Using Mating Programs To Control Inbreeding

Use of Computerized Mate Selection Programs to Control Inbreeding of Jersey Cattle in the Next Generation

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Inbreeding is an increasing concern in dairy cattle breeding. Inbreeding decreases heterozygosity and increases the frequency of deleterious recessive genes, thereby reducing phenotypic performance and viability. This phenomenon, known as inbreeding depression, ultimately causes a decrease in dairy farm profitability.

Inbreeding can be of particular concern for numerically small breeds that are making rapid genetic progress, such as Jerseys. Wiggans et al. found mean inbreeding coefficients of 3.3% for sire-identified U.S. Jersey cows born in 1990. However, many of these cows had incomplete maternal pedigree information, and the level of inbreeding may have been underestimated. Losses per 1% inbreeding were estimated at 21.3 kg (46.9 lbs.) milk, 1.0 kg (2.2 lbs.) fat and 0.9 kg (1.98 lbs.) protein per lactation in Jerseys.

Breeders have traditionally tried to control inbreeding by avoiding matings of genetically related animals. However, as relationships within the breed increase, it becomes difficult to avoid such matings without the aid of a computer. Many bulls and cows that appear to be unrelated based on one or two generations of pedigree data are in fact closely related due to common ancestors in earlier generations. Therefore, computerized mate selection programs, which have traditionally been used for corrective mating of conformation traits, may have potential as a tool for controlling inbreeding.

Although some existing mating programs consider inbreeding, this may not be done in an optimal manner. For example, some programs enforce an arbitrary maximum value for inbreeding of proposed matings, but there is little scientific evidence with regard to the choice of an acceptable level of inbreeding. In addition, some commercial mating programs use pedigree data from only the most recent generations, and this can lead to underestimation of inbreeding.

The objective of this study was to examine the potential of several alternative mate selection strategies for the purpose of maximizing net profit and minimizing inbreeding in Jersey cattle.

Brief Summary of Findings

Three different computerized mating programs were compared in this research, which is excerpted from an article to be published in the *Journal of Dairy Science*. The results suggest an important new role for mating programs in controlling inbreeding.

The first mating program evaluated simply selected the service sire with highest Net Merit, without considering inbreeding of the calf. This is what a producer might do if he or she simply picked the best sires available and didn't worry about individually mating each cow. The second mating program again selected the service sire with highest Net Merit, but this time controlled for the maximum level of inbreeding that would be allowed in the recommended mating. Inbreeding levels were set at 8%, 9%, or 10% and any prospective mating higher than these levels was rejected. This is how most currently available mating programs work.

The third mating program selected the service sire with highest Net Merit, after adjusting for expected inbreeding depression in the calf. The researchers used a value of $23 depression in lifetime income per 1% inbreeding, based upon work conducted at Virginia Tech.

Weigel and Lin offer three conclusions.

First, *computerized mating programs can effectively reduce inbreeding in the next generation of replacement heifers.* Average inbreeding of calves from recommended matings was up to 40% lower when inbreeding was considered in the mating program. Interestingly, applying a maximum level of inbreeding for potential matings was a less effective way to reduce inbreeding than was selection for Net Merit adjusted for inbreeding depression. The reason is that the first type of program does not actually minimize inbreeding. Instead, it simply looks for any mating that gives less inbreeding than the user-specified value. For example, if you choose a maximum inbreeding level of 6%, then a mating that gives 5.9% inbreeding is fair game, even though different mating might give only 2% inbreeding.

Second, *allowing a little more inbreeding doesn't necessarily mean you'll end up with sires that have higher genetic merit.* Increasing the allowable inbreeding level from 8% to 10% didn't increase the average Net Merit of selected sires, it just allowed more inbreeding (and less profit). Why? All bulls on the Active A.I. list are highly selected, with many generations of superior sires in their pedigrees. Therefore, these bulls (as a group) have a high genetic relationship to the national dairy cow population. However, the average dairy cow is no more closely related to the top bull on the list than to an average bull from this group.

Finally, *the best way to maximize profitability of the next generation of replacement heifers is to select for genetic merit adjusted for expected inbreeding depression.* Expected lifetime profit per heifer calf increased from $20 to $59 when a mating program that considered inbreeding was used. But lifetime profit was substantially higher when selection was based on Net Merit adjusted for inbreeding depression than when a user-specified inbreeding level was applied.

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Methods

`Data from a random sample of 25 large Jersey herds located in California and Minnesota were used in the present study. Only registered cows were included in the study, because complete pedigree information was required for all animals. All cows that had a reported breeding in the current lactation to a U.S. A.I. sire with a valid NAAB code number were included. Pedigrees of cows, service sires, currently available Jersey A.I. sires, and their ancestors were traced back to 1960. Animals born prior to 1960 were considered as unrelated.

Optimizing Sire Selection and Matings Using Active A.I. Sires

Selection of service sires, determination of the usage level of each service sire, and selection of mating pairs were considered jointly. For each herd, a random sample of potential service sires was chosen from the top 50% of sires on the February, 1999 active A.I. list ranked by the USDA Net Merit index (NM$). Twenty (20) possible service sires were chosen for each herd. A constraint was imposed such that no service sire could be mated to more than 15% of the herd.

Three alternative strategies were considered for selection of service sires and allocation of mating pairs. First, service sires were randomly chosen and mated to cows within each herd. Second, the mean NM$ of service sires (weighted by the number of matings per sire) was maximized, subject to the constraint that no individual sire-by-cow mating could exceed a fixed threshold level of inbreeding (8%, 9%, and 10%). In addition, mean NM$ was maximized with no constraint on inbreeding, and this represented an additional control. Third, the following profit function was calculated for each possible sire by cow mating in each herd:

Expected Profit =
(Exp. lifetime merit) – (Exp. inbreeding) x
(Inbreeding depression)

where expected lifetime merit of each mating was calculated as: ((NM$ of cow + NM$ of service sire) / 2) x (expected number of lactations). The expected number of lactations was 2.83. Because NM$ values were not available for all cows, the Jersey breed average of $58.00 was substituted. Expected inbreeding was equal to the inbreeding coefficient for a hypothetical offspring of each possible sire-by-cow mating, expressed as a deviation from the mean inbreeding for Jerseys. An inbreeding depression value of -$23.11 in lifetime net profit per 1% inbreeding was used, based on an average of the inbreeding depression estimates for fluid and manufacturing markets in the study of Smith et al. A linear programming algorithm was used to maximize the mean of the expected profit function for each herd, subject to the constraint that no service sire was allowed to mate more than 15% of the cows in a given herd. Means of inbreeding coefficients, NM$ and expected lifetime profit were calculated for each mate selection scheme.

Lastly, the impact of incomplete pedigree information was assessed. Inbreeding coefficients were recalculated using pedigrees of cows and service sires traced back to 1985, rather than 1960. Means and correlations of inbreeding coefficients with differing amounts of historical pedigree data were examined.

Table 1. Mean, minimum and maximum inbreeding coefficients (%) for Jersey herds resulting from actual matings or matings that minimized inbreeding while keeping service sires and the number of matings per sire the same as for actual matings.

Mate Selection Scheme	Inbreeding Coefficients (%)
Actual	
Mean	6.5
Minimum herd mean	5.2
Maximum herd mean	7.3
Minimize inbreeding	
Mean	4.6
Minimum herd mean	3.4
Maximum herd mean	5.2

Results and Discussion

Table 1 shows the mean inbreeding coefficients for actual matings in the study herds. The mean actual inbreeding was 6.5% and herd means ranged from 5.2% to 7.3%. When inbreeding was minimized via linear programming, the mean inbreeding coefficient was 4.6%. Thus, mean inbreeding was reduced by 1.9% or 2.5% compared with actual mating, respectively. Assuming a decrease in lifetime profit of approximately $23.11 per 1% inbreeding, the mate selection algorithm provided a financial benefit of $43.91 or $57.78 relative to actual or random matings, respectively. This represents a substantial annual economic benefit.

The effects of a mate selection algorithm for sire selection and mate allocation are shown in Table 2. Random mating to a sample of 20 sires from the top 50% of the active A.I. list gave means of 7.1% inbreeding, $168.01 NM$, and $305.26 estimated lifetime profit. Ignoring inbreeding while maximizing NM$ resulted in 7.2% inbreeding, once again indicating that the difference between relationships with high NM$ sires and average NM$ sires is minimal. Mean NM$ and estimated lifetime profit were $186.39 and $327.56, respectively, when inbreeding was ignored.

Restricting inbreeding to 8% reduced mean inbreeding by 1.4% relative to maximization of NM$ ignoring inbreeding, and mean NM$ decreased by only $0.45. Therefore, estimated lifetime profit was $32.91 higher when inbreeding was limited to 8%, due to a reduction in inbreeding depression. Maximum inbreeding levels of 9% or 10% level gave slightly higher mean inbreeding with a minimal gain in NM$, so estimated lifetime profit was reduced. Maximization of estimated lifetime profit adjusted for inbreeding depression gave mean inbreeding of 4.4%, mean NM$ of $182.44, and mean lifetime profit of $387.33. Although NM$ was $3.50 lower than when inbreeding was limited to 8%, lifetime profit was $26.86 higher, and this was due to an additional 1.4% reduction in inbreeding. Therefore, mate selection algorithms effectively reduced inbreeding and increased expected lifetime profit in these Jersey herds. The algorithm based on maximizing expected profit minus inbreeding depression was the most effective.

Table 3 shows the consequences of ignoring historical pedigree information. Tracing all pedigrees back to 1960 resulted in estimated inbreeding coefficients that were 5.5% higher than coefficients estimated from pedigrees traced to 1985.

Correlations between inbreeding coefficients from base years of 1960 and 1985 were only 0.25 to 0.59. For this reason, it is extremely important to have complete historical pedigree data for all animals. If pedigrees are incomplete, inbreeding coefficients will be erroneous, and mating recommendations will not be optimal. Obviously there are many (grade) cows for which pedigree data are incomplete. Mate

Table 2. Mean inbreeding coefficients, Net Merit, and expected lifetime profit for Jersey herds resulting from random matings to a sample of 20 current active A.I. sires, matings that maximized Net Merit with a constraint inbreeding, or matings that maximized expected lifetime profit adjusted for inbreeding depression.

Mate Selection Scheme	Inbreeding	Net Merit	Lifetime Profit
Random mating	7.1%	$168.01	$305.26
Maximize Net Merit regardless of inbreeding	7.2%	$186.39	$327.56
Maximize Net Merit with < 8% inbreeding	5.8%	$185.94	$360.47
Maximize Net Merit with < 9% inbreeding	6.1%	$186.39	$354.04
Maximize Net Merit with < 10% inbreeding	6.4%	$186.39	$347.98
Maximize profit minus inbreeding depression	4.4%	$182.44	$387.33

selection programs can be used for such cows, but their effectiveness will be reduced. Many commercial mating programs consider only one or two recent generations of pedigree data. If more historical pedigree data exist, it should be used.

The importance of complete pedigree data is different for each sex. Because the group of cows to be mated is typically fixed (i.e., no cow selection is being practiced), results will still be useful if pedigrees for some cows are incomplete. However, incomplete pedigrees for service sires can lead to ridiculous results. For example, if a foreign sire or a grade sire has incomplete pedigree data, estimated inbreeding coefficients for all of his future progeny will be underestimated, and this bull will be recommended for far too many matings. For this reason, it may be necessary to exclude or somehow penalize potential service sires that have incomplete historical pedigree data.

Table 3. Effect of ignoring pedigree information prior to 1985 on mean inbreeding coefficient (%) from actual matings, random matings to actual service sires, and random matings to sires from the current active AI list.

	Mean Inbreeding Coefficient (%)
Actual matings	
Pedigree data since 1960	6.5
Pedigree data since 1985	1.0
Correlation (1960, 1985)	0.37
Random matings with actual service sires	
Pedigree data since 1960	7.1
Pedigree data since 1985	1.5
Correlation (1960, 1985)	0.58
Random matings to current active AI sires	
Pedigree data since 1960	7.1
Pedigree data since 1985	1.6
Correlation (1960, 1985)	0.59

Conclusions

This study clearly demonstrates the important role that computerized mate selection programs can play in reducing inbreeding and increasing farm profitability. Mate selection algorithms based on maximizing NM$ subject to a fixed inbreeding threshold of 8% increased estimated lifetime profitability per mating by $32.91 relative to programs that maximized NM$ while ignoring inbreeding. Allowing higher levels of inbreeding reduced profits, because mean inbreeding coefficients increased but mean NM$ did not. This occurred because genetic relationships with elite A.I. sires were no higher than genetic relationships with average AI sires. Algorithms based on maximizing expected lifetime profit adjusted for inbreeding depression provided an additional economic benefit of $26.86 relative to programs that enforced an inbreeding threshold. Thus, total gains in expected lifetime profit per mating due to the optimal mate selection program were $59.77.

Application of these mating programs to control inbreeding could be of tremendous economic benefit. Mate selection programs were beneficial in sire selection and in mate pair allocation. Even in situations where service sires and matings per sire were fixed, inbreeding was reduced substantially by reallocation of mating pairs.

Optimal mate selection programs rely on calculation of expected inbreeding coefficients for all possible mating pairs. This can be a computationally demanding task, particularly if the number of potential service sires is large. However, widespread implementation of such programs is feasible, due to the availability of powerful, inexpensive computers and alsoefficient means for extracting ancestor pedigrees and calculating inbreeding coefficients.

A difficulty may be the availability of complete (inter)national pedigree files. Pedigrees of each cow and each potential service sire must be traced back to the original base population. Therefore, mating services that wish to apply these mate selection algorithms must routinely access a large herdbook file from the national evaluation center or breed association. Incomplete pedigree data for cows will reduce the economic benefits of mate selection programs. Perhaps results of inbreeding studies such as this one can be used to motivate producers into improving pedigree recording of their animals. Incomplete pedigree data for service sires is a more serious problem, as this can bias mating recommendations in favor of bulls with missing ancestor data. Such bulls must be eliminated or otherwise penalized by the mating program.

In summary, mate selection programs can successfully reduce inbreeding in the next generation and increase profitability of commercial dairy operations. However, mating programs cannot solve long-term inbreeding or genetic diversity problems at the population level. Such problems can only be addressed by breeding companies and pedigree breeders; these individuals must maintain genetic diversity in selected animals to which advanced reproductive technologies are applied.

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