

The California experience of mating Holstein cows to A.I. sires from the Swedish Red, Norwegian Red, Montbeliarde, and Normande breeds

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- Inbreeding is increasing at about 0.1% per year in the Holstein breed, which is causing increased inbreeding depression, especially for mortality, fertility, health, and survival.
- Crossbreeding results in heterosis, which is the opposite of inbreeding depression.
- Heterosis is a bonus that comes on top of the average genetic level of the two parent breeds and should be about 5% for production and at least 10% for mortality, fertility, health, and survival.
- Mating Holsteins to Swedish Red, Norwegian Red, Montbeliarde, and Normande A.I. sires resulted in fewer stillborn calves, as well as cows with less calving difficulty, enhanced fertility, and improved survival compared to pure Holsteins.
- Production of Montbeliarde-Holstein crossbreds and Scandinavian Red-Holstein crossbreds was very similar to production of pure Holsteins (about 4 to 5% lower across lactations).
- Crossbreeding is a mating system that complements genetic improvement within breeds.
- Continuous use of top progeny-tested A.I. sires is essential for genetic improvement.
- Crossbreeding systems with dairy cattle should use three breeds to capitalize adequately on the benefits of heterosis.

CIRCUMSTANCES HAVE CHANGED

Interest in crossbreeding is at an all-time high among commercial dairy producers internationally. Over the past 50 years, North American Holsteins have steadily increased as a percentage of the national dairy herd in most countries. Generally speaking, however, circumstances have changed regarding the historical superiority of pure Holsteins compared to crossbreds for profitability. To begin with, milk pricing in most markets now places greater emphasis on the solids in milk rather than the fluid carrier, which gives the Holstein breed less of a competitive advantage than in the past compared to other breeds.

The reproductive decline of Holsteins, on both an observed and a genetic basis, has been documented in most countries of the world. Also, all dairy breeds in the world have fewer problems than the Holstein breed for the direct and maternal effects of calving difficulty and for stillborn calves. Furthermore, post-calving complications of Holsteins have become more pronounced in recent years in most environments; therefore, dairy producers are placing much

greater emphasis on management of transitioning cows from pre-calving to post-calving. Holstein cows continue to become larger in body size due to genetic selection and are often too large for optimum survival in facilities because of inadequate stall size. The combined effect of these factors is fewer calvings during the lifetimes of pure Holstein cows today than in the past.

Inbreeding

The global Holstein population has become more inbred over time. As expected, relationships continue to mount within the Holstein breed because of highly effective selection programs. As relationships between individuals rise, it becomes more and more likely that bulls and cows that are mated to each other will be closely related. Most consequences of inbreeding are masked and not readily noticeable. Inbreeding robs dairy producers of income by increasing stillbirths, reducing cow fertility, inhibiting disease resistance, and shortening herd life. Reducing cow fertility should be a major negative consequence of inbreeding, because highly inbred embryos are more likely to be non-viable and sloughed.

Table 1 has the relationship in 2007 of individual sires of high impact to the USA Holstein population. These relationships were estimated by USDA with a base year of 1960, and earlier relationships were ignored. Two bulls born in the 1960s – Elevation and Chief – together comprise about 30% of the Holstein breed today. All of the other bulls in Table 1 are descendants of at least one of these two stalwarts of the breed.

Table 1. Relationships of individual sires to the Holstein breed in the USA (August 2007).

Sire	Pedigree	Birth year	Relationship (%)
Blackstar	Elevation and Chief are 37.5% of his pedigree	1983	15.6
Elevation		1965	15.0
Chief		1962	14.4
Valiant	Son of Chief	1973	13.6
Mark	Son of Chief	1973	13.4
Leadman	Grandson of Elevation	1985	12.6
Starbuck	Son of Elevation	1979	12.4

Blackstar is a relatively "young" ancestor with a birth year of 1983, yet he already has a relationship of 15.6% to the Holstein breed. Many of Blackstar's sons (Juror, Lord Lily, Duster,

Patron) and grandsons (Mtoto, Tugolo, Outside) are currently having a large impact on the breed. Canadian Holsteins have a 20% relationship to Starbuck, a son of Elevation. Globally, the “narrowing of the genetic base” is almost as severe as in the USA, because North American Holstein genetics have replaced native breeding stock internationally. Also, Interbull evaluations result in the same sires of sons being used by A.I. organizations throughout the world. Essentially, no “outcross” Holstein genetics exists globally.

Six Holstein bulls – Blackstar, Rudolph, Prelude, Jocko Besne, Leadman (more in Europe), and Manfred (more in the USA) – currently dominate the pedigrees of sires and dams of progeny-test young bulls entering A.I., because their descendants tend to rank highly for cow fertility and survival. A seventh sire, Elton, does not rank as highly for cow fertility or survival and has a relationship to the breed in 2007 of “only” 11.8%; however, Elton’s relationship to the breed could increase through his sons (Durham and Convincer) and especially his grandsons (O-Man, BW Marshall, Addison, Jesther, and Machoman).

Table 2 has the average inbreeding of Holstein females in the USA from milk recording by birth year. The estimates are conservative, because pedigrees go back to a base year of 1960. Knowledge of additional relationships prior to the 1960 base suggests 2% should be added to all current estimates of inbreeding with the 1960 base for pedigrees.

Table 2. Average inbreeding of Holstein females in the USA.

Birth year	Inbreeding
	(%)
1991	2.8
1994	3.5
1997	4.1
2000	4.6
2003	4.9
2006	5.3

Inbreeding is increasing at a fairly constant rate of 0.1% per year for USA Holsteins, and heifers born in 2006 have an average inbreeding of 5.3%. The standard recommendation for commercial milk production has been that inbreeding should not surpass 6.25%. With an average of 5.3%, many individual Holstein matings surpass the 6.25% threshold. What does the 6.25% mean? Cows have two genes at every location on their chromosomes – one from each parent. The inbreeding coefficient measures the percentage of those pairs of two genes that are identical because they came from the same ancestor. As the inbreeding % goes up, the

likelihood of doubling up on genetic recessive genes (of either major or minor consequence) becomes greater.

Most dairy producers are probably unaware that individual cows in their herd have inbreeding % higher than what is recommended. With increased relationships among Holsteins, inspection of pedigrees is essential when mating individual bulls to individual cows. The mating programs offered by A.I. organizations help to avoid the mating of A.I. bulls with cows that will result in unacceptable levels of inbreeding. However, pedigrees of cows must be provided to the mating programs, and the mating programs must go deeply into pedigrees.

CROSSBREEDING

Concerns about inbreeding are eliminated with crossbreeding. The effects of heterosis are the opposite of the effects of inbreeding depression. At each location on the pairs of chromosomes, the two genes are much less likely to be identical with crossbreeding than with same-breed matings. Therefore, genetic recessives of both major and minor consequence are not expressed. Old research has indicated that heterosis is greatest for traits related to mortality, fertility, health, and survival.

Heterosis should be of most benefit when environments are limited and when dairy producers are unable or resistant to keep reliable records on parentage of cows in their herds. New research is underway to help uncover the potential value of crossbreeding for commercial milk production. However, the commercial pig, beef cattle, and sheep production have relied on crossbreeding to improve mortality, fertility, growth, and disease resistance for 50 years!

Background

The decline in fertility and survival of pure Holsteins led the managers of seven large dairies in California to mate Holstein heifers and cows with imported semen of the Normande and Montbeliarde breeds from France, as well as the Swedish Red (SRB) and Norwegian Red (NRF) breeds. Some cows continued to be bred to Holstein A.I. bulls for a period of time in these dairies. The Swedish Red and Norwegian Red breeds share similar ancestry and exchange sires of sons; therefore, the breeds were collectively regarded as “Scandinavian Red” for this study.

Production

Crossbreds and pure Holsteins that calved for the first time from June 1, 2002 to January 31, 2005 were studied for production. A total of 1,447 cows calved for the first time during this period, and these cows were followed throughout their lifetimes to gauge production, fertility, and survival. No cows calving the first time after January 31, 2005 were included in the comparison of pure Holsteins and F1 crossbreds. Also, later lactations of other cows were not included in the analysis. Sires of all cows were A.I. bulls, and all Holstein sires had NAAB-

assigned sire codes. Furthermore, the Holstein maternal grandsires of all cows (both purebred and crossbred) were likewise required to be A.I. bulls with NAAB-assigned sire codes. Therefore, cows were removed from the study that had natural service or unidentified Holstein sires or Holstein maternal grandsires.

Actual production (milk, fat, and protein) for 305-day lactations was calculated with the Best Prediction technique used by USDA for national genetic evaluations in the USA. Best Prediction was applied separately to each of the seven dairies and used herd-specific lactation curves to calculate 305-day actual production. Adjustment was made for age at calving and milking frequency (test days with 3X were adjusted to 2X), and records less than 305 days in length were projected to 305 days.

Herd-year-season of calving (4-month seasons) and genetic level of each cow's Holstein maternal grandsire were included in a statistical analysis of 305-day actual production of cows. Cows that calved in herd-year-seasons with only one breed group represented were removed from the analysis, because they provided no basis for comparison of breed groups. Furthermore, multiple lactations of cows were included in the same "mixed model" with cow as a "random effect", as was the fixed effect of interaction of breed group and lactation number. Table 3 has the number of cows and sires of cows analyzed for production by breed group.

Breed	Cows	Sires
Holstein	380	69
Normande-Holstein	245	24
Montbeliarde-Holstein	494	23
Scandinavian Red-Holstein	328	13

Results for 305-day actual production during first lactation are in Table 4, and all cows had the opportunity to complete first lactations. Fat (kg) plus protein (kg) was used to gauge the overall production of the pure Holsteins versus crossbreds. The Scandinavian Red-Holstein crossbreds (-3%), Montbeliarde-Holstein crossbreds (-5%) and the Normande-Holstein crossbreds (-9%) were all significantly lower (statistically speaking) than the pure Holsteins for fat (kg) plus protein (kg). However, the actual differences were small for the Montbeliarde-Holstein and Scandinavian Red-Holstein crossbreds compared to pure Holsteins, at about 15 kg and 9 kg, respectively, for the two crossbred groups for both lactational fat production (kg) and lactational protein production (kg).

Table 4. First lactation production (actual 305-day with 2X milking).

	Holstein	Normande-Holstein	Montbeliarde-Holstein	Scandinavian Red-Holstein
Number of cows	380	245	494	328
Milk (kg)	9,891	8,595 **	9,202 **	9,309 **
Fat (kg)	352	323 **	337 **	343
Protein (kg)	307	278 **	292 **	298 *
Fat (kg) + Protein (kg)	659	601 **	629 **	641 *
% of Holstein		-9%	-5%	-3%

* Statistically significant difference from pure Holsteins ($p < .05$).

** Statistically significant difference from pure Holsteins ($p < .01$).

Table 5 has results for production for second lactation, and all cows had the opportunity to complete second lactation, too. Production of the pure Holsteins climbed substantially from first to second lactation; for example, milk volume increased from 9,891 kg to 11,965 kg, which is an increase of 2,074 kg from first to second lactation. The three crossbred groups also greatly increased in production from first to second lactation, but not at quite the rate of the pure Holsteins. Consequently, the pure Holsteins continued to have a statistically significant advantage for fat (kg) plus protein (kg) production, and the difference from pure Holsteins increased from 9% to 12% for the Normande-Holstein crossbreds, from 5% to 7% for the Montbeliarde-Holstein crossbreds, and from 3% to 6% for the Scandinavian Red-Holstein crossbreds.

Table 5. Second lactation production (actual 305-day with 2X milking).

	Holstein	Normande-Holstein	Montbeliarde-Holstein	Scandinavian Red-Holstein
Number of cows	310	217	432	274
Milk (kg)	11,965	9,990 **	10,683 **	10,782 **
Fat (kg)	427	375 **	400 **	404 **
Protein (kg)	373	326 **	342 **	347 **
Fat (kg) + Protein (kg)	800	701 **	742 **	751 **
% of Holstein		-12%	-7%	-6%

** Statistically significant difference from pure Holsteins ($p < .01$).

However, the differences from pure Holstein for lactational production during second lactation were only 27 kg fat and 31 kg protein for the Montbeliarde-Holstein crossbreds and 23 kg fat and 26 kg protein for the Scandinavian Red-Holstein crossbreds. To put these differences in perspective, active A.I. sires within breed (Holstein, for example), at any point in time, may differ by these amounts for PTA (predicted transmitting ability) or EBV (estimated breeding value). Some cows have not completed their 305-day lactations and Best Prediction was used to project incomplete records of cows to 305 days; therefore, some modest changes in production averages for the second lactations might surface in the future.

The results for third lactation are in Table 6. Some cows in the original data file (Table 3) have not yet calved for a third time and lactations for other cows are incomplete; consequently, the results in Table 6 are somewhat preliminary. Production of pure Holsteins again increased from second to third lactation, but at a much reduced rate compared to the increase from first to second lactation, and all three of the crossbred groups out-paced the pure Holsteins for increase of fat plus protein production from second to third lactation (+26 kg for pure Holstein, +39 kg Normande-Holstein, +41 kg Montbeliarde-Holstein, and +37 kg Scandinavian Red-Holstein).

Therefore, the Montbeliarde-Holstein crossbreds returned to a 5% difference from pure Holsteins for fat plus protein production (kg) for third lactation, which was the difference of the Montbeliarde-Holstein crossbreds from pure Holsteins during first lactation. The Normande-Holstein crossbreds improved to 10% less fat plus protein production than the pure Holsteins, and the Scandinavian Red-Holstein crossbreds improved somewhat (from 6% for second lactation to 5% for third lactation) for difference from the pure Holsteins.

Table 6. Third lactation production (actual 305-day with 2X milking).

	Holstein	Normande-Holstein	Montbeliarde-Holstein	Scandinavian Red-Holstein
Number of cows	213	156	307	192
Milk (kg)	12,311	10,625 **	11,359 **	11,400 **
Fat (kg)	447	398 **	423 **	425 **
Protein (kg)	379	342 **	360 *	363 **
Fat (kg) + Protein (kg)	826	740 **	783 **	788 **
% of Holstein		-10%	-5%	-5%

* Statistically significant difference from pure Holsteins ($p < .05$).

** Statistically significant difference from pure Holsteins ($p < .01$).

Table 7 has very preliminary results for production of fourth lactation cows. Production was fairly constant, but slightly reduced, for pure Holsteins from third to fourth lactation (-4 kg of fat plus protein). The Normande-Holstein crossbreds also tended to have slightly lower production in fourth lactation compared to third lactation (-7 kg of fat plus protein); however, the

Montbeliarde-Holstein crossbreds (+7 kg of fat plus protein) and Scandinavian Red-Holstein crossbreds (+4 kg of fat plus protein) both tended to increase in production from third to fourth lactations, which brought their difference for fat plus protein production from pure Holsteins to only 4%. Therefore, total fat plus protein production across the first four lactations for the Montbeliarde-Holstein and the Scandinavian Red-Holstein crossbreds was very similar and only 4% to 5% less than pure Holsteins. Fat plus protein production across the first four lactations of the Normande-Holstein crossbreds was about 10% less than pure Holsteins.

Table 7. Fourth lactation production (actual 305-day with 2X milking).

	Holstein	Normande-Holstein	Montbeliarde-Holstein	Scandinavian Red-Holstein
Number of cows	89	85	109	56
Milk (kg)	12,372	10,602 **	11,456 **	11,517 **
Fat (kg)	443	392 **	426	429
Protein (kg)	379	341 **	364 *	363 *
Fat (kg) + Protein (kg)	822	740 **	790	792
% of Holstein		-11%	-4%	-4%

* Statistically significant difference from pure Holsteins ($p < .05$).

** Statistically significant difference from pure Holsteins ($p < .01$).

Average production of Swedish Red cows versus Swedish Holsteins in Sweden suggests that the production of Swedish Red-Holstein crossbreds should be very near the production of pure Holsteins if heterosis of 5% for production traits is assumed. Perhaps, less than 5% heterosis for production was realized in this study, because the Swedish Red and Holstein breeds share distant ancestry and because they were developed in the same general region of northern Europe. On the other hand, the Montbeliarde and Holstein breeds share little ancestry, even distantly; therefore, Montbeliarde-Holstein crossbreds might express a higher average level of heterosis than crosses strictly among dairy breeds of the plains or islands of northern Europe, which include Holstein.

Importantly, no adjustment was made to production for differences in days open during the current lactation (pregnancy status) of cows. Cows with very short days open are penalized for 305-day production, and cows with long days open or do not become pregnant have inflated 305-day production. However, second and third lactations of cows were adjusted for effects of days open in the previous lactation with Best Prediction. Production and fertility must both be included, along with other important traits, in selection indexes to determine total merit of cows.

Table 8 has averages for fat and protein content (%) by lactation for each of the breed groups. Fat and protein content (%) is of secondary importance compared to fat and protein solids (kg) in the USA, because the USA production system does not revolve around a fat (kg) quota and the fluid carrier of milk is seldom penalized. The Normande-Holstein crossbreds had the highest fat

and protein contents, which were about .15% higher for both fat and protein content than the pure Holsteins. The Montbeliarde-Holstein crossbreds and Scandinavian Red-Holstein crossbreds were similar for fat and protein content across lactations, and they surpassed the pure Holsteins by roughly .12% for fat content and .10% for protein content.

Table 8. Fat and protein content of milk by lactation (actual 305-day with 2X milking).

Lactation number	<u>Holstein</u>		<u>Normande-Holstein</u>		<u>Montbeliarde-Holstein</u>		<u>Scandinavian Red-Holstein</u>	
	Fat	Protein	Fat	Protein	Fat	Protein	Fat	Protein
	----- (%) -----							
1st lactation	3.56	3.10	3.76	3.23	3.66	3.17	3.68	3.20
2nd lactation	3.57	3.11	3.72	3.24	3.74	3.20	3.75	3.22
3rd lactation	3.63	3.10	3.74	3.22	3.74	3.17	3.66	3.19
4th lactation	3.58	3.07	3.70	3.21	3.72	3.18	3.73	3.15

Somatic cell score (as an indicator of mastitis) in these seven dairies was uniformly low compared to the entire USA. Lactation averages for cows across lactations for somatic cell score did not differ for three of the four breed groups – the pure Holsteins, the Montbeliarde-Holstein crossbreds, and the Scandinavian Red-Holstein crossbreds – and averaged 2.9. On the other hand, the Normande-Holstein crossbreds average 3.1 for somatic cell score, which was significantly higher than the pure Holsteins.



Swedish Red x Holstein
2-01 305d 11,549 kg m, 409 kg f, 352 kg p



Montbeliarde x Holstein
2-01 305d 13,104 kg m, 502 kg f, 396 kg p

We have not and will not separate the daughters of Swedish Red versus Norwegian Red sires because of the small number of sires represented compared to the other breeds in this study.

Only four Swedish Red bulls (Backgard, Stensjo, T-Bruno, Stopafors) and nine Norwegian Red bulls sired the Scandinavian Red-Holstein crossbreeds in this study.

All cows in the study were sired by A.I. bulls, and the seven California dairies historically used high-ranking Holstein A.I. sires. Among the European breeds, sires tended to be high ranking; however, the Montbeliarde-sired daughters in this study likely had a disadvantage relative to average rank of their sires within breed. The Montbeliarde sires with most daughters in this study tended to be those with comparatively low ranking within breed for production in 2007.

Calving Difficulty and Stillbirths

Results for calving ease and stillbirths are the same as previously reported. Calving difficulty was measured on a 1 to 5 scale, with 1 representing a quick and easy birth without assistance and 5 representing an extremely difficult birth that required a mechanical puller. Scores of 1 to 3 were combined and regarded as no calving difficulty, and scores of 4 and 5 were combined and represented calving difficulty. Stillbirths were recorded as alive or dead within 24 hours of birth. Calving difficulty and stillbirth are traits of both the sire and the dam.

Breed of sire

To analyze effects of breed of sire, dams of calves were separated into first calving versus 2nd to 5th calving. Adjustments were made for sex of calf and herd-year-season (4-month seasons) of calving. Across breeds of sire for first-calf heifers, calving difficulty averaged 15.9% for bull calves and 7.0% for heifer calves, and stillbirth rates were 18.6% for bull calves and 5.0% for heifer calves. Clearly, calving difficulty and stillbirth were more pronounced for bull calves.

Table 9 provides the number of births, calving difficulty rate, and stillbirth rate by breed of sire for first-calf pure Holstein dams. Inadequate numbers prevented the evaluation of Normande sires; however, some Brown Swiss semen was used by these dairies. Scandinavian Red sires had both significantly less calving difficulty and significantly less stillbirth than Holstein sires when dams of calves were first-calf pure Holsteins.

Table 9. Calving difficulty and stillbirths for breed of sire for first-calf pure Holstein dams.

Breed of sire	Number of births	Calving difficulty ----- (%) -----	Stillbirth
Holstein	371	16.4	15.1
Montbeliarde	158	11.6	12.7
Brown Swiss	209	12.5 **	11.6
Scandinavian Red	855	5.5 **	7.7 **

** Significant difference from Holstein sires ($p < .01$).

Table 10 has number of births, calving difficulty rate, and stillbirth rate for pure Holstein cows calving for the 2nd to 5th time. Cows calving for the 2nd to 5th time had less calving difficulty and fewer stillbirths than first-calf heifers. However, bull calves again were more of a problem than heifer calves, with much higher rates of calving difficulty (7.5% versus 4.3%) and stillbirth (8.5% versus 5.6%). Again, calves sired by Scandinavian Red sires had significantly less calving

difficulty than Holstein-sired calves. Furthermore, significantly more Holstein-sired calves were stillborn than calves sired by bulls of other breeds.

Table 10. Calving difficulty and stillbirths for breed of sire when pure Holstein dams calved for the 2nd to 5th time.

Breed of sire	Number of births	Calving difficulty	Stillbirth
		----- (%) -----	
Holstein	303	8.4	12.7
Normande	326	8.7	7.3 **
Montebeliarde	2,373	5.4	5.0 **
Brown Swiss	524	4.9	5.6 **
Scandinavian Red	515	2.1 *	4.7 **

* Significant difference from Holstein sires ($p < .05$).

** Significant difference from Holstein sires ($p < .01$).

All non-Holstein breeds of sire had (for first-calf heifers) or tended to have (for 2nd to 5th lactation cows) fewer stillbirths than Holstein sires. Dams of all calves for the breed of sire analysis were pure Holsteins, so calves sired by Holstein sires were purebreds, whereas calves sired by bulls from the other breeds were crossbreds. Therefore, inbreeding probably caused the higher stillbirth rates for Holstein-sired calves, perhaps due to lethal genetic recessives that have not yet been uncovered.

Breed of dam

To estimate differences in breed group of dam for calving difficulty and stillbirths, breeds of sire were limited to Brown Swiss, Montebeliarde, and Scandinavian Red, because numbers of births by sires of other breeds were small and were not well distributed across breed group of dam. Therefore, all births analyzed for effect of breed of dam were for crossbred calves. Adjustments were made for breed of sire, sex of calf, and herd-year-season of calving. Cows calving for the first time were analyzed separately. Across breed group of dam, calving difficulty rates were 14.7% for bull calves and 5.3% for heifer calves, and stillbirth rates were 15.4% for bull calves and 2.2% for heifer calves for cows calving the first time. Table 11 has number of births, calving difficulty rate, and stillbirth rate for 1,572 first births of cows.

Table 11. Calving difficulty and stillbirths for breed group of dam at first calving.

Breed of dam	Number of births	Calving difficulty	Stillbirth
		----- (%) -----	
Holstein	676	17.7	14.0
Normande-Holstein	262	11.6 *	9.9
Montebeliarde-Holstein	370	7.2 **	6.2 **
Scandinavian Red-Holstein	264	3.7 **	5.1 **

* Significant difference of crossbreds from pure Holsteins ($p < .05$).

** Significant difference of crossbreds from pure Holsteins ($p < .01$).

All crossbred cow groups had significantly less calving difficulty than pure Holsteins (17.7%) at first calving. Stillbirth rates tended to follow the averages for calving difficulty respective to

breed group of dam, and Montbeliarde-Holstein dams (6.2%) and Scandinavian Red-Holstein dams (5.1%) had significantly lower stillbirth rates than pure Holstein dams (14.0%).



Normande x Holstein

1-11 305d 10,995 kg m, 450 kg f, 361 kg p
3-01 305d 12,011 kg m, 518 kg f, 387 kg p



Montbeliarde x Holstein

2-02 305d 12,211 kg m, 462 kg f, 405 kg p
3-03 290d 13,749 kg m, 583 kg f, 452 kg p

Survival

First-lactation cows that calved from June 2002 to January 2005 in the seven California dairies were compared for survival to 30 days, 150 days, and 305 days post-calving. Survival rates were adjusted for herd-year of calving, and cows were required to have contemporaries from another breed group within 4-month seasons of calving to be included in the analysis. Table 12 has the survival rates for the 380 pure Holsteins and 1,067 crossbreds. Pure Holsteins left these dairies sooner than all crossbreds groups, with 83% of pure Holsteins surviving 305 days post-calving compared to 90% to 93% of crossbreds.

Table 12. Survival rates during first lactation.

Breed	Number of cows	30 days	150 days	305 days
		----- (%) -----		
Holstein	380	96	96	83
Normande-Holstein	245	99	98	90 **
Montbeliarde-Holstein	494	99	98	93 **
Scandinavian Red-Holstein	328	99	97	90 **

** Statistically significant difference of crossbreds from pure Holsteins ($p < .01$).

Cows that had an opportunity to calve a second time were compared for three thresholds for calving interval by breed group – within 14 months of first calving, within 17 months of first calving, and within 20 months of first calving (Table 13). All crossbred groups had significantly higher percentages of cows calving a second time within the fixed windows of opportunity than the pure Holsteins. From 15% to 19% more crossbred cows calved a second time within 14 months of first calving compared to pure Holsteins. When cows were provided more time to calve a second time (20 months – which is an ideal 12-month calving interval plus an additional 8 months), the difference of the crossbred groups from the pure Holsteins narrowed (8% to 14%); yet, the differences remained substantial and significant statistically.

Table 13. Percentage of cows that calved a second time after first calving within fixed windows of opportunity.

Breed	Number of cows	14 months	17 months	20 months
		----- (%) -----		
Holstein	380	44	63	71
Normande-Holstein	245	61 **	79 **	85 **
Montbeliarde-Holstein	494	63 **	78 **	84 **
Scandinavian Red-Holstein	328	59 **	72 *	79 *

* Significant difference of crossbreds from pure Holsteins ($p < .05$).

** Statistically significant difference of crossbreds from pure Holsteins ($p < .01$).

Fertility

Fertility of the pure Holsteins and crossbreds was measured as actual days open for cows that had a subsequent calving or had pregnancy status confirmed by a veterinarian. To be included in the analysis, cows were required to have at least 250 days in milk, which meant the pure Holsteins had an advantage because they were a more highly-selected group compared to the crossbreds – a smaller percentage of pure Holsteins than crossbreds survived to 250 days postpartum. Cows with more than 250 days open had days open set to 250. Adjustment was made for herd-year of calving, and cows were required to have contemporaries from another breed group within 4-month seasons of calving to be included in the analysis.

Average days open increased slightly for cows in all breed groups compared to an earlier report from this study. Cows were added to the study since the earlier report; however, some cows that were confirmed pregnant to a given A.I. service (for the earlier report) had a subsequent calving date that did not fit the confirmed pregnancy. Each of the dairies had natural service bulls in corrals to breed cows that lost confirmed pregnancies.

The 360 pure Holsteins in these dairies had average days open of 147 days (Table 14) during first lactation, and all of the crossbred groups had significantly fewer days open than the pure Holsteins. The difference from the pure Holsteins ranged from 16 days for the 315 Scandinavian Red-Holstein crossbreds to 25 days for the 235 Normande-Holstein crossbreds. These results agree with most other recent research on fertility of pure Holsteins versus F1 crossbreds involving Holstein, which have typically reported two to three weeks fewer days open of crossbreds versus pure Holsteins.

Table 14. Days open during first lactation with a maximum of 250 days.

Breed	Number of cows	Number of sires	Days open
Holstein	360	69	147
Normande-Holstein	235	24	122 **
Montbeliarde-Holstein	478	23	124 **
Scandinavian Red-Holstein	315	13	131 *

* Significant difference of crossbreds from pure Holsteins ($p < .05$).

** Statistically significant difference of crossbreds from pure Holsteins ($p < .01$)

3-breed versus 2-breed crossbreds

All first generation (F1) crossbreds in the seven California dairies are bred to bulls from a third breed; however, these dairies were no longer calving first-lactation pure Holsteins by the time the 3-breed crossbreds began to calve. Therefore, the comparison of 3-breed crossbreds versus contemporary pure Holsteins is not possible in these dairies. On the other hand, comparison of 2-breed and 3-breed crossbreds that calved during the same 4-month herd-year-seasons is possible.

The data file for 2-breed crossbreds for comparison with 3-breed crossbreds is different than the data file for comparison of 2-breed crossbreds with pure Holsteins. Only 2-breed crossbreds that calved within the same 4-month herd-year-seasons as 3-breed crossbreds were included in the analysis of 2-breed versus 3-breed crossbreds. Furthermore, at least two breed groups of cows were required within each herd-year-season for cows to be included in the analysis. All maternal grandsires were required to be an A.I. bull, so granddaughters of natural service bulls were removed from the analysis. Breed combinations (2-breed as well as 3-breed) were required to have at least 20 first-lactation cows to be included in the analysis.

Actual 305-day production during first lactations of 2-breed and 3-breed crossbreds was obtained with Best Prediction within each dairy using individual test-day observations. The statistical model for analysis included herd-year-season of calving, 2-breed crossbred versus 3-breed crossbred, and breed combination within 2-breed crossbred versus 3-breed crossbred.

Table 15 has first lactation production for the 2-breed versus 3-breed crossbreds. The production of 2-breed and 3-breed crossbreds was very similar, and differences were not statistically significant. A reduced Holstein content might be expected to lower the production capability of 3-breed crossbreds (25% Holstein) versus 2-breed crossbreds (50% Holstein). However, preliminary results comparing 2-breed and 3-breed crossbreds in these seven dairies suggest the production of 3-breed crossbreds is extremely similar to the production of 2-breed crossbreds.

Type of crossbred	Number of cows	Number of sires	Milk	Fat	Protein	Fat plus protein
			----- (kg) -----			
2-breed crossbreds	607	66	9314	349	300	649
3-breed crossbreds	173	27	9189	345	300	645

No differences were statistically significant.

Production of the various breed combinations of 2-breed versus 3-breed crossbreds is reviewed in Table 16. A limited amount of Brown Swiss semen was used by these dairies for a period of time, which permitted Brown Swiss-sired cows to be included in the comparison of 2-breed versus 3-breed crossbreds. Production traits of the various 2-breed and 3-breed combinations were not significantly different from one another, statistically, except those crossbreds that contained Normande influence were significantly lower. The 3-breed crossbred combination of Montbeliarde/(Scandinavian Red-Holstein) tended to rank highest for fat plus protein (kg) production and, interestingly, this is the 3-breed combination that the managers of the seven California dairies intend to use most frequently in the future.

Breed combination	Number of cows	Number of sires	Milk	Fat	Protein	Fat plus Protein
			----- (kg) -----			
<u>2-breed crossbreds</u>						
Brown Swiss/Holstein	42	10	9508	349	305	654
Normande/Holstein	37	9	8865	345	288	633
Montbeliarde/Holstein	366	32	9432	351	302	653
Scandinavian Red/Holstein	162	15	9450	350	305	655
<u>3-breed crossbreds</u>						
Brown Swiss/ (Montbeliarde-Holstein)	44	8	9297	349	302	651
Montbeliarde/ (Scandinavian Red-Holstein)	43	9	9461	356	308	664
Scandinavian Red/ (Normande-Holstein)	86	10	8809	331	289	620

Number of breeds to use in crossbreeding systems

Extent of heterosis realized from crossbreeding systems differs tremendously based on the number of breeds included in the rotation. Table 17 reviews the extent of heterosis for each generation in crossbreeding systems that include 2, 3, or 4 unrelated breeds. The average extent of heterosis during the first four generations of 2, 3, and 4 breed crossbreeding systems is 72%, 91%, and 97%, respectively, which means that moving from 2 to 3 breeds increases average extent of heterosis by 19%; however, adding a 4th breed increases average extent of heterosis only 6%.

Table 17. Heterosis by generation for crossbreeding using 2, 3, and 4 unrelated breeds.

Generation	2 breeds	3 breeds	4 breeds
	----- (%) -----		
1	100	100	100
2	50	100	100
3	75	75	100
4	63	88	88
5	69	88	94
6	66	84	94
7	67	86	94
8	67	86	93
9	67	86	93

Once dairy producers become accustomed to heterosis from crossbreeding, they prefer dairy cattle that maintain at least 75% of full heterosis in all generations. For 2-breed crisscrossing systems of crossbreeding, extent of heterosis dips as low as 50% in the second generation and surpasses 69% only once following the initial cross. After eight generations, extent of heterosis plateaus at 67% when only 2 breeds are used for crossbreeding; however, extent of heterosis plateaus at 86% when 3 breeds are used in a fixed rotation, and it plateaus at 93% when 4 breeds are used in a fixed rotation. Importantly, breeds must be unrelated to achieve the extent of heterosis that is reviewed here.

Generally speaking, finding more than three breeds that are especially well-suited for a specific environment or management system might be difficult. Crossbreeding systems using only 2 breeds limit the impact of heterosis, and crossbreeding systems using more than 3 breeds limit impact of single breeds of high merit for specific needs. Therefore, 3 breeds is likely the optimum number of breeds to use in a fixed rotation for most crossbreeding systems.

Some have argued that crossbreeding systems are confusing; however, this is not at all the case. When three breeds are used in a simple 3-breed rotation, a color tagging system eliminates the need for paper or electronic records. Calves sired by breed “A” are tagged with a blue tag, calves sired by breed “B” are tagged with a yellow tag, and calves sired by breed “C” are tagged with an orange tag. Then, whenever employees see a blue tag, they know that semen from breed “B” goes in that heifer or cow, and calves from that heifer or cow are sired by breed “B”.

Similarly, whenever employees see a yellow tag, they breed the animal with semen from breed “C”, and calves from that animal are sired by breed “C”. Finally, animals with orange tags are always bred to semen from breed “A”, and all calves from those animals are sired by breed “A”. This is an extremely simple mating and identification system, and it is much simpler than calculating inbreeding coefficients at the time of mating, which is essential when using only same-breed matings.



Montbeliarde x (Jersey/Holstein)
2-01 305d 10,895 kg m, 374 kg f, 338 kg p



Swedish Red x (Normande/Holstein)
2-00 305d 13,608 kg m, 444 kg f, 397 kg p

RECOMMENDATIONS

Crossbreeding should be regarded as a mating system that complements genetic improvement within breeds. Continuous use of progeny-tested and highly-ranked A.I. bulls is critical to genetic improvement regardless of mating system (purebreeding or crossbreeding). Unfortunately, some dairy producers might interpret the merit of crossbreeding as justification to use natural service bulls rather than A.I. That would be an unfortunate consequence of dairy producers' interest in crossbreeding.

Heterosis is a bonus that dairy producers can expect in addition to the positive effects of individual genes obtained by using top A.I. bulls within breed. The bonus from heterosis should be about 5% for production and at least 10% for mortality, fertility, health, and survival, and heterosis comes on top of the average genetic level of the two parent breeds. Therefore, the impact of heterosis on profit should be substantial for commercial milk production. However, some dairy producers might need to get beyond the notion that level of milk production is the only measure of profitability of dairy cows. In these seven dairies, production of the Montbeliarde-Holstein crossbreds and the Scandinavian Red-Holstein crossbreds was slightly reduced (4% to 5% for fat plus protein production across the first three lactations) compared to pure Holsteins.

Research on crossbreeding has been initiated at many of the major agricultural universities in the USA and around the world. However, the rate of increase in inbreeding of Holsteins (+0.1% per year) might make crossbreeding almost essential in the more distant future for commercial milk production internationally.

Crossbreeding systems should make use of **three** breeds. The use of two breeds limits the long-term impact of heterosis. The use of four breeds limits the contribution of any single breed of especially high merit to herd composition. Individual dairy producers should carefully choose three breeds that are optimum for conditions unique to their dairy operations (facilities, climate, nutritional regime, reproductive status, level of management, and personal preferences).



First 3-breed crossbred at the University of Minnesota, St. Paul
Sire: Montbeliarde (Micmac) Dam: Jersey x Holstein

2-00 293d 8,476 kg milk 3.6% 302 kg fat 3.1% 265 kg protein
 3-00 305d 10,503 kg milk 3.9% 414 kg fat 3.2% 337 kg protein

1st calving on November 25, 2005 with a heifer by the Holstein sire, Clover-Valley Duster Ivan.
 2nd calving on November 13, 2006 with a heifer by the Holstein sire, McCloe-Pond Trent.