 4 yr after first calving. Profit per cow-day was then calculated as lifetime profit divided by total days in the herd for each cow. However, 352 cows (66 NO $\times$ HO, 160 MO $\times$ HO, 90 SR $\times$ HO, and 36 pure HO cows) of the total of 920 cows in the 3 herds survived beyond 4 yr after first calving.

The additional profit of the 352 cows that survived beyond the first 4 yr (1,461 d) after first calving was projected by multiplying the profit per day of a cow up to 4 yr after first calving (excluding replacement cost, salvage value, or dead cow disposal cost) by the predicted number of additional days that a cow remained in the herd. Hazards (risk of leaving the herd each day) were obtained from the survival rates of cows using the actuarial method in the LIFETEST procedures of SAS (SAS Institute, 2008), which predicted the additional number of days a cow would survive in the herd beyond the first 4 yr after first calving. The additional projected profit was then added to the actual profit from the first 4 yr after first calving to obtain the projected lifetime profit of a cow. In turn, projected profit per cow-day was obtained by dividing projected lifetime profit by projected total days in the herd since first calving for each cow.

Table 2 has default revenues and expenses used to determine lifetime profit. Milk price was \$0.3441/kg of milk (\$0.023/kg for milk volume, \$3.155/kg for fat solids, \$7.064/kg for protein solids, and \$0.395/kg for other solids), which was the mean milk price from 2007 to 2009 from component prices of the Federal Milk Marketing Order in the United States (USDA-AMS, 2010). Premiums for SCC (\$0.0008 per 1,000 somatic cells, plus or minus, from 350,000) were likewise from Federal Milk Marketing Order prices in the United States from 2007 to 2009. The mean percentage of other solids in milk (5.65%) was from Bailey et al. (2005).

The values of calves (\$250 for heifers and \$100 for bulls) and salvage value (\$525) for culled cows were from the Lifetime Net Merit of the USDA-Animal Improvement Programs Laboratory (VanRaden, 2006). Calf value and salvage value were each assumed to be

Table 2. Default revenues and expenses and alternative values for sensitivity analysis

Variable	Unit	Value	Reference
Revenue			
Milk price	kg	\$0.3441	USDA-AMS (2010)
Live female calf	Calf	\$250	VanRaden (2006)
Live male calf	Calf	\$100	VanRaden (2006)
Salvage value	Cow	\$525	VanRaden (2006)
Expense			
Dead cow disposal	Cow	\$125	Herds that were studied
Feed cost	kg (DMI)	\$0.2306	California Department of Food and Agriculture (2009)
Replacement cost	Heifer	\$1,200	Meadows et al. (2005)
Breeding cost	Breeding	\$40	VanRaden (2006)
Fixed lactation cost	d	\$1.50	Herds that were studied
Fixed dry cow cost	d	\$2.00	California Department of Food and Agriculture (2009)
Sensitivity			
Higher feed cost	kg (DMI)	\$0.3171	California Department of Food and Agriculture (2009)
Higher milk price	kg	\$0.4544	USDA-AMS (2010)
Lower milk price	kg	\$0.2339	USDA-AMS (2010)
Greater replacement cost	Heifer	\$1,625	Cole and VanRaden (2009)
Higher salvage value	Cow	\$800	Herds that were studied
Heavier BW for Normande × Holstein and Montbéliarde × Holstein	kg	+35 kg for first and +40 kg for later lactations	Hazel et al. (2009)

the same for crossbred and pure HO cows. Dead cow disposal cost was \$125, which was the approximate cost for the herds in the study. For the 352 cows that survived beyond 4 yr after first calving, salvage value was reduced by weighted mean death rates of cows (4.3% for NO × HO, 5.8% for MO × HO, 5.6% for SR × HO, and 7.3% for pure HO cows) during third, fourth, and fifth lactation.

Daily DMI was predicted using NRC (2001) requirements based on daily FCM from best prediction (Cole et al., 2009), BW, and days postpartum for each cow. Daily DMI was summed across lactations of cows for the first 4 yr after first calving. Fixed BW of 545 kg for first lactation and 680 kg for second-and-later lactations was assumed for all crossbred and pure HO cows for the prediction of DMI, because actual BW were not available. The mean daily feed cost (\$5.33/d) for lactating cows in crossbred herds in California from 2007 to 2009 (California Department of Food and Agriculture, 2009) was divided by the total DMI weighted by one-third for first-lactation cows and two-thirds for later-lactation cows to obtain the feed cost of \$0.2306 per kilogram of DMI.

The replacement cost was \$1,200 per cow, which was assumed to be the mean cost to raise a replacement heifer in the United States (Meadows et al., 2005). Fixed breeding expense was assumed to be \$40 per breeding, which included heat detection, hormones for synchronization programs, labor, semen cost, and pregnancy examination (VanRaden, 2006). Additionally, a daily fixed cost of \$1.50 was assumed for each lactating cow, which included costs of milking parlor supplies and labor. Furthermore, a daily fixed cost of \$2

was assumed for cows during the dry period (California Department of Food and Agriculture, 2009).

Cows that did not survive to the first test day in a lactation were assigned 11.34 kg (25 lb) of 3.5% FCM per day, which is considerably lower than the mean FCM for the first test day (29.9 kg/d) for these herds. However, cows that died or were culled before the first test day were expected to have greater health problems that would reduce FCM. Additionally, cows that did not survive to the first test day were assigned zero premium for SCC, and 11 kg of DMI per day, which was the mean DMI of HO cows from NRC (2001) during the first week of lactation. All other revenues and expenses for cows that did not survive to the first test day were the same as cows that did survive to the first test day.

Profitability was calculated as projected lifetime profit per cow and projected profit per cow-day. Lifetime profit is an appropriate measure when the number of heifers calving is the limiting factor. This measure assumes no opportunity costs of delayed replacement. To account for the time value of money, revenues and costs were discounted from the day of first calving by the discount factor $1/(1 + 0.05/365)^{t/365}$, where t is the number of days since first calving, and the annual interest rate is 5% (Brealey et al., 2009).

Profit per cow-day is an appropriate measure when the number of slots, or stalls, in the dairy is the limiting factor. We assumed cows that leave the herd are replaced by springing heifers of the same breed or crossbred group, and the supply of springing heifers was unlimited. We further assumed that the breed group demographics were constant over time. Consequentially, breed group total revenues and costs were constant

over time as well. Daily costs were multiplied by 5% for the opportunity cost of capital tied up maintaining the herd.

Sensitivity Analysis

Sensitivity analyses were performed to evaluate the effects of changes in the input variables on projected lifetime profit per cow and projected profit per cow-day. Alternative feed cost, milk price, replacement heifer cost, salvage value, as well as BW for NO $\times$ HO and MO $\times$ HO cows were used for sensitivity analysis (Table 2). Feed cost was increased from \$0.2306/kg to \$0.3171/kg of DMI. Two alternative milk price scenarios were higher milk price (32% higher at \$0.4544/kg) and lower milk price (32% lower at \$0.2339/kg), which coincided with component prices of \$0.045/kg for milk volume, \$3.527/kg for fat solids, \$10.375/kg for protein solids, and \$0.582/kg for other solids at the higher milk price, and with \$0.019/kg for milk volume, \$2.363/kg for fat solids, \$4.352/kg for protein solids, and \$0.130/kg for other solids at the lower milk price. Replacement heifer cost was increased from \$1,200 to \$1,625, which reflected circumstances when replacement heifers are sold for income rather than brought into the lactating herd or a higher cost of raising heifers. Salvage value was increased from \$525 to \$800. The BW for calculation of daily DMI from NRC prediction equations (NRC, 2001) for the NO $\times$ HO and MO $\times$ HO cows were increased by 35 kg for first lactation and 45 kg for later lactations, respectively. Increased BW for the 2 crossbred groups was based on the results of Hazel et al. (2009), who reported MO $\times$ HO cows had 36 kg greater BW than did pure HO cows during first lactation that was all due to greater body condition and not because of greater frame size compared with pure HO cows.

For statistical analysis of projected lifetime profit per cow and projected profit per cow-day, independent variables were fixed effects of herd and breed group.

For lifetime profit per cow, the GLM procedure of SAS (SAS Institute, 2008) was used to obtain solutions and conduct the ANOVA. However, for profit per cow-day, the MIXED procedure of SAS (SAS Institute, 2008) was used to obtain solutions and conduct the ANOVA, because all cows had a profit or loss for each day of herd life. Additionally, for the analysis of profit per day, the WEIGHT statement of MIXED was used for the unbalanced number of days cows spent in the herd.

RESULTS AND DISCUSSION

Survival

The number and percentage of 1,075 crossbred and 416 pure HO cows that died or were removed during first lactation are in Table 3. Deaths and all losses reflected the actual cows that left the 6 herds before the first test day and up to d 305 of lactation. The difference of NO $\times$ HO, MO $\times$ HO, and SR $\times$ HO cows compared with pure HO cows was statistically significant ($P < 0.05$) in all cases.

Only 18 of 1,075 crossbred cows (1.7%) compared with 22 of 416 pure HO cows (5.3%) died during the first 305 d of the first lactation. More crossbred cows remained in the herds than did pure HO cows, with only 2.6% of crossbred cows removed (died or culled) before the first test day compared with 8.7% of pure HO cows. In other words, crossbred cows were one-third as likely to die or be culled compared with pure HO cows in these herds before the first test day. Also, 7.4% of the crossbred cows versus 15.9% of the pure HO cows in these 6 herds were removed by d 305 of the first lactation.

The death rates in this study are higher than those of Miller et al. (2008), who reported death rates during first lactation of 2.1% for pure HO cows; however, some deaths before the first test day were not included in their 2.1%. Additionally, Miller et al. (2008) reported that death occurs more frequently in early lactation,

Table 3. Deaths and all losses during first lactation for Normande $\times$ Holstein, Montbéliarde $\times$ Holstein, and Scandinavian Red $\times$ Holstein crossbred cows and pure Holstein cows

Item	Pure Holstein (n = 416)		Normande $\times$ Holstein (n = 251)		Montbéliarde $\times$ Holstein (n = 503)		Scandinavian Red $\times$ Holstein (n = 321)	
	n	%	n	%	n	%	n	%
Deaths								
Prior to first test day	15	3.6	2	0.8*	5	1.0**	3	0.9*
Calving to 305 d	22	5.3	3	1.2**	10	2.0**	5	1.6**
All losses								
Prior to first test day	36	8.7	9	3.6*	12	2.4**	7	2.2**
Calving to 305 d	66	15.9	24	9.6*	35	7.0**	20	6.2**

* $P < 0.05$ for difference from pure Holsteins; ** $P < 0.01$ for difference from pure Holsteins.

which was the case for the pure HO in this study. Likewise, Dechow and Goodling (2008) found a 4.8% culling rate before first milk recording for pure HO cows, which is lower than the 8.7% in this study, but they concluded that only 19% of herds record culls before first milk recording during first lactation. Death rates of cows during first lactation are likely higher in the United States than is often reported, because some cows that die before the first test day are excluded from data files.

Table 4 has survival to subsequent calving and odds ratios for crossbred and pure HO cows in the 3 herds that had at least 20 cows in each of the 4 breed groups, and all crossbred groups had a greater ($P < 0.01$) percentage of cows calve a second, third, and fourth time than pure HO cows. The main difference for survival of crossbred cows versus pure HO cows was up to the third calving. Only 11 to 15% of crossbred cows did not calve a second time, whereas 25% of pure HO cows failed to calve a second time. Seventy-one to 75% of crossbred cows calved a third time, whereas only 51% of pure HO cows calved a third time. Also, a greater percentage of crossbred cows (21 to 25%) than pure HO cows calved a fourth time. The logistic regression analysis indicated higher odds ratios for survival to subsequent calving for crossbred cows compared with pure HO cows.

Survival rates to second, third, and fourth calving for pure HO cows in this study were comparable to those of Hare et al. (2006), who reported survival to second, third, and fourth calving of 73, 50, and 32%, respectively. Factors contributing to disappointing survival rates of pure HO cows include increases in inbreeding, calving difficulty, increases in death rate, hampered fertility, and more health disorders (Pinedo et al., 2010).

Lifetime Production

Results for lifetime production during the first 4 yr (1,461 d) after first calving are in Table 5. The NO $\times$ HO cows were not significantly ($P > 0.05$) different from pure HO cows for lifetime milk volume; however,

MO $\times$ HO and SR $\times$ HO cows had significantly ($P < 0.05$) higher lifetime milk volume than did pure HO cows. The NO $\times$ HO ($P < 0.05$), MO $\times$ HO ($P < 0.01$), and SR $\times$ HO cows ($P < 0.01$) had significantly greater lifetime fat, lifetime protein, and lifetime fat plus protein production than did pure HO cows during the first 4 yr after first calving. Furthermore, NO $\times$ HO, MO $\times$ HO, and SR $\times$ HO cows had significantly ($P < 0.05$) more revenue from production than did pure HO cows during the 4 yr after first calving. The greater lifetime production and revenue from production of the crossbreds was simply a consequence of their greater survival in these herds compared with pure HO cows.

On a percentage basis, the advantages for the crossbreds versus pure HO cows for fat plus protein production were 10.9% for NO $\times$ HO, 21.5% for MO $\times$ HO, and 15.5% for SR $\times$ HO cows. The results for lifetime production are different from the study of McAllister et al. (1994), who reported that Ayrshire $\times$ HO cows had similar lifetime milk, fat, and protein production compared with pure HO cows. Heins et al. (2012) reported that Jersey $\times$ HO cows had similar lifetime milk, fat, and protein production compared with pure HO cows, but that study included only the first 1,220 d after first calving.

Profitability

For projected lifetime profit per cow (Table 6), NO $\times$ HO (+\$1,120), MO $\times$ HO (+\$2,156), and SR $\times$ HO (+\$1,925) cows all had significantly ($P < 0.01$) greater projected lifetime profit per cow than did pure HO cows. However, all of the crossbred groups had significantly ($P < 0.01$) more projected days of herd life than did pure HO cows (Table 6). Therefore, the greater lifetime profit was spread over many more days in the herd for the crossbreds compared with pure HO cows. Dairy producers typically have a fixed capacity for the number of cows in their herds—either the number of stalls in a barn or the amount of land for grazing.

Table 4. Survival to subsequent calving for Normande $\times$ Holstein, Montbéliarde $\times$ Holstein, and Scandinavian Red $\times$ Holstein crossbred cows compared with pure Holstein cows¹

Parity	Pure Holstein		Normande $\times$ Holstein			Montbéliarde $\times$ Holstein			Scandinavian Red $\times$ Holstein		
	n	%	n	%	Odds ratio	n	%	Odds ratio	n	%	Odds ratio
1	165	—	168	—	—	369	—	—	218	—	—
2	124	75.2	148	+12.9**	2.42	328	+13.7**	2.70	186	+10.1**	1.88
3	84	50.9	123	+22.3**	2.63	276	+23.9**	2.92	155	+20.1**	2.36
4	48	29.1	89	+23.9**	2.75	203	+25.9**	3.07	110	+21.4**	2.47

¹Means for crossbred cows are expressed as a difference from pure Holsteins.

** $P < 0.01$ for difference from pure Holsteins.

Table 5. Least squares means for lifetime milk, fat, and protein production¹ to 1,461 d for Normande × Holstein, Montbéliarde × Holstein, and Scandinavian Red × Holstein crossbred cows compared with pure Holstein cows²

Trait	Pure Holstein (n = 151)		Normande × Holstein (n = 162)		Montbéliarde × Holstein (n = 360)		Scandinavian Red × Holstein (n = 212)	
	Mean	SE	Mean difference	SE	Mean difference	SE	Mean difference	SE
Milk (kg)	28,086	1,069.4	+1,680	1,037.4	+4,805**	704.0	+3,190*	902.5
Fat (kg)	996	40.6	+108*	39.4	+221**	26.7	+158**	34.2
Protein (kg)	871	33.9	+95*	32.9	+179**	22.3	+132**	28.6
Fat plus protein (kg)	1,867	74.3	+203*	72.1	+401**	48.9	+290**	62.7
Revenue from production (\$)	10,695	418.9	+1,105*	406.4	+2,217**	275.7	+1,602**	353.5
Days of herd life (d)	937	33.6	+172**	32.6	+213**	22.1	+155**	28.4

¹Production within the 4-yr period (1,461 d) after first calving.

²Least squares means for crossbred cows are expressed as a difference from pure Holsteins.

* $P < 0.05$ for difference from pure Holsteins; ** $P < 0.01$ for difference from pure Holsteins.

Consequently, the opportunity for profit per day from a fixed number of cows in the herd is likely of most economic importance for dairy producers.

The NO × HO cows had significantly ($P < 0.01$) less profit per day (−\$0.28) than did pure HO cows; however, the MO × HO (+\$0.22) and SR × HO (+\$0.15) cows had significantly ($P < 0.01$) more profit per day than pure HO cows. The differences among the crossbred breed groups for profit per day were rather striking, because the MO × HO crossbreds had 5.3% more profit per day and the SR × HO crossbreds had 3.6% more profit per day compared with the pure HO cows; however, the NO × HO crossbreds had 6.7% less profit per day than did the pure HO cows. The results suggest projected profit per cow-day of NO × HO cows was unfavorable at the high production levels of these confinement herds in California. Perhaps, NO × HO cows would perform better for daily profit compared with pure HO cows in low-input grazing environments.

The results for opportunity for profit per cow-day differed substantially from the results for lifetime profit per cow for the breed groups. The advantages for profit per day of the MO × HO and SR × HO crossbred cows over pure HO cows may seem modest. However, the daily profit margin must be multiplied by 365 d to estimate annual difference in profit, and the estimates of profit per day ignore potential differences in breed groups for health costs. The additional profit per day on an annual basis was \$80 for MO × HO and \$55 for SR × HO cows compared with pure HO cows, which, for a 250-cow herd, would result in an additional annual profit of \$20,000 for MO × HO cows and \$13,750 for SR × HO cows compared with pure HO cows.

The specific partitions of revenue and costs that contributed to projected lifetime profit per cow and projected profit per cow-day are in Tables 7 and 8, respectively. All crossbred groups had significantly ($P < 0.01$) more lifetime revenue than did pure HO cows from production, from the SCC premium, and from the value of calves (Table 7). Specifically, the highest revenue was from the fat and protein solids in milk, especially the protein solids.

For lifetime costs, crossbred cows had significantly ($P < 0.05$) higher feed cost, breeding cost, fixed lactation cost, and fixed dry cow cost than did pure HO cows (Table 8). Not surprisingly, feed cost was the highest expense for all breed groups of cows, and all of the crossbred groups had significantly ($P < 0.01$) greater feed cost than did pure HO cows. The expense for each of these categories was logically higher, because the crossbred groups of cows remained in the herds 300 to 400 d longer than the pure HO cows (Table 6).

For profit per day (Table 8), NO × HO cows had significantly ($P < 0.01$) less value of milk on a daily

Table 6. Least squares means for projected days of herd life, projected lifetime profit per cow, and projected profit per cow-day for Normande × Holstein, Montbéliarde × Holstein, and Scandinavian Red × Holstein crossbred cows compared with pure Holstein cows¹

Item	Pure Holstein (n = 165)		Normande × Holstein (n = 168)		Montbéliarde × Holstein (n = 369)		Scandinavian Red × Holstein (n = 218)	
	Mean	SE	Mean difference	SE	Mean difference	SE	Mean difference	SE
Days of herd life	946	50.0	+317**	49.8	+412**	33.9	+360**	43.5
Lifetime profit (\$)	4,347	309.1	+1,120**	307.6	+2,156**	209.8	+1,925**	268.8
Profit per day (\$)	4.17	0.01	−0.28**	0.01	+0.22**	0.01	+0.15**	0.01

¹Means for crossbred cows are expressed as a difference from pure Holsteins.

** $P < 0.01$ for difference from pure Holsteins.

basis than did pure HO cows. On the other hand, the NO × HO cows had the lowest feed cost per day of all breed groups, which was significantly ($P < 0.01$) lower than that of pure HO cows. Replacement costs were the second largest expense for all breed groups on a daily basis after feed cost, and NO × HO (−\$0.38), MO × HO (−\$0.49), and SR × HO (−\$0.41) cows had significantly ($P < 0.01$) lower replacement cost per day than did pure HO cows. The crossbreds survived longer and calved more frequently than the pure HO cows; therefore, they produced more female offspring.

Costs for health treatments were not available from the herds in this study, and inclusion of costs for health treatments may have affected the results for profit. For all livestock species, heterosis tends to be expressed most notably for traits related to fitness; therefore, the inability to compare the crossbred cows with pure HO cows for health costs is a glaring deficiency of this study. Increased health cost of pure HO cows over time

is a major justification provided by dairy producers for deciding to use crossbreeding. Testimonials from the owners of these 3 herds indicated that crossbreds had fewer health problems near the time of calving and fewer metabolic disorders throughout their lifetimes. The results of this study were similar to those of VanRaden and Sanders (2003), who reported that crossbred cows had more profit than pure HO cows without the inclusion of health costs.

Sensitivity Analysis

Results from the sensitivity analysis for projected lifetime profit per cow are in Table 9. A higher feed cost decreased the difference between all of the crossbred groups and pure HO cows compared with default values; however, the crossbred groups continued to have a significant advantage for projected lifetime profit per cow (Table 9). Consequently, the NO × HO gained

Table 7. Least squares means for projected lifetime profit per cow by specific component of revenue and cost for Normande × Holstein, Montbéliarde × Holstein, and Scandinavian Red × Holstein crossbred cows compared with pure Holstein cows¹

Item	Pure Holstein (n = 165)		Normande × Holstein (n = 168)		Montbéliarde × Holstein (n = 369)		Scandinavian Red × Holstein (n = 218)	
	Mean	SE	Mean difference	SE	Mean difference	SE	Mean difference	SE
Revenue (\$)								
Milk volume	638	35.1	+128**	34.9	+239**	34.9	+211**	30.5
Fat solids	3,178	184.3	+811**	183.4	+1,368**	125.1	+1,213**	160.3
Protein solids	6,216	349.0	+1,597**	347.2	+2,577**	236.8	+2,318**	303.5
Other solids	632	34.8	+127**	34.6	+237**	23.6	+209**	30.2
SCC premium	141	9.3	+38**	9.2	+68**	6.3	+60**	8.0
Calf value	443	26.2	+148**	26.0	+202**	17.7	+149**	22.7
Salvage value	433	13.0	+19	12.9	+15	246.3	+18	11.3
Cost (\$)								
Dead cow disposal cost	19	3.2	−4	3.1	−5	2.1	−5	2.8
Feed cost	4,552	245.2	+1,221**	244.0	+1,842**	166.4	+1,617**	213.2
Replacement cost	1,260	0.0	0	0.0	0	0.0	0	0.0
Breeding cost	321	19.2	+59*	19.1	+113**	13.0	+116**	16.7
Fixed lactation cost	1,313	66.1	+395**	65.7	+525**	44.8	+459**	57.4
Fixed dry cow cost	228	17.9	+126**	17.8	+145**	12.2	+124**	15.6

¹Means for crossbred cows are expressed as a difference from pure Holsteins.

* $P < 0.05$ for difference from pure Holsteins; ** $P < 0.01$ for difference from pure Holsteins.

Table 8. Least squares means for projected profit per cow-day by specific component of revenue and cost for Normande × Holstein, Montbéliarde × Holstein, and Scandinavian Red × Holstein crossbred cows compared with pure Holstein cows¹

Item	Pure Holstein (n = 165)		Normande × Holstein (n = 168)		Montbéliarde × Holstein (n = 369)		Scandinavian Red × Holstein (n = 218)	
	Mean	SE	Mean difference	SE	Mean difference	SE	Mean difference	SE
Revenue (\$)								
Milk volume	0.68	0.000	−0.08**	0.000	−0.04**	0.000	−0.04**	0.000
Fat solids	3.37	0.001	−0.22**	0.001	−0.01**	0.001	−0.03**	0.001
Protein solids	6.60	0.002	−0.44**	0.001	−0.15**	0.001	−0.12**	0.001
Other solids	0.67	0.000	−0.07**	0.000	−0.03**	0.000	−0.03**	0.000
SCC premium	0.15	0.000	−0.01**	0.000	+0.01**	0.000	0.00	0.000
Calf value	0.48	0.001	−0.02**	0.001	0.00	0.001	−0.02**	0.001
Salvage value	0.44	0.003	−0.07**	0.002	−0.11**	0.002	−0.09**	0.002
Cost (\$)								
Dead cow disposal cost	0.03	0.001	−0.02**	0.001	−0.02**	0.000	−0.02**	0.001
Feed cost	4.82	0.001	−0.25**	0.001	−0.12**	0.000	−0.10**	0.001
Replacement cost	1.43	0.01	−0.38**	0.01	−0.49**	0.01	−0.41**	0.01
Breeding cost	0.33	0.000	−0.02**	0.000	−0.01**	0.000	+0.01**	0.000
Fixed lactating cost	1.39	0.000	−0.03**	0.000	−0.04**	0.000	−0.03**	0.000
Fixed dry cow cost	0.24	0.000	+0.04**	0.000	+0.04**	0.000	+0.02**	0.000

¹Means for crossbred cows are expressed as a difference from pure Holsteins.

** $P < 0.01$ for difference from pure Holsteins.

(−\$0.28 to −\$0.25) for profit per day relative to the pure HO cows. Furthermore, higher feed costs had a proportionately greater effect on NO × HO and pure HO cows (−39%) than on the MO × HO and SR × HO cows (−30%).

A higher milk price resulted in much higher ($P < 0.01$) lifetime profit for the crossbred groups compared with pure HO cows, which was simply a reflection of their higher lifetime production. For profit per day, the difference of NO × HO and pure HO cows expanded from −\$0.28 to −\$0.58 with the higher milk price. The MO × HO (+\$0.08) cows continued to have significantly ($P < 0.01$) greater profit per day with the higher milk price than did pure HO cows, but the difference from pure HO cows was reduced.

A lower milk price dramatically reduced lifetime profit for all breed groups, but NO × HO cows were no longer significantly different from pure HO cows when milk price was lower. However, MO × HO and SR × HO cows continued to have substantial ($P < 0.01$) advantages (+101% and +89%, respectively) compared with pure HO cows for lifetime profit. The gap between NO × HO and pure HO cows was substantially reduced for profit per day (−\$0.28 to −\$0.06) at the lower milk price; however, the MO × HO (+\$0.22 to +\$0.24) and SR × HO (+\$0.15 to +\$0.16) cows had greater advantage over pure HO cows when milk price was lower.

The higher replacement cost increased profit per day (Table 10) for NO × HO (−\$0.28 to −\$0.19), MO × HO (\$0.22 to \$0.34), and SR × HO (\$0.15 to \$0.24)

Table 9. Least squares means for projected lifetime profit per cow from sensitivity analysis for Normande × Holstein, Montbéliarde × Holstein, and Scandinavian Red × Holstein crossbred cows compared with pure Holstein cows¹

Scenario	Pure Holstein (n = 165)		Normande × Holstein (n = 168)		Montbéliarde × Holstein (n = 369)		Scandinavian Red × Holstein (n = 218)	
	Mean	SE	Mean difference	SE	Mean difference	SE	Mean difference	SE
Default revenue and expenses (\$)	4,347		+1,120		+2,156		+1,925	
Higher feed cost (\$0.3171/kg)	2,690	225.2	+682*	224.1	+1,497**	152.8	+1,339**	195.8
Higher milk price (\$0.4544/kg)	7,849	507.0	+2,019**	504.4	+3,626**	344.1	+3,238**	440.9
Lower milk price (\$0.2339/kg)	631	110.0	+206	109.5	+640**	74.6	+564**	95.7
Greater replacement cost (\$1,625)	3,900	310.6	+1,126**	309.1	+2,167**	210.8	+1,929**	270.1
Higher salvage value (\$800)	4,553	312.4	+1,135**	310.8	+2,175**	212.0	+1,938**	271.6
Heavier BW for NO and MO ²	4,412	312.5	+1,057*	310.9	+2,100**	212.1	+1,963**	271.8

¹Means for crossbred cows are expressed as a difference from pure Holsteins.

²NO = Normande × Holstein, MO = Montbéliarde × Holstein.

* $P < 0.05$ for difference from pure Holsteins; ** $P < 0.01$ for difference from pure Holsteins.

Table 10. Least squares means for projected profit per cow-day from sensitivity analysis for Normande $\times$ Holstein, Montbéliarde $\times$ Holstein, and Scandinavian Red $\times$ Holstein crossbred cows compared with pure Holstein cows¹

Scenario	Pure Holstein (n = 165)		Normande $\times$ Holstein (n = 168)		Montbéliarde $\times$ Holstein (n = 369)		Scandinavian Red $\times$ Holstein (n = 218)	
	Mean	SE	Mean difference	SE	Mean difference	SE	Mean difference	SE
Default revenue and expense (\$)	4.17		-0.28		+0.22		+0.15	
Higher feed cost (\$0.3171/kg)	2.59	0.01	-0.25**	0.01	+0.18**	0.01	+0.11**	0.01
Higher milk price (\$0.4544/kg)	8.10	0.01	-0.58**	0.01	+0.08**	0.01	+0.02	0.01
Lower milk price (\$0.2339/kg)	0.45	0.01	-0.06**	0.01	+0.24**	0.01	+0.16**	0.01
Greater replacement cost (\$1,625)	3.91	0.01	-0.19**	0.01	+0.34**	0.01	+0.24**	0.01
Higher salvage value (\$800)	4.34	0.01	-0.31**	0.01	+0.16**	0.01	+0.09**	0.01
Heavier BW for NO and MO ²	4.46	0.01	-0.41**	0.01	+0.07**	0.01	+0.09**	0.01

¹Means for crossbred cows are expressed as a difference from pure Holsteins.

²NO = Normande $\times$ Holstein, MO = Montbéliarde $\times$ Holstein.

** $P < 0.01$ for difference from pure Holsteins.

cows compared with pure HO cows. Dairy producers are aware of the cost of raising a replacement heifer, and the results of this study indicate that more profit per day can be achieved from crossbreeding compared with pure HO when replacement costs are greater. The current study assumed the same cost (\$1,200) to raise a crossbred or pure HO heifer. However, the difference for lifetime profit may have been greater for crossbreds than pure HO because crossbred young stock may have higher survival and enhanced fertility and, therefore, fewer days to first calving, which results in reduced rearing costs of heifers.

The higher salvage value did not affect the results for difference in lifetime profit per cow of crossbred versus pure HO cows; however, for profit per cow-day, the difference from pure HO increased \$0.03 for NO $\times$ HO cows, and decreased \$0.06 for MO $\times$ HO and SR $\times$ HO cows. Fewer crossbred versus pure HO cows were culled on a given day in the herd, which resulted in less revenue from salvage value on a daily basis for the crossbreds. Also, the difference between replacement cost and salvage value has a large effect on the profitability of dairying. When salvage value is very high and replacement cost is very low, the cost of replacing cows becomes quite small. On the other hand, when salvage value is low and replacement cost is high, replacing cows is very costly.

Results for profit per day with increased BW of NO $\times$ HO and MO $\times$ HO cows must be interpreted with caution. As expected, the profit per day was reduced for the NO $\times$ HO (-\$0.13) and MO $\times$ HO (-\$0.15) crossbred cows with the higher BW. Some may assume NO $\times$ HO and MO $\times$ HO crossbred cows consume more DM than do pure HO cows because of greater BW; however, the potential for greater BW of NO $\times$ HO and MO $\times$ HO cows may not actually reflect increased DMI compared with pure HO cows. First, the greater BW of

MO $\times$ HO crossbreds is expected to result from greater body condition and not from greater frame size (Hazel et al., 2009) and second, heterosis is anticipated for feed efficiency of dairy cattle. Hazel et al. (2009) reported that MO $\times$ HO cows were similar to pure HO cows for DMI (numerically, the crossbreds were 1 kg/d lower for DMI) and identical for fat plus protein production; however, the MO $\times$ HO cows had more body condition with no difference in hip height.

Unfortunately, health costs are often overlooked by dairy producers when assessing the profitability of alternative genotypes of dairy cattle. For this study, lifetime profit per cow and profit per cow-day excluded health costs, because health events were not provided by the herd owners. Data on health costs will be important for dairy producers to compare crossbred and pure HO cows. Moreover, dairy producers typically prefer to work with cows with fewer health problems. Therefore, additional research that includes routine collection of health costs is needed to fully assess the profitability of NO $\times$ HO, MO $\times$ HO, and SR $\times$ HO cows compared with pure HO cows.

Research has been initiated around the world to compare NO $\times$ HO, MO $\times$ HO, and SR $\times$ HO crossbred cows to pure HO cows for profitability, and some of these studies include health costs. Regardless of breeds used for crossbreeding, complete recording of production, survival, fertility, and health is essential to assess the profitability of crossbred versus purebred cows.

CONCLUSIONS

Dairy producers may improve the survival of cows and the profitability of dairying by crossing pure HO cows with bulls of at least some other breeds of dairy cattle. The NO $\times$ HO, MO $\times$ HO, and SR $\times$ HO cows had more projected lifetime profit per cow than did

pure HO cows; however, crossbreds remained in herds much longer to achieve the substantial advantages for projected lifetime profit per cow. Projected profit per cow-day was significantly greater for MO $\times$ HO (+\$0.22) and SR $\times$ HO (+\$0.15) than for pure HO cows, but significantly lower for NO $\times$ HO (−\$0.28) than pure HO cows in these confinement dairies.

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