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ProCROSS crossbreds were more profitable than their Holstein herdmates in a 10-year study with high-performance Minnesota dairy herds

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TAKE HOME MESSAGES

- Unlike previous research on crossbreeding of dairy cattle, this 10-year study had controlled and balanced enrollment of foundation cows, had a clear design, used high-ranking proven A.I. bulls for all breeds (Holstein, Viking Red, and Montbeliarde), and had dedicated recording of data by the high-performance participating herds.
- The use of the Holstein, Viking Red, and Montbeliarde breeds in a 3-breed rotational program is marketed as ProCROSS.
- Daily fat + protein production for lifetimes of cows was +1% higher for 2-breed crossbreds (Viking Red×Holstein and Montbeliarde×Holstein) and was –1% lower for 3-breed crossbreds than their Holstein herdmates.
- All generations of the crossbred cows had lower stillbirth rates, and the 3-breed crossbred calves born to 2-breed crossbred dams had one-half the number of stillborn calves at 1st calving than their Holstein herdmates.
- The 2-breed crossbreds had 12 fewer days open and the 3-breed crossbreds had 17 fewer days open than their Holstein herdmates.
- Health treatment cost was –23% lower for the 2-breed crossbreds and –17% lower for 3-breed crossbreds than their Holstein herdmates.
- Lifetime death loss was –4% lower for both the 2-breed crossbreds and the 3-breed crossbreds than their Holstein herdmates.
- The combined 2-breed and 3-breed crossbreds had +153 more days in the herd than their Holstein herdmates. Therefore, replacement cost was substantially lower for both the 2-breed and 3-breed crossbreds than their Holstein herdmates.
- Daily profit was +13% higher for the 2-breed crossbreds and +9% higher for the 3-breed crossbreds than their Holstein herdmates.
- The average inbreeding coefficient of U.S. Holstein females born in 2019 surpassed 8%, and the annual rate of increase in average inbreeding is approaching +0.4%, which seems to be an unsustainable increase into the future.
- Heterosis (hybrid vigor) from crossbreeding is most influential for traits related to fertility, health, and survival, and it comes on top of genetic improvement within breeds.

MOTIVATION FOR THE STUDY

Interest in crossbreeding of dairy cattle continues to increase globally. The Holstein **(HO)** breed has been tremendously successful in selection for milk production over the past 40 years. The success resulted in the HO breed almost becoming a monoculture for milk production globally at the start of the 21st century. However, the HO breed also selected strongly for larger body size and more angularity of cows on top of the selection for production. All three of these traits have genetic antagonism with fertility, health, and survival of cows. Therefore, the HO breed experienced rapid decline in these functional traits. In recent years, effort has been made to increase selection in the HO breed for these functional traits, but the traits have low genetic control and continue to be antagonistic with the continued selection for production.

The adoption and use of genomic selection in the U.S. over the past 10 years has greatly accelerated the annual increase of average inbreeding of HO females, mostly because the generation interval (time between each generation) has been halved. Therefore, the average inbreeding coefficient rose to 8.02% for HO females born during the very beginning of 2019. For reference, the inbreeding resulting from a bull mated to his own daughter is 25% and the mating of 1st cousins results in inbreeding of 6.25%, which is the level of inbreeding the HO breed surpassed in 2014. Even more alarming is the acceleration of average inbreeding in recent years, because average inbreeding has increased about +0.35% in each of the past 4 years. Inbreeding depression silently steals profit from dairy producers, because it is expressed mostly for traits that are not readily noticeable such as embryo loss, less disease resistance, and shortened survival.

Heterosis (hybrid vigor) from crossbreeding is expressed as an equal and opposite effect of inbreeding depression. When parents of different breeds are mated to create a crossbred animal, the 2 genes at the same location on the chromosomes cannot be identical from a common ancestor. Therefore, recessive genes of both major and minor consequence are not likely to be expressed with crossbreeding. Heterosis (hybrid vigor) has been embraced by the pig, beef, sheep, chicken, and turkey industries for more than 40 years.

However, it's important to keep in mind heterosis (hybrid vigor) does not replace genetic improvement within breeds, which increases the frequency of desirable genes. The support for, and the stewardship of, breeds with robust genetic improvement programs is critical for successful crossbreeding programs. Dairy producers should select 3 breeds of dairy cattle that are appropriate for their specific management systems and use the highest-ranking artificial insemination (A.I.) bulls from each of the 3 breeds.

This 10-year study compared cows from a 3-breed rotational crossbreeding program using the HO, Viking Red **(VR)**, and Montbeliarde **(MO)** breeds with their pure HO herdmates. The study was initiated in 2008 and continued through 2017. This 3-breed crossbreeding program is referred to as ProCROSS and is jointly marketed by 2 breeding companies (Viking Genetics and Coopex Montbeliarde). The VR breed is the result of combining the genetic improvement programs of the previously separate Swedish Red, Finnish Ayrshire, and Danish Red breeds.

The goal of the study was to compare the profitability of crossbreds and their HO herdmates with special interest in differences for health treatment costs and other input costs. The dairy producers who participated in the study want cows in their herds with high production but with lowest input cost and excellent health. The participating managers of the 7 herds were aware MO×HO and Nordic Red×HO crossbreds had 4% to 5% higher daily profit than their HO herdmates in an earlier field study in California.

DESIGN OF THE STUDY

The 7 Minnesota herds were enrolled in the study in 2008 by researchers at the University of Minnesota, and the managers of the herds committed 3,550 HO virgin heifers and cows as the "foundation" females. The herds were located in central, southeastern, and southwestern Minnesota and were elite for production. At the end of the study in December 2017, the 7 herds had average production of 13,587 kg milk, 512 kg fat, and 426 kg protein with an average herd size of 982 cows. All herds fed a total mixed ration, and lactating cows were housed in free-stall confinement barns.

This study is very unique, because no previous study on crossbreeding with U.S. commercial dairy herds was carefully designed in regard to matings across generations. Each of the 7 herds in the study offered a minimum of 250 foundation HO females, which were assigned by the researchers to be mated such that their descendants across generations would be either HO or ProCROSS. The foundation females were paired and assigned to the 2 breed types based on their age (for heifers), lactation number (for cows), sire, and production level.

At least 150 foundation females were mated in each herd to HO A.I. bulls, as were their descendants across generations. Also, at least 100 foundation HO females were mated in each herd to either VR or MO A.I. bulls (in equal number) to initiate a 3-breed rotational program in both directions. The 2-breed crossbred offspring of the foundation females were mated to the 3rd breed to create 3-breed crossbreds. Finally, all 3-breed crossbreds were mated to HO A.I. bulls to keep the rotation moving forward. The 2 alternative rotations of breeds in each direction continued in successive generations in a designated order such as in Figure 1.

Some of the herds decided to enroll more than 250 HO foundation females in the study, and those herds chose which breed type the additional foundation females would be assigned. The enrollment by individual herds ranged from 250 to 785 foundation females, and 44% of these were mated to HO A.I. bulls and 56% were mated equally to VR and MO A.I. bulls. Female progeny were housed and managed together in the herds and treated the same in all ways including age at 1st breeding, health treatment, and culling. Lactating cows in the herds were grouped according to lactation number, days in milk, or pregnancy status.

Semen from proven A.I. bulls from the 3 breeds was used to breed heifers and cows in the study. Producers chose the A.I. bulls in consultation with 2 genetic advisors of Minnesota Select Sires Co-op, Inc. The VR and MO A.I. bulls were imported to the U.S. by Creative Genetics of California and ranked highly for the Nordic Total Merit index or the French ISU index, which are the national indices for the 2 breeds. Herd managers were asked to select proven HO A.I. bulls ranking among the top 10% for the U.S. Net Merit Index, and all of the HO A.I. bulls were marketed by Select Sires, Inc.

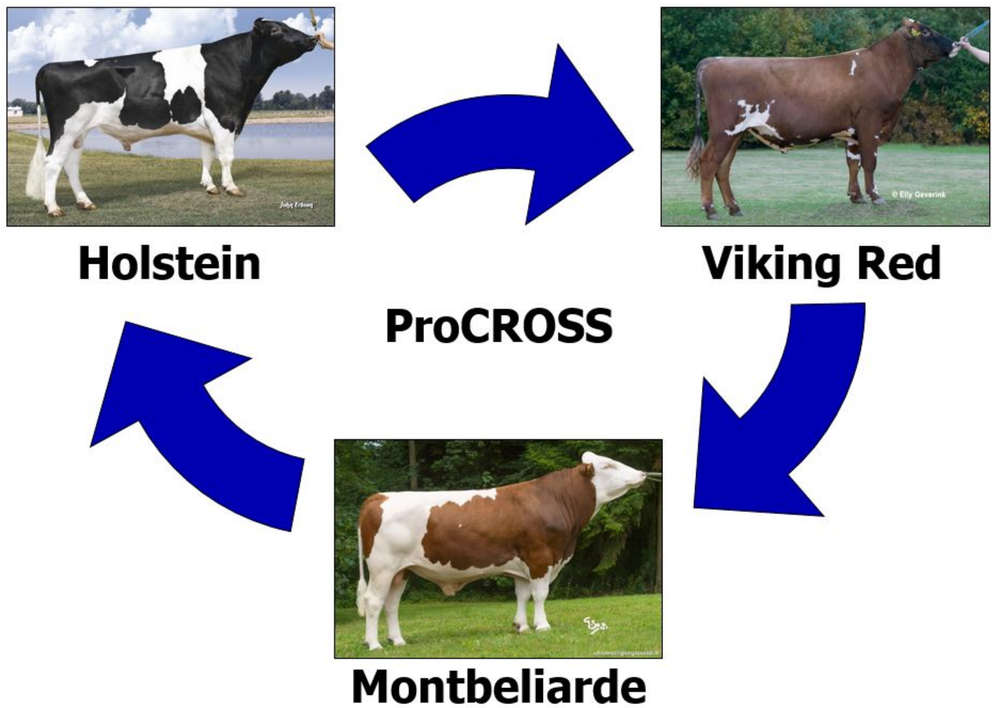

Figure 1. ProCROSS rotation initiated with Viking Red on Holstein female.

All heifers and cows were mated to individual A.I. bulls by the 2 genetic advisors with corrective mating for conformation. Furthermore, all matings of HO A.I. bulls with HO cows received inbreeding protection. A small number of cows were not bred to the appropriate breed of A.I. bull for each of the breed types, and the resulting offspring were excluded from the study.

A total of 7,791 heifer calves across 5 generations were born during the 10 years of the study. The 2-breed crossbreds and their HO herdmates calved a 1st time starting in December 2010. The number of females born in the 1st generation was 709 VR×HO and 708 MO×HO 2-breed crossbreds with 1,670 HO herdmates for comparison. The 3-breed crossbreds and their HO herdmates began calving in November 2012, and the 728 VR×MO/HO and 669 MO×VR/HO and had 1,791 HO herdmates for comparison. Finally, the 3rd generation of HO-sired ProCROSS cows and their HO herdmates began calving in December 2014. The 573 ProCROSS sired by HO A.I. bulls had 934 HO herdmates for comparison.

The window of time for each of the 3 generations of cows in the study wasn't distinct and the generations overlapped, especially in the later years of the study. For example, some HO cows were herdmates with 2-breed as well as some 3-breed crossbreds. Furthermore, some HO cows were herdmates with 3-breed crossbreds as well as some HO-sired ProCROSS cows in the 3rd generation. For all 3 generations of cows, observations were recorded up to December 31, 2017, which was when data collection ended. Only a few 4th generation cows and none of the 5th generation cows calved before the end of the study.

ANALYSIS

Traits were analyzed within lactation number and also separately for the 2-breed crossbred and 3-breed ProCROSS generations and their HO herdmates. A high percentage of cows in these herds were culled prior to 4th calving. Therefore, comparison of breed types with small numbers of cows in 4th and later lactations was not possible. In the 3rd generation, the HO-sired ProCROSS cows and their HO herdmates had less time to be included in the study, because their 1st calving was during the final 3 years of the study. Therefore, only 1st lactation traits of the HO-sired ProCROSS cows were compared to their Holstein herdmates.

Cows that started lactation with an abortion (gestation length less than 260 days) were removed from the analysis of gestation length, stillbirth, fertility, production, and conformation, but were included for the analysis of health treatment cost and survival. Also, cows sold for dairy purposes were excluded from the analysis of survival.

Three seasons of calving were defined as January to April, May to August, and September to December for each herd. Cows that calved during seasons with fewer than 3 crossbred and 3 HO cows of the same generation and lactation number were removed from the analysis for a trait. Therefore, the number of cows analyzed varied somewhat from trait to trait.

All traits were analyzed accounting for the effects of lactation number (1st, 2nd, or 3rd), herd-season of calving, and breed type of cow (such as VR×HO, MO×HO, and HO for the 1st generation). Sex of calf was also taken into account for analysis of gestation length and stillbirth. Furthermore, service sire was taken into account for the analysis of conception rate. For the conformation traits, stage of lactation was taken into account.

Analysis provided probabilities that indicated whether reported differences are large enough to be statistically significant (can be taken seriously). The probability of $P < 0.10$ (symbolized with "†") indicates a difference with a 90% certainty of being real rather than due to chance. The probability of $P < 0.05$ (symbolized with "*") indicates a difference with a 95% certainty, and $P < 0.01$ (symbolized with "**") indicates a difference with a 99% certainty of being real rather than due to chance. The lack of a symbol accompanying a difference for breed types indicates a difference may be due simply to chance.

RESULTS

Gestation length and stillbirth

Gestation length was significantly longer by 3 to 4 days for the 1st and 3rd generations of crossbreds (Table 1). The 3 breeds of Brown Swiss, Fleckvieh, and MO are all known to have 7 to 10 days longer gestation length than other breeds of dairy cattle. Gestation length is a trait determined by the breed composition of the calf. Therefore, the results for the 3-breed crossbred calves were not surprising, because those calves contained either 25% or 50% Montbeliarde content, on average, and had 3 or 4 days longer gestation length. Typically, dairy producers should expect little, if any, difference in the gestation length of ProCROSS cows bred to HO bulls, but they should expect 3 to 4 days longer gestation length when the MO breed is the sire of the calf or the sire of the dam.

Table 1. Gestation length and stillbirth rate for 2-breed, 3-breed, and HO-sired ProCROSS crossbreds and their HO herdmates.

	Holstein (HO-sired calf)	Difference for VR×HO (MO-sired calf)	Difference for MO×HO (VR-sired calf)
1st lactation			
Cows (number)	1,138	541	533
Gestation length (days)	276	+4**	+3**
Stillbirth	9%	–4%**	–5%*
2nd and 3rd lactation			
Lactations (number)	1,244	642	669
Gestation length (days)	278	+3**	+2**
Stillbirth	3%	–1%	0%
	Holstein (HO-sired calf)	**Difference for VR×MO/HO (HO-sired calf)**	**Difference for MO×VR/HO (HO-sired calf)**
1st lactation			
Cows (number)	1,256	557	508
Gestation length (days)	276	0	+1**
Stillbirth	7%	–3%**	–1%
2nd and 3rd lactation			
Lactations (number)	1,010	529	459
Gestation length (days)	278	0	0
Stillbirth	2%	0%	–1%
	Holstein (HO-sired calf)	**Difference for HO-sired cross (VR-sired or MO-sired calf)**	
1st lactation			
Cows (number)	560	412	
Gestation length (days)	276	+3**	
Stillbirth	5%	–1%	

* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

Stillbirth rates were numerically lower for all of the crossbred types at 1st calving and were significantly lower for both types of 2-breed crossbreds and about one-half lower for the VR×MO/HO 3-breed crossbreds compared to their HO herdmates (Table 1). Stillbirth rates were lower for cows at 2nd and 3rd calving regardless of breed type, and the differences were not statistically significant for the breed types.

Viking Red × Holstein
1-10 305d 10741 kg m, 436 kg f, 342 kg p

Montbeliarde × Holstein
1-08 305d 11851 kg m, 455 kg f, 348 kg p
2-08 305d 15892 kg m, 568 kg f, 451 kg p

Fertility

Fertility traits for lactations of cows bred to bulls that did not follow the mating design of the study were excluded from analysis. Days open was the days from calving to pregnancy. Cows with days open greater than 250 days were assigned a maximum of 250 days, so extremely long calving intervals and infertility of cows did not unfairly influence results. Pregnancy rate is a group statistic that cannot be determined for individual cows and was estimated from days open (4 days open = 1% pregnancy rate).

Both the VR×HO and MO×HO 2-breed crossbreds had significant advantages for fertility over their HO herdmates (Table 2). Averaged across lactations, the 2-breed crossbreds had +7.3% higher conception rate at 1st breeding than their HO herdmates, and the 2-breed crossbreds also had fewer times bred (–0.2 to –0.4) than their HO herdmates in 1st and 2nd lactation. Days open averaged 134 days across the 3 lactations for the HO herdmates, which is superior to the average of 145 days open of DHI herds enrolled in Dairy Records Management Systems in the U.S. However, the VR×HO 2-breed crossbreds had –8 fewer days open and the MO×HO 2-breed crossbreds had –17 fewer days open than their HO herdmates averaged across the 3 lactations. Pregnancy rate was 4 percentage points higher for the 2-breed crossbreds compared to their HO herdmates averaged across lactations.

The 3-breed crossbreds had superior fertility over their HO herdmates as measured by all traits (Table 3). The HO herdmates had reasonable conception rate at 1st breeding (43% in 1st lactation and 35% for 2nd and 3rd lactation). Yet, the conception rate at 1st breeding was +8.7% higher for the 3-breed crossbreds averaged across lactations than their HO herdmates. Days open were more than 2 weeks fewer in 1st lactation, 2.5 weeks fewer in 2nd lactation, and almost 3 weeks fewer in 3rd lactation for the 3-breed crossbreds than their HO herdmates, and this was an average advantage of –16.5 days open. The pregnancy rate superiority of the 3-breed crossbreds over their HO herdmates was from +5% to +11%. None of the differences for fertility traits were statistically significant for the 1st lactations of HO-sired ProCROSS cows and their HO herdmates (Table 4).

The advantages of the crossbreds over their HO herdmates for fertility were not a surprise. Concern about fertility is often the primary reason dairy producers consider crossbreeding. The 7 herds in the study surpassed standard benchmarks for respectable fertility of HO cows. The superior fertility of the crossbreds may result mostly from heterosis (hybrid vigor). However, the outstanding performance of the 3-breed crossbreds compared to their HO herdmates is likely also due to the direct contributions of the VR and MO breeds, which have selected heavily for improved fertility for many years. Perhaps, more importantly, the VR and MO breeds have not selected for less body condition of cows over the years. The relationship between less body condition and poor fertility of dairy cows is well established.

Table 2. Fertility during 1st, 2nd, and 3rd lactations for VR×HO and MO×HO 2-breed crossbreds and their HO herdmates.

	Holstein		Difference from Holstein			
			VR×HO		MO×HO	
	Cows (n)	Average	Cows (n)	Difference	Cows (n)	Difference
1st lactation						
Conception rate at 1st breeding	1,125	37%	558	+8%**	534	+6%*
Overall conception rate	1,127	37%	558	+4%*	534	+8%**
Times bred (up to 5)	1,142	2.4	564	–.2*	541	–.3**
Days open	1,061	127	541	–7	517	–12**
Pregnancy rate	1,061	27%	541	+3%	517	+5%**
2nd lactation						
Conception rate at 1st breeding	822	29%	425	+7%**	409	+11%**
Overall conception rate	824	31%	427	+4%*	410	+9%**
Times bred (up to 5)	840	2.6	435	–.3**	424	–.4**
Days open	704	139	382	–11*	387	–22**
Pregnancy rate	704	24%	382	+3%*	387	+7%**
3rd lactation						
Conception rate at 1st breeding	389	30%	251	+1%	253	+11%**
Overall conception rate	391	31%	252	+1%	255	+9%**
Times bred (up to 5)	411	2.5	259	0	266	–.3*
Days open	336	143	231	–4	245	–23**
Pregnancy rate	336	23%	231	+1%	245	+7%**

* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

Table 3. Fertility during 1st, 2nd, and 3rd lactations for VR×MO/HO and MO×VR/HO 3-breed crossbreds and their HO herdmates.

	Holstein		Difference from Holstein			
			VR×MO/HO		MO×VR/HO	
	Cows (n)	Average	Cows (n)	Difference	Cows (n)	Difference
1st lactation						
Conception rate at 1st breeding	1,124	43%	515	+9%**	458	+8%**
Overall conception rate	1,042	41%	491	+7%**	446	+9%**
Times bred (up to 5)	1,033	2.2	491	–.3**	455	–.2**
Days open	1,022	126	471	–15**	433	–16**
Pregnancy rate	1,022	28%	471	+6%**	433	+7%**
2nd lactation						
Conception rate at 1st breeding	612	35%	331	+7%†	292	+12%**
Overall conception rate	535	36%	301	+6%*	269	+8%**
Times bred (up to 5)	566	2.4	306	–.2*	282	–.3**
Days open	512	134	283	–20**	263	–17**
Pregnancy rate	512	25%	283	+8%**	263	+6%**
3rd lactation						
Conception rate at 1st breeding	250	35%	164	+7%	153	+13%*
Overall conception rate	215	33%	141	+11%**	132	+15%**
Times bred (up to 5)	226	2.4	144	–.5**	142	–.5**
Days open	183	134	128	–15†	124	–25**
Pregnancy rate	183	25%	128	+5%†	124	+11%**

† Significantly ($P \leq 0.10$) different from Holstein.
* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

Table 4. Fertility during 1st lactation for HO-sired ProCROSS cows and their HO herdmates.

	Holstein		HO-sired cross	
	Cows (n)	Average	Cows (n)	Difference
Conception rate at 1st breeding	484	43%	305	+3%
Overall conception rate	421	42%	256	+4%
Times bred (up to 5)	428	2.2	281	–.1
Days open	415	128	274	–7
Pregnancy rate	415	27%	274	+3%

Health treatment cost

The recording and the analysis of health treatments of cows was a primary objective of the study. Health treatment cost of dairy cattle is not well-documented in the U.S. because of the lack of complete and uniform recording. The 7 herds in the study consistently recorded 16 different types of health treatment events for the duration of the study. Interviews with the veterinarians who provided service to the 7 herds resulted in obtaining an estimated cost of medication and cost of veterinary care. Furthermore, the 7 herd managers provided the estimated time required by their staff to restrain cows and to administer treatment. The time required for a treatment was converted to a labor cost for each of the 16 treatment types. The health treatment costs of a cow were assigned to each treatment event and added across lactation. This allowed multiple treatments of the same type for a cow within lactation. The cost of the 16 types of health treatment cost was added within each lactation of a cow, and this approach permitted a robust distribution of total health treatment costs for cows.

Health treatment cost for 1st lactation cows was low compared with the cost for 2nd and 3rd lactation cows for all breed types of cows (Table 5). The MO×HO 2-breed crossbreds had significantly lower total health treatment cost (–28%) than their HO herdmates during 1st lactation. The VR×HO 2-breed crossbreds had a tendency for lower total health treatment cost (–16%) than their HO herdmates during 1st lactation. Total health treatment cost during 1st lactation was not significantly different for the 3-breed crossbreds, and the HO-sired ProCROSS cows in 1st lactation were not significantly different from their HO herdmates. In general, the 7 herds had relatively low health treatment cost for all breed types during the 1st lactations of cows. However, differences between the breed types were noticeable in 2nd and 3rd lactation. Overall, the 2-breed crossbreds averaged –23% less total health treatment cost and the 3-breed crossbreds averaged –17% less total health treatment cost across their 3 lactations.

Health treatment cost was broken down into 5 categories:
- mastitis (including mastitis diagnostic tests)
- lameness
- reproductive (retained placenta, metritis, cystic ovary, and other reproductive)
- metabolic (milk fever, displaced abomasum, ketosis, and digestive)
- miscellaneous (respiratory, injury, and all other).

Analysis of each separate health category indicated differences in total health treatment cost came mostly from 3 of the 5 categories – less mastitis, less metabolic, and less miscellaneous treatment cost – for both the 2-breed and 3-breed crossbreds than their HO herdmates.

Health treatment cost reported in this study was the economic cost for treatment of disease, but that cost may be a conservative reflection of the actual difference in disease status between the crossbreds and their HO herdmates. Recording of treatment events excluded subclinical disease that may have gone undetected, the time for disease recovery, and time spent in a hospital pen. The gains from heterosis (hybrid vigor) for these sorts of health events, which are difficult to accurately record, were not captured. Furthermore, culling records from the herds revealed the dairy managers often chose to cull or euthanize cows with diseases that had high treatment cost or cows with poor recovery prognosis.

Dairy breeding companies are currently making large investments to genetically improve the health of HO cows. Selection for improved health of cows is recommended, but slow progress is expected within a breed because the genetic control of health is much less (heritability of 1% to 3%) than the genetic control of other traits such as production and conformation. The exploitation of heterosis (hybrid vigor) for improved cow health in addition to genetic improvement within breeds is expected to be more effective in achieving improved cow health than relying on genetic improvement alone within a breed.

Table 5. Total health treatment cost for 2-breed, 3-breed, and HO-sired ProCROSS compared to Holstein cows.

			Difference from Holstein			
	Holstein		VR×HO		MO×HO	
Lactation number	Cows (n)	Average	Cows (n)	Difference	Cows (n)	Difference
First	1,280	\$43	624	–\$7†	592	–\$12**
Second	1,007	\$68	498	–\$20**	471	–\$21**
Third	577	\$92	328	–\$14**	334	–\$25**

			Difference from Holstein			
	Holstein		VR×MO/HO		MO×VR/HO	
Lactation number	Cows (n)	Average	Cows (n)	Difference	Cows (n)	Difference
First	1,186	\$43	537	–\$3	502	–\$5
Second	654	\$81	333	–\$15**	305	–\$27**
Third	267	\$109	158	–\$18*	147	–\$37**

			Difference from Holstein	
	Holstein		HO-sired cross	
Lactation number	Cows (n)	Average	Cows (n)	Difference
First	444	\$36	275	+\$4

† Significantly ($P \leq 0.10$) different from Holstein.
* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

Survival

For most measures of survival, the crossbreds survived longer than their HO herdmates. This was not surprising, because of similar results from a previous field study in California in which both Nordic Red×HO 2-breed crossbreds (+360 days) and MO×HO 2-breed crossbreds (+412 days) had significantly longer days in the herd than their HO herdmates. In this study, 3% more VR×HO 2-breed crossbreds survived from 2 days of age to 1st calving (Table 6) than their HO herdmates.

Despite the low average health treatment cost of 1st lactation HO cows in this study, significantly more of the VR×HO 2-breed and MO×HO 2-breed crossbreds calved a 2nd time within 14 months and 17 months than did their HO herdmates (Table 6). The obvious explanation is the superiority of the 2-breed crossbreds for fertility over their HO herdmates in 1st lactation (Table 2). More VR×HO and MO×HO 2-breed crossbreds calved a 3rd time within 14 months (+8% and +15%) and within 17 months after 2nd calving (+5% and +11%) than their HO herdmates (Table 6).

The percentage of cows that calved back within 14 and 17 months measured both the time required for cows to calve again as well as whether they actually calved again. Few cows required longer than 17 months to calve again, because the 7 herds in the study culled aggressively for both fertility and persistency of production in later lactation.

Actual survival to next calving is in Table 6 for the 2-breed crossbreds and their HO herdmates, and cows were required to calve a 1st time in order to be included. For the 2-breed crossbreds, 57% of the VR×HO, 62% of the MO×HO calved a 3rd time, but only 51% of their HO herdmates calved a 3rd time. Survival to 4th calving was even more different for the 2-breed crossbreds and their HO herdmates, because 32% of the VR×HO, 44% of the MO×HO, and 28% of the HO calved a 4th time.

Table 6. Survival of VR×HO and MO×HO 2-breed crossbreds and their HO herdmates.

	Holstein		Difference from Holstein			
			VR×HO		MO×HO	
	Cows (n)	Average	Cows (n)	Difference	Cows (n)	Difference
Virgin heifers						
Survival to 1st calving	1,581	86.7%	706	+3.0%†	695	+.2%
1st lactation						
2nd calving within 14 months	1,250	62%	608	+6%*	582	+8%**
2nd calving within 17 months	1,239	75%	604	+5%*	576	+6%**
Death loss	1,223	3%	593	–1%	568	0%
2nd lactation						
3rd calving within 14 months	983	46%	496	+8%**	470	+15%**
3rd calving within 17 months	980	61%	496	+5%†	470	+11%**
Death loss	959	7%	483	–4%**	451	–2%
3rd lactation						
4th calving within 14 months	559	41%	322	+9%*	329	+18%**
4th calving within 17 months	549	52%	322	+6%	328	+17%**
Death loss	560	7%	319	0%	330	–3%
Survival to subsequent calving						
Survival to 2nd calving	1,223	80%	593	+4%†	568	+4%†
Survival to 3rd calving	1,201	51%	581	+6%*	551	+11%**
Survival to 4th calving	1,012	28%	550	+5%†	516	+16%**
Died up to 45 months (after 1st calving)	640	16.3%	376	–5.2%**	358	–2.7%
Lived to at least 45 months (after 1st calving)	640	18.0%	376	+6.7%**	358	+15.3%**

† Significantly ($P \leq 0.10$) different from Holstein.
* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

Death loss within 1st, 2nd, and 3rd lactation was the number of cows that died divided by the number of cows that calved in that lactation (Table 6). Death loss was low during 1st lactation for all breed types. However, during 2nd lactation, the VR×HO 2-breed crossbreds had 3% death loss compared to 7% death loss of their HO herdmates. Death loss was also compared up to 45 months after 1st calving. The HO herdmates of the crossbreds had 16.3% death loss, which is similar to the 15% to 16% death loss of HO cows born in 2008 to 2012 that are used for U.S. genetic evaluation. However, the VR×HO 2-breed crossbreds had significantly less death loss (11.1%) than their HO herdmates.

The VR×MO/HO 3-breed crossbreds (89.6%) and the MO×VR/HO 3-breed crossbreds (88.8%) had significantly higher survival rates than their HO herdmates (85.7%) from 2 days of age to 1st calving (Table 7). Larger percentages of the 3-breed crossbreds (+6% and +9%) had a 2nd calving within 14 months than the 62% survival rate of their HO herdmates (Table 7). For cows that calved a 2nd time, significantly more 3-breed crossbreds calved a 3rd time, and the difference for survival rate was +15% to 18% higher by 14 months after calving and 13% to 14% by 17 months after 1st calving. Differences between the breed types grew even larger for cows that calved a 4th time within 14 months of 3rd calving, because the VR×MO/HO (65%) and MO×VR/HO (60%) 3-breed crossbreds had a significantly higher survival rate than their HO herdmates (38%).

Table 7. Survival for VR×MO/HO and MO×VR/HO 3-breed crossbreds and their HO herdmates.

			Difference from Holstein			
	Holstein		VR×MO/HO		MO×VR/HO	
	Cows (n)	Average	Cows (n)	Difference	Cows (n)	Difference
Virgin heifers						
Survival to 1st calving	1,557	85.7%	667	+3.9%*	613	+3.1%
1st lactation						
2nd calving within 14 months	1,103	62%	506	+9%**	474	+6%†
2nd calving within 17 months	1,018	75%	475	+4%	447	+1%
Death loss	1,057	3%	490	–1%	456	+2%
2nd lactation						
3rd calving within 14 months	586	48%	297	+15%**	275	+18%**
3rd calving within 17 months	545	61%	273	+14%**	252	+13%**
Death loss	569	6%	293	–4%**	269	–2%
3rd lactation						
4th calving within 14 months	202	38%	129	+27%**	115	+22%**
4th calving within 17 months	165	46%	97	+23%**	97	+20%**
Death loss	181	5%	111	–2%	103	–3%
Survival to subsequent calving						
Survival to 2nd calving	1,057	79%	490	+5%*	456	–1%
Survival to 3rd calving	681	51%	318	+14%**	309	+8%*
Survival to 4th calving	311	22%	124	+24%**	135	+15%**
Died up to 45 months (after 1st calving)	250	12.3%	109	–5.6%†	117	–2.8%
Lived to at least 45 months (after 1st calving)	250	17.4%	109	+13.9%**	117	+8.9%*

† Significantly ($P \leq 0.10$) different from Holstein.
* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

For the 3-breed crossbreds, death loss within each of the 3 lactations was about one-half of their HO herdmates. The 2% death loss of the VR×MO/HO crossbreds in 2nd lactation was significantly lower than the 6% death loss of their HO herdmates. Up to 45 months after 1st calving, 6.7% of the VR×MO/HO and 9.5% of the MO×VR/HO 3-breed crossbreds died, but 12.3% of their HO herdmates died (Table 7).

The percentage of cows that survived to at least 45 months after 1st calving was 29% for the 2-breed crossbreds and 3-breed ProCROSS combined. On the other hand, only 18% of the 1st generation and 17% of the 2nd generation HO herdmates survived to at least 45 months after 1st calving. Replacement cost is among the top 3 expenses for most dairy herds. Therefore, the longer survival of the crossbred cows would have had a large financial impact.

Only a small number of HO-sired ProCROSS cows and their HO herdmates were analyzed for survival in 1st lactation, because the 3rd generation of cows in the study calved between 2015 and 2017 (Table 8). None of the numerical differences were statistically significant.

Table 8. Survival for HO-sired ProCROSS cows and their HO herdmates.

	Holstein		HO-sired cross	
	Cows (n)	Average	Cows (n)	Difference
Virgin heifers				
Survival to 1st calving	809	86.4%	490	+2.8%
1st lactation				
2nd calving within 14 months	356	65%	215	+6%
2nd calving within 17 months	299	77%	182	+2%
Death loss	327	4%	195	–2%
Survival to 2nd calving	327	81%	195	+1%

Production

Actual (not mature equivalent) 305-day production was calculated from test-day records of milk, fat, and protein. Cows were required to have at least 2 test days to be included in the analysis. Cows that were milked longer than 305 days in lactation were limited to 305 days of production. Cows that became pregnant quickly after calving, which resulted in lactations less than 305 days, and cows that left the herd prior to 305 days in milk had their lactations projected to 305 days.

Lifetime production of a cow was actual daily production added across all days she was in the herd. Production from lactations longer than 305 days were included, and lactations of cows that were less than 305 days were not projected to 305 days for lifetime production. Cows that did not survive to a 1st test day were assigned 11.3 kg of milk, 0.397 kg of fat, and 0.340 kg of protein production for each day between calving and removal from the herd.

For lifetime production, 315 cows (23%) of the 1st generation cows lived beyond 45 months in the herd or were still in the herd at the end of the study. For 2nd generation cows, 100 cows (21%)

lived beyond 45 months. For these cows, additional daily production was projected by multiplying the production per day up to 45 months after 1st calving by the predicted number of additional days that the cow remained in the herd. The projected production of each cow after 45 months was added to the production during their initial 45 months in the herd. Daily production for each cow was her lifetime production divided by the number of days she was in the herd (or her projected days in the herd) including the dry period.

All of the herds routinely milked most of their cows 3 times daily. However, a small number of cows were milked 2 times daily (3% of the individual test days of cows). The breed types did not differ for the percentage of test days that were from 2-time or 3-time milking.

The herds had a young average age at 1st calving compared to the U.S. average. Age at calving was not significantly different for the 2-breed crossbreds compared to their HO herdmates for both 1st and 2nd lactation (Table 9), and the MO×HO 2-breed crossbreds had a tendency to calve a half-month earlier than their HO herdmates in 3rd lactation. The fat plus protein production of the MO×HO 2-breed crossbreds was 3% higher than their HO herdmates in the 1st and 2nd lactation. Furthermore, the VR×HO 2-breed crossbreds were not significantly different from their HO herdmates for fat plus protein production in any of the 3 lactations.

For fluid milk volume, the VR×HO 2-breed crossbreds were significantly lower than their HO herdmates, but the MO×HO 2-breed crossbreds were not significantly different from their HO herdmates. The majority of dairy herds in the world are paid for the fat and protein solids in milk rather than the volume of fluid that carries the solids. Cows with extra fluid carrier (water) are often considered to be less desirable, because more expense is needed to cool and ship the additional fluid carrier. Therefore, most dairy producers believe less fluid volume with higher percentages of solids is advantageous.

On a lifetime basis, both the VR×HO 2-breed crossbreds (+96 days) and the MO×HO 2-breed crossbreds (+219 days) had significantly more longevity (days) in the herd than their HO herdmates. The differences for days are equivalent to +3.2 months for the VR×HO 2-breed crossbreds and +7.2 months for the MO×HO 2-breed crossbreds compared to their HO herdmates. The additional length of time in the herd resulted in significantly more lifetime fat + protein production for the MO×HO 2-breed crossbreds than their HO herdmates (Table 9). For daily fat + protein production across the lifetimes of cows, the VR×HO 2-breed crossbreds had 1% less and the MO×HO 2-breed crossbreds had 2% more daily fat + protein production than their HO herdmates.

Table 9. Production (actual, not mature equivalent) for 1st, 2nd, and 3rd 305-day lactations, for lifetime, and per day for the 2-breed crossbreds and their HO herdmates.

		Difference from Holstein	
	Holstein	VR×HO	MO×HO
1st lactation			
Cows (number)	1,180	582	556
Age at calving (months)	23.8	0	0
305-d fat + protein (kg)	765	+11	+23**
305-d milk (kg)	11,378	–419**	+67
2nd lactation			
Cows (number)	883	461	443
Age at calving (months)	36.5	–.1	–.1
305-d fat + protein (kg)	887	–5	+19**
305-d milk (kg)	13,338	–790**	–3
3rd lactation			
Cows (number)	451	281	297
Age at calving (months)	48.9	–.4	–.5†
305-d fat + protein (kg)	927	0	+13
305-d milk (kg)	13,932	–665**	–72
Lifetime			
Cows (number)	640	376	358
Days in the herd	886	+96*	+219**
Fat + protein production (kg)	2,201	+196	+609**
Daily across lifetime			
Cows (number)	640	376	358
Fat + protein production (kg)	2.51	–.02**	+.06**

† Significantly ($P \leq 0.10$) different from Holstein.
* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

The 3-breed crossbreds, unlike the 2-breed crossbreds, had significantly younger age at calving for 1st, 2nd, and 3rd lactation than their HO herdmates (Table 10). On average, the 3-breed crossbreds calved 12 days sooner for 1st lactation, 21 days sooner for 2nd lactation, and 49 days sooner for 3rd lactation than their HO herdmates. The explanation for their younger ages at calving was their advantage for fertility over their HO herdmates (Table 3).

The VR×MO/HO and MO×VR/HO 3-breed crossbreds had significantly lower fat + protein solids production during 1st (–4%), 2nd (–3%), and 3rd (–4%) lactations than their HO herdmates (Table 10). The lower 305-day production was not surprising for 2 reasons: 1) the 305-day production was not adjusted for the fewer days open (advantage for fertility) of the 3-breed crossbreds over their HO herdmates, because research has documented fewer days open lowers production of cows in the final trimester of pregnancy, and 2) the 3-breed crossbreds had an average HO content of only 25%. The primary reason for including the HO breed in ProCROSS is to exploit its producing ability.

On a lifetime basis, both the VR×MO/HO (+5.8 months) and MO×VR/HO (+3.8 months) 3-breed crossbreds had more longevity than their HO herdmates, although the advantage of the MO×VR/HO crossbreds was not statistically significant. Because of their longer lives, both types of 3-breed crossbreds had numerically higher lifetime fat + protein production. For daily production of fat + protein production across their lifetimes, the VR×MO/HO 3-breed crossbreds were –2% lower and the MO×VR/HO 3-breed crossbreds were +1% higher than their HO herdmates.

Table 10. Production (actual, not mature equivalent) for 1st, 2nd, and 3rd 305-day lactations, for lifetime, and per day for the 3-breed crossbreds and their HO herdmates.

		Difference from Holstein	
	Holstein	VR×MO/HO	MO×VR/HO
1st lactation			
Cows (number)	1,073	505	462
Age at calving (months)	23.2	–.5**	–.3*
305-d fat + protein (kg)	795	–38**	–22**
305-d milk (kg)	11,803	–1,202**	–932**
2nd lactation			
Cows (number)	582	309	291
Age at calving (months)	35.9	–.9**	–.6**
305-d fat + protein (kg)	906	–44**	–16†
305-d milk (kg)	13,551	–1,326**	–850**
3rd lactation			
Cows (number)	228	143	134
Age at calving (months)	48.5	–1.7**	–1.6**
305-d fat + protein (kg)	953	–56**	–27*
305-d milk (kg)	14,295	–1,466**	–1,087**
Lifetime			
Cows (number)	250	109	117
Days in the herd	850	+176*	+117
Fat + protein production (kg)	2,132	+385†	+307
Daily across lifetime			
Cows (number)	250	109	117
Fat + protein production (kg)	2.55	–.06**	+.03**

† Significantly ($P \leq 0.10$) different from Holstein.
* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

ProCROSS is a long-term and continuous rotational breeding program, and dairy producers must focus on the combined impact across generations of the rotation. This study reported lifetime results for only the 1st and 2nd generations of the 3-breed rotation. When the daily fat + protein production of the VR×HO and MO×HO 2-breed crossbreds (–1% and +2%, respectively) and of the VR×MO/HO and MO×VR/HO 3-breed crossbreds (–2% and +1%, respectively) are combined, the difference for daily fat + protein production from their HO herdmates was zero.

The daily fat + protein production of cows across their lifetimes is a more appropriate measure for comparing the differences between breed types than is 305-day production. Daily profit for the days a cow remains in the herd should be the goal of dairy producers. Daily fat + protein production includes the days that cows are dry. On average, the crossbreds in this study had more dry days than their HO herdmates because they calved more times during their lifetimes. However, calving more frequently resulted in the crossbreds having more days during their lifetimes with peak production than their HO herdmates. The daily fat + protein production of the crossbreds would have been higher compared to their HO herdmates if only lactating days had been analyzed.

Only age at 1st calving and 305-day production for the 1st lactations of HO-sired ProCROSS cows and their HO herdmates were available for analysis (Table 11). This generation of ProCROSS did not have adequate opportunity at the end of the study to complete their 2nd or 3rd lactations. The HO-sired ProCROSS cows calved 9 days sooner than their HO herdmates despite the young average age at 1st calving of 22.9 months for the HO herdmates. The 305-day actual fat + protein production for the breed types was not significantly different.

Table 11. Production (actual, not mature equivalent) for 1st 305-day lactation for HO-sired ProCROSS cows compared to Holstein cows.

	Holstein	Difference for HO-sired ProCROSS cows
Cows (number)	417	257
Age at calving (months)	22.9	–.3*
305-d fat + protein (kg)	824	–11
305-d milk (kg)	12,254	–589**

* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

Conformation and body condition score

Conformation had a scale of 1 to 9, and cows were evaluated once each lactation between 2 and 150 days after calving (average of 35 days) by the 2 genetic advisors of Minnesota Select Sires Co-op, Inc. Cows were evaluated every lactation, and this approach is unique for cows as they aged, because cows aren't routinely evaluated for conformation after 1st lactation by U.S. breed associations. Cows were evaluated during 2nd and 3rd lactations only for the initial 8 years of the study. Therefore, only evaluations of cows during the 1st and 2nd lactations were available for the 3-breed crossbreds.

Stature. Stature had a scale of 1 = shorter to 9 = taller. The HO herdmates to the 3 generations of crossbreds increased in stature during 1st lactation (from 5.4 to 5.7 to 6.0). This result confirms the HO herdmates of crossbred cows in this study became taller with time, despite an effort by dairy producers to select for shorter stature of their HO cows.

Both the VR×HO 2-breed (4.0) and MO×HO 2-breed (4.7) crossbreds were significantly shorter in stature than their HO herdmates (5.4) in 1st lactation. This trend continued for 2nd and 3rd lactations. The 3-breed crossbreds were also shorter in stature than their HO herdmates for all lactations. Furthermore, the VR×MO/HO 3-breed (4.3) and MO×VR/HO 3-breed (4.5) crossbreds were both intermediate for stature between the extremes of their 2-breed dams. The HO-sired ProCROSS cows (5.3) were also significantly shorter in stature than their HO herdmates (6.0) during 1st lactation.

Angularity and body condition score (BCS). Angularity had a scale of 1 = round to 9 = angular. Body condition score had a scale from 1 = thin to 5 = obese. As expected, angularity and BCS had a strong relationship. All breed types of cows became more angular (less BCS) with age. Also, all generations of crossbreds had less angularity and more BCS than their HO herdmates. The MO×HO 2-breed (2.6) and MO×VR/HO 3-breed (2.6) crossbreds had the least angularity and MO×VR/HO 3-breed crossbreds had the highest BCS (3.90) for all breed types in 1st lactation. The relationship of lower BCS and reduced fertility, health, and survival of dairy cows is well documented.

Body depth. Body depth had a scale of 1 = shallow to 9 = deep. All of the 2-breed, 3-breed, and HO-sired ProCROSS crossbreds had significantly shallower body depth than their HO herdmates. Other research has documented cows with more body depth are more likely to have displaced abomasum after calving because the digestive tract has more space to move after the calf is born. Therefore, less body depth of the crossbreds than their HO herdmates may have contributed to the lower incidence of metabolic treatment cost of the crossbreds in this study.

Foot angle. Foot angle had a scale of 1 = low to 9 = steep. The VR×HO 2-breed crossbreds had significantly lower foot angle than their HO herdmates, but only in 2nd lactation (5.1 versus 5.6) and 3rd lactation (4.9 versus 5.3). However, the MO×HO 2-breed crossbreds had significantly steeper foot angle than their HO herdmates in all 3 lactations. Likewise, the MO×VR/HO 3-breed crossbreds had steeper foot angle than their HO herdmates. The VR×MO/HO 3-breed crossbreds had +0.5 steeper foot angle than their HO herdmates during 1st lactation, probably due to a MO content of 25% on average. The HO-sired ProCROSS cows were +0.3 steeper than their HO herdmates during 1st lactation.

Udder clearance. Udder clearance had a scale from 1 = low to 9 = high and was evaluated as distance of the udder floor from the hock and not as distance from the ground. Therefore, cows with shorter stature (and shorter legs) had a disadvantage for udder clearance compared to their HO herdmates with longer legs on average. In other words, udders with identical dimension received a lower score for cows with shorter legs. All of the 2-breed and 3-breed crossbreds had lower udder clearance than their HO herdmates, and the difference averaged –0.9 for the VR-sired crossbreds and –1.5 for the MO-sired crossbreds across lactations.

Rear teat width. Rear teat width had a scale of 1 = wide to 9 = close. In 1st lactation, the 2-breed (5.6) and 3-breed (5.4) crossbreds averaged more width between the rear teats and had scores closer to the midpoint of 5 than their HO herdmates (6.6). Also, the rear teat width became closer with time for the HO herdmates in 1st lactation (6.5 to 6.7 to 6.8). In 2nd and 3rd lactation, the 2-breed and 3-breed crossbreds also had more width between the rear teats with an average difference for score of 1.1.

Dairy producers express frustration with rear teats of cows that are close (touch or cross), especially for robotic milking. Significantly fewer 2-breed crossbreds in this study had touching or crossing rear teats than their HO herdmates in 1st lactation (5% versus 13%), 2nd lactation (17% versus 28%), and 3rd lactation (17% versus 29%). Also, significantly fewer 3-breed ProCROSS crossbreds had touching or crossing rear teats than their HO herdmates in 1st lactation (5% versus 14%) and 2nd lactation (13% versus 34%).

Teat length. Teat length had a scale from 1 = short to 9 = long. The VR×HO 2-breed crossbreds were not different for teat length from their HO herdmates. However, the MO×HO 2-breed crossbreds had significantly longer teats than their HO herdmates in 2nd lactation (+0.7) and 3rd lactation (+0.4). The 3-breed MO×VR/HO crossbreds had slightly longer (+0.4 and +0.5) teat length on average than their HO herdmates in 1st and 2nd lactations. The HO-sired ProCROSS did not differ from their HO herdmates for teat length in 1st lactation.

Viking Red × Holstein
1-10 305d 11754 kg m, 415 kg f, 366 kg p
2-10 305d 16135 kg m, 608 kg f, 499 kg p
3-09 305d 14371 kg m, 602 kg f, 459 kg p
4-11 305d 16643 kg m, 608 kg f, 508 kg p
5-11 305d 17315 kg m, 592 kg f, 531 kg p

Montbeliarde × Holstein
1-10 284d 10484 kg m, 374 kg f, 327 kg p
2-09 265d 11231 kg m, 410 kg f, 361 kg p
3-08 305d 15218 kg m, 564 kg f, 482 kg p
4-10 293d 15106 kg m, 526 kg f, 461 kg p

Lifetime profit and daily profit

To be included in the analysis of lifetime profit and daily profit, cows were required to have had the opportunity (based on the cut-off of data at the end of the study) to survive to 45 months in the herd. Also, at least 20 cows were required for each breed type of either 2-breed crossbreds or 3-breed crossbreds and their HO herdmates. This requirement provided for a fair comparison of breed types for lifetime performance by eliminating comparisons that included a small number of cows within herd. Therefore, cows from only 3 of the 7 herds were compared for lifetime performance.

Lifetime profit was estimated from the income and expense accumulated by each cow on a daily basis and added across all days they were in a herd after 1st calving. The income and expense for estimation of lifetime profit are in Table 12. The income from production came from daily production of milk, fat, protein, and other solids, as well as income or loss from SCS, with the cost of hauling and milk marketing subtracted for each cow. The production prices were from the U.S. Federal Milk Marketing Order for the Upper Midwest for 2013 to 2017. Average component prices used were $4.9650 per kg of fat, $5.8631 per kg of protein, and $.6177 per kg of other solids.

Lifetime profit was projected for all cows that lived beyond 45 months in a herd by multiplying each cow's daily profit up to 45 months by the predicted number of additional days the cow remained in the herd based on the survival rates of cows in each herd. However, cows that were projected beyond 45 months did not receive additional income from cull value and were not assessed additional expense for replacement or carcass disposal.

Table 12. Income and expense to determine lifetime profit

	Value	Unit	Reference
Income			
Milk price	$38.01	100 kg	USDA FMMA 30[1]
Live female calf	$200	Calf	Lifetime Net Merit
Live male calf			
Holstein	$100	Calf	Heins et al. (2012)
Crossbred	$130	Calf	Study herds
Cull value during 1st lactation			
Holstein	$876	Cow	Study herds
VR-sired crossbred	$876	Cow	Study herds
MO-sired crossbred	$1,033	Cow	Study herds
Cull value during 2nd and later lactation			
Holstein	$941	Cow	Study herds
VR-sired crossbred	$1,049	Cow	Study herds
MO-sired crossbred	$1,047	Cow	Study herds
Expense			
Feed (during lactation)	$.2341	kg of DM	FINBIN[2]
Lactation overhead	$4.76	Day	FINBIN[2]
Replacement[3]	$1,910	Cow	Tranel (2019)
Dry cow overhead (including feed)	$3.50	Day	FINBIN[2]
Breeding	$27	Event	Study herds
Fertility hormones	$18	Event	Study herds
Palpation	$7	Event	Study herds
Hoof trimming	$15	Event	Study herds
Carcass disposal	$34	Cow	Study herds

[1] Upper Midwest average for 2013 to 2017
[2] Average for 2013 to 2017 from Center for Farm Financial Management, University of Minnesota
[3] Replacement expense varied based on age at 1st calving for each cow

Daily profit of a cow was lifetime profit divided by the number of days in the herd. The most appropriate measure of profitability of cows on an ongoing basis within a herd is the daily profit per unit of available stall, cubicle, or pasture space. Both lifetime profit and daily profit of cows were analyzed adjusting for the effects of herd and breed type.

The daily income from production was –1% lower for VR×HO 2-breed crossbreds and +2% higher for MO×HO 2-breed crossbreds than their HO herdmates (Table 13), and this difference agreed well with the difference of the 2-breed crossbreds and their HO herdmates for daily fat + protein production. The calf value averaged +$0.07 more per cow per day for the 2-breed crossbreds than their HO herdmates (Table 13). The reason the 2-breed crossbred cows had a +17% greater daily calf value than their HO herdmates was likely because 1) crossbred male calves, particularly those with white faces from the MO breed, had a +$30 higher sale price than HO calves, 2) crossbred cows had fewer stillborn calves than their HO herdmates, and 3) the crossbred cows calved more times during their lifetimes than their HO herdmates.

Table 13. Daily income and expense that contributed to daily profit for VR×HO and MO×HO 2-breed crossbreds compared to their HO herdmates.

		Difference from Holstein	
	Holstein	VR×HO	MO×HO
Cows (number)	640	376	358
Income			
Production	$14.82	–$.20**	+$.31**
Calf value	$.42	+$.06**	+$.07**
Cull value	$.69	+$.04**	–$.03**
Total income	$15.92	–$.09**	$.36**
Percentage difference from Holstein		–1%	+2%
Expense			
Feed (during lactation)	$5.33	–$.11**	+$.02**
Lactation overhead	$4.19	–$.05**	–$.03**
Replacement	$1.59	–$.13**	–$.27**
Dry cow overhead (including feed)	$.42	+$.03**	+$.02**
Health treatment	$.24	–$.08**	–$.06**
Breeding	$.19	–$.01**	–$.02**
Total expense	$12.19	–$.33**	–$.36**
Percentage difference from Holstein		–3%	–3%

** Significantly ($P \leq 0.01$) different from Holstein.

Lifetime cull value favored the 2-breed crossbreds over their HO herdmates. The average cull value for VR×HO 2-breed crossbreds ($908) and MO×HO 2-breed crossbreds ($906) was significantly higher than their HO herdmates ($785). However, these differences were not obvious when the cull value was divided by days in the herd to obtain daily cull value (Table 13), because the crossbreds averaged +158 more days in the herd than their HO herdmates. The total of production income, calf value, and cull value resulted in a daily total income of $16.05 for the combined 2-breed crossbreds, which was +1% higher than the $15.92 of their HO herdmates.

Expense for feed while cows were lactating was the single largest expense for cows in the study. Individual feed intake was not available for cows. Therefore, feed intake was predicted from the formulas of the National Research Council. Feed intake was independently assigned for each cow on each day and depended on the week of lactation, on daily fat-corrected milk, and on body weight of cows. Body weight was not available for cows in the study, so body weight was set to 567 kg for all 1st lactation cows and 680 kg for all 2nd and later lactation cows regardless of breed type to estimate daily feed intake. Feed expense was calculated by multiplying estimated dry matter intake by $.2341, which was the fixed cost of a kg of dry matter. Feed expense (Table 13) for the VR×HO 2-breed crossbreds (–$.11) and MO×HO 2-breed crossbreds (+$0.02) were significantly different than the average daily feed cost of their HO herdmates ($5.33). This result was not surprising, because feed intake was mostly a reflection of the production of cows.

Lactation overhead was slightly lower for the 2-breed crossbreds than their HO herdmates because they had a smaller proportion of lactating days relative to their total days in the herd (Table 13). Likewise, the dry cow overhead was slightly higher for the crossbred cows than their HO herdmates, because of a larger proportion of dry days relative to total days for the crossbreds. Dry cow overhead also included feed cost for dry cows, and feed intake of dry cows was set equal for the crossbreds and their HO herdmates.

Replacement cost was variable for cows and differed based on age at 1st calving. The average age of 1st calving across breed types and years in this study was 23.4 months, and heifers calving the 1st time at 23.4 months had a replacement cost of $1910. Heifers calving at younger or older ages had $2.40 per day deducted or added to the replacement cost of $1910. For lifetime replacement cost, the 2-breed crossbreds ($1927) and their HO herdmates ($1929) were similar. However, the 2-breed crossbreds (–$.20) had significantly lower replacement cost per day, because the replacement cost was distributed across more days in the herd for the crossbred cows than their HO herdmates (Table 13).

The 2-breed crossbreds (–13%) had significantly lower lifetime health treatment cost than their HO herdmates. Therefore, when lifetime cost was divided by days in the herd for each cow (Table 13), the 2-breed crossbreds averaged –29% lower daily health treatment cost than their HO herdmates.

Additional expense was for breeding, palpation, hoof trimming, and carcass disposal. For each of these 4 events, the difference between the 2-breed crossbreds and their HO herdmates was less than $.03 per cow per day. Yet, the differences were statistically significant in all cases. However, these 4 events had much less impact on total expense compared to the larger impact of feed for lactation, lactation overhead, replacement cost, dry cow overhead, and health treatment cost.

Total daily expense was $11.84 for the 2-breed crossbreds and $12.19 for their HO herdmates (Table 13), which is –3% less daily expense for the 2-breed crossbreds than their HO herdmates. The most important contributor to reduction of expenses for the 2-breed crossbreds was their lower replacement cost than their HO herdmates that resulted from the longer days in the herd of the 2-breed crossbreds than their HO herdmates. The lower replacement cost was 57% of total difference in expense for the combined 2-breed crossbreds and their HO herdmates.

The VR×MO/HO 3-breed crossbreds had –3% less daily income from production than their HO herdmates. However, the MO×VR/HO 3-breed crossbreds had 1% more daily income from production than their HO herdmates (Table 14). Daily calf value averaged +\$.06 more for the combined 3-breed crossbreds than their HO herdmates. Lifetime cull value was higher for the VR×MO/HO 3-breed crossbreds (\$944) and the MO×VR/HO 3-breed crossbreds (\$953) than their HO herdmates (\$814). However, the 3-breed crossbreds had +147 days longer in the herd than the 850 days of their HO herdmates. Therefore, average cull value on a daily basis was –\$.01 lower for the VR×MO/HO 3-breed crossbreds and +\$.03 higher for the MO×VR/HO 3-breed crossbreds and not a major contributor to the difference in profit between the breed types. The combined 3-breed crossbreds had –1% lower daily income (\$16.13) than their HO herdmates (\$16.23).

Table 14. Daily income and expense that contributed to daily profit for VR×MO/HO and MO×VR/HO 3-breed crossbreds and their HO herdmates.

		Difference from Holstein	
	Holstein	VR×MO/HO	MO×VR/HO
Cows (number)	250	109	117
Income			
Production	\$15.09	–\$.45**	+\$.10**
Calf value	\$.43	+\$.07**	+\$.05**
Cull value	\$.72	–\$.01**	+\$.03**
Total income	\$16.23	–\$.38**	\$.18**
Percentage difference from Holstein		–2%	+1%
Expense			
Feed (during lactation)	\$5.39	–\$.16**	–\$.04**
Lactation overhead	\$4.20	–\$.04**	–\$.01
Replacement	\$1.60	–\$.26**	–\$.16**
Dry cow overhead (including feed)	\$.41	+\$.03**	+\$.01
Health treatment	\$.25	–\$.08**	–\$.09**
Breeding	\$.19	–\$.02**	–\$.02**
Total expense	\$12.28	–\$.52**	–\$.33**
Percentage difference from Holstein		–4%	–3%

** Significantly ($P \leq 0.01$) different from Holstein.

The VR×MO/HO 3-breed crossbreds had –\$.16 less and the MO×VR/HO 3-breed crossbreds had –\$.04 less feed cost during lactation than their HO herdmates (Table 14). The lower feed cost of the 3-breed crossbreds reflected their lower production. The 3-breed crossbreds had fewer lengthy lactations and calved back sooner each lactation than their HO herdmates. Therefore, the estimated feed intake for maintenance for the crossbred cows was lower, because the crossbred cows had more days near peak production during their lifetimes than their HO herdmates.

The 3-breed crossbreds had less lactation overhead (–$.02) and more dry cow overhead (+$.02) than their HO herdmates. Lifetime replacement expense was significantly lower for the VR×MO/HO 3-breed crossbreds ($1,887) and the MO×VR/HO 3-breed crossbreds ($1,902) than their HO herdmates ($1,923) because of younger age at 1st calving for the 3-breed crossbreds. Furthermore, the 3-breed crossbreds distributed costs over more days in the herd on average, and this resulted in a substantial reduction in daily replacement cost (–$.21) compared to their HO herdmates (Table 14).

Lifetime health treatment cost was –26% less for the 3-breed crossbreds ($170) than their HO herdmates ($229), and daily health treatment cost was –$.09 lower for the 3-breed crossbreds than their HO herdmates. Also, the lifetime breeding expense, which included semen, insemination fees, and supplies, was similar for the 3-breed crossbreds and their HO herdmates. However, average daily breeding expense for the 3-breed crossbreds ($0.17) was lower than their HO herdmates ($0.19).

The 3-breed crossbreds ($11.84) had –4% lower daily expenses than their HO herdmates ($12.28). Difference for replacement cost was the expense with the most influence and accounted for 48% of the total difference in expenses between the combined 3-breed crossbreds and their HO herdmates.

All 4 of the crossbred breed types had significantly higher lifetime profit than their HO herdmates, and the difference ranged from +18% to +58% (Table 15). Both types of 2-breed crossbreds had significantly higher daily profit than their HO herdmates. The combined 2-breed crossbreds had +13% higher daily profit than their HO herdmates (Table 15). Likewise, the combined 3-breed crossbreds had +9% higher daily profit. This outcome may seem surprising, because the 3-breed crossbreds had less fat + protein production than their HO herdmates. However, the lower expense of the 3-breed crossbreds than their HO herdmates resulted in an advantage for daily profit of the VR×MO/HO 3-breed crossbreds (+4%) and MO×VR/HO 3-breed crossbreds (+13%).

A previous study on crossbreeding in confinement herds compared Nordic Red×HO 2-breed crossbreds (a combination of VR×HO and Norwegian Red×HO) and MO×HO 2-breed crossbreds in 3 California herds. In that study, the Nordic Red×HO 2-breed crossbreds had 4% higher profit and the MO×HO 2-breed crossbreds had 5% higher profit than their HO herdmates. However, the California study didn't include health treatment cost, and a major contributor to the differences of the crossbreds and their HO herdmates in this study was the difference in health treatment cost. Also, for the California study, many of the MO sires of cows were low-ranking for production within the MO breed at the time. On the other hand, the MO sires of cows in this study ranked highly for production within the MO breed.

Table 15. Lifetime profit and daily profit for VR×HO and MO×HO 2-breed crossbreds and VR×MO/HO and MO×VR/HO 3-breed crossbreds and their HO herdmates.

		Difference from Holstein	
	Holstein	VR×HO	MO×HO
Cows (number)	640	376	358
Lifetime profit	$2,842	+$498†	+$1638**
Percentage difference from Holstein		+18%	+58%
Daily profit	$3.74	+$.22**	+$.72**
Percentage difference from Holstein		+6%	+19%
		Difference from Holstein	
	Holstein	VR×MO/HO	MO×VR/HO
Cows (number)	250	109	117
Lifetime profit	$2,823	+$902*	+$938*
Percentage difference from Holstein		+32%	+33%
Daily profit	$3.95	+$.17**	+$.51**
Percentage difference from Holstein		+4%	+13%

† Significantly ($P \leq 0.10$) different from Holstein.
* Significantly ($P \leq 0.05$) different from Holstein.
** Significantly ($P \leq 0.01$) different from Holstein.

Sensitivity analysis for feed intake

The actual feed intake of individual cows was not available for cows in this study, because the herds did not have the ability to collect individual feed intake. Production and stage of lactation were the only factors used to estimate feed intake of individual cows for this study, and no potential differences in feed intake or feed efficiency of the breed types were taken into account. However, previous research at the University of Minnesota compared ProCROSS crossbreds to their HO herdmates for feed intake during the initial 150 days of lactation. Daily feed intake was recorded, converted to dry matter intake, and analyzed. The ProCROSS cows had 4.8% less dry matter intake in 1st lactation and 6.5% less dry matter intake in 2nd and 3rd lactations than their HO herdmates with absolutely no difference for fat + protein production (kg).

The breed type differences for feed intake from the previous study were applied to this study to estimate the feed intake of cows and then were converted to feed cost. The previous study included HO-sired ProCROSS cows and included only the initial 150 days of lactation. However, the percentage reduction of dry matter intake of the crossbreds compared to their HO herdmates in the previous study was applied to all lactation feed intakes for this study. The outcome was a much larger advantage in daily profit for both the 2-breed crossbreds (+$0.79 per day) and 3-breed crossbreds (+$0.66 per day) compared to their HO herdmates. The higher daily profit of the 2-breed crossbreds (+21%) and the 3-breed crossbreds (+17%) than their HO herdmates, including their potential advantages for feed efficiency, may better reflect the actual daily profit of the ProCROSS crossbreds compared to HO cows in this study.

<u>The impact of heterosis (hybrid vigor)</u>

The MO×HO 2-breed crossbreds (+19%) and the MO×VR/HO 3-breed crossbreds (+13%) had larger increases in daily profit over their HO herdmates than the VR×HO 2-breed crossbreds (+6%) and the VR×MO/HO 3-breed crossbreds (+4%). Perhaps, an explanation for the larger increase for the MO-sired crossbreds is more "genetic distance" separating the MO, Brown Swiss, and Fleckvieh breeds from other European breeds of dairy cattle such as the HO and VR. The crossing of dairy breeds that are less related historically should result in higher average heterosis (hybrid vigor). Nonetheless, ProCROSS is a 3-breed rotational program, and 3 distinct breeds provides average heterosis (hybrid vigor) of 86% across generations. Use of only 2 breeds for crossbreeding provides average heterosis (hybrid vigor) of 67% across generations, and this is a 17% reduction of average heterosis (hybrid vigor) from a 3-breed to 2-breed rotation.

The goal of selecting 3 breeds to include in a crossbreeding rotation should be based on breeds that 1) have highly-effective genetic improvement programs that emphasize important traits that promote profitability, 2) best complement each other for individual traits, and 3) give a blended result across generations that is most appropriate for the environmental conditions of a herd.

Four generations of ProCROSS cows at the University of Minnesota dairy herd.
Sire of cows by generation (left to right): Montbeliarde (Micmac), Holstein (Clover), Viking Red (Peterslund), Montbeliarde (Urbaniste).