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Mate selection to control inbreeding and maximise farm profit of commercial dairy cattle

N. LOPEZ-VILLALOBOS, B. L. HARRIS[1], J. E. PRYCE[1]

Institute of Veterinary, Animal and Biomedical Sciences
Massey University, Private Bag 11222, Palmerston North, New Zealand

ABSTRACT

The objective of this study was to demonstrate the potential benefits of computerised mate selection in a commercial crossbred dairy herd of 411 cows mated to 10 Holstein-Friesian and 10 Jersey bulls. Mate selection was carried out using an evolutionary algorithm to perform single- or multiple-objective optimisation to maximise farm profit ($/4.5 t DM) and/or minimise inbreeding level of progeny. Restrictions were placed on the total number of mating pairs, the maximum number of matings per bull and per cow. Selection and mate allocation of bulls and cows at random produced progeny with average farm profit of $94 and inbreeding level of 1.70%. Mate selection applied to maximise farm profit yielded a mating set with an average farm profit of $181 and inbreeding level of 2.07%. Mate selection applied to minimise inbreeding level selected a mating set with average farm profit of $65 and inbreeding level of 0.03%. Mate selection applied to optimise farm profit and minimise level of inbreeding with a weighted ratio of 1:1, resulted in a mating set with average farm profit of $176 and inbreeding level of 0.44%. The results demonstrate that in the short term, inbreeding can be controlled at the same time as maximising farm profit using a computerised mating selection program with multiple-objective optimisation.

Keywords: Mate selection; evolutionary algorithm; multiple-objective optimisation

INTRODUCTION

Dairy farmers in New Zealand breed replacement heifers from cows mated to bulls with high Breeding Worth (BW). One major problem with this is that the bulls used are potentially closely related to some of the cows being mated, resulting in offspring with a high percentage of inbreeding. Inbreeding in dairy cows reduces their viability and their productive, reproductive and economic performance (Smith *et al*., 1998).

BW is calculated as the sum of the estimated breeding values for cow mature live weight, fertility, and longevity and lactation yields of milk, fat, and protein, each weighted by an appropriate economic value. BW measures the genetic superiority of an animal to convert 4.5 tonnes of dry matter (in average quality pasture) consumed into farm profit. The expected farm profit of a cow for each lactation during its productive life is given by the Production Worth (PW) index. PW is calculated as the sum of the estimated production values for cow mature live weight and lactation yields of milk, fat, and protein, each weighted by an appropriate economic value. Production value is a measure of the cow's expected lifetime performance for a trait relative to its contemporaries. It is calculated as the sum of breeding value, permanent effects and crossbreeding effects.

Mate selection is defined as the simultaneous selection of parents and mate allocation according to predicted progeny merit (Hayes *et al*., 2002). Computerised mate selection in dairy cattle using linear programming was illustrated by Jansen & Wilton (1985) and has been applied in several dairy cattle studies (e.g. DeStefano & Hoeschele, 1992; Weigel & Lin, 2000). DeStefano & Hoeschele (1992) applied mate selection to exploit specific combining ability between pairs of bulls and cows. Specific combining ability was defined as the non-additive genetic effect of a cow due to the interaction of the genes from its sire with the genes from its dam. Mate selection yielded an average progeny merit that was slightly but significantly higher than random mating. Weigel & Lin (2000) applied mate selection to maximise the mean expected lifetime profit after adjustment for inbreeding depression in Holstein and Jersey herds. Compared to random mating, the computerised mate selection program decreased mean expected inbreeding by 1.8 and 2.8% and increased lifetime profit by US$37.37 and US$59.77 in Holstein and Jersey herds.

In all the studies mentioned above there was one objective to be optimised by the mate selection algorithm, to maximise progeny merit as the sum of additive and specific combining ability (DeStefano & Hoeschele, 1992) or expected lifetime profit after adjustment for inbreeding depression (Weigel & Lin, 2000). Tozer & Stokes (2001) illustrated the principle of multiple objective programming for a dairy cow breeding program to maximise net merit, to minimise inbreeding and to minimise total expenditure on semen, simultaneously. The results indicate the weights placed on each objective by the dairy farmer substantially affect the optimal levels of each objective within the multiple-objective model.

[1] Livestock Improvement Corporation, Private Bag 3016, Hamilton

TABLE 1: Number of bulls and cows per breed group and their mean, minimum and maximum values of breeding worth.

	Proportion of Holstein-Friesian					Breeding worth ($)		
		≤7/8		<4/8				
	>7/8	>4/8	4/8	≥1/8	<1/8	Mean	Min	Max
Bulls	10	0	0	0	10	236	220	255
Cows	13	99	164	109	26	97	18	175

In New Zealand, Livestock Improvement has developed DataMATE™ (Livestock Improvement, 2002), a computerised tool to control inbreeding in commercial cattle. DataMATE™ stores simple pedigree information on cows and on bulls to be used for artificial insemination on a specific date. The tool warns the artificial insemination technician if a cow to be inseminated is closely related to a specific bull about to be used, and alternative bull can be used. However DataMATE™ was not designed for mate selection and a more advanced tool is required for selection and mate allocation of bulls and cows to control inbreeding and maximise expected genetic merit of progeny in commercial herds.

The objective of this study was to demonstrate the potential benefits of a computerised mating selection tool with multiple objective optimisation to minimise inbreeding and maximise farm profit in the progeny of the next generation.

MATERIAL AND METHODS

Data

Information on pedigree and breeding values of 20 bulls was provided by the Animal Evaluation Unit and 411 cows from a commercial dairy herd was provided by Livestock Improvement (Table 1). There were 10 straightbred Holstein-Friesian and 10 Jersey bulls with and average BW of $236 and a range from $220 to $255. Most of the cows of the commercial dairy herd were crossbred (n=372) and only 39 cows were straightbred Holstein-Friesian or Jersey. The average BW of the cows was $97 with a range from $18 to $175.

Expected performance of progeny

Mate selection algorithms select and allocate bulls and cows based on expected performance or progeny. Estimated production values (EPV) for lactation yields of milk, fat and protein and for live weight for each expected progeny were calculated as

$$\mathrm{EPV}_{bc} = (\mathrm{EBV}_b + \mathrm{EBV}_c)/2 + \mathbf{q}_b\text{'}\mathbf{H}\mathbf{q}_c$$

where EPV_{bc} is the production value of progeny product of mating bull b to cow c, EBVs are the estimated breeding value for bull b and cow c, $\mathbf{q}_b$ and $\mathbf{q}_c$ are vectors of order 2, with their elements representing the proportion of Holstein-Friesian and Jersey genes for the bull and cow, respectively, and **H** is a symmetric matrix of order 2 × 2, with diagonal elements being zero and off-diagonal elements being the first-cross heterotic effects between Holstein-Friesian and Jersey. Values of heterosis were 137 litres milk, 7.1 kg fat, 5.2 kg protein and 7.7 kg live weight. This expression assumes that EBVs are calculated from across-breed genetic evaluation, and thus breed effects are already accounted for in the estimation of these breeding values.

Expected BW of progeny was calculated as the parental average. Expected PW ($/4.5 t DM) of progeny was calculated as a function of EPVs for fat (F), protein (P), milk (M) and live weight (W) and respective economic values as follows:

$$\mathrm{PW}_{bc} = (1.25 \times \mathrm{EPV}_{\mathrm{F}bc}) + (6.04 \times \mathrm{EPV}_{\mathrm{P}bc}) - (0.072 \times \mathrm{EPV}_{\mathrm{M}bc}) - (0.89 \times \mathrm{EPV}_{\mathrm{W}bc})$$

Economic values were the official values used for the national genetic evaluation of dairy cattle for the season 2003-04 but they can be customised.

Expected inbreeding in the progeny

The inbreeding coefficient (I) for each potential progeny was calculated as half of the additive relationship (R) between its potential sire and dam. That is,

$$I_{bc} = 0.5 \times R_{bc}$$

Pedigrees were tracked back to 1940's to calculate R values following the procedure used for national genetic evaluation of New Zealand dairy cattle. The principles are based on the method of Meuwissen & Luo (1992) with link-listing to reduce memory requirements.

Multiple objective optimisation

Multiple criteria optimisation was solved using goal programming procedures (Sposito, 1975). This essentially requires the individual objectives to be treated as constraints. Goal programming requires the development of an overall objective which weights the output from the individual objective constraints. The weights for each objective correspond to the relative priority placed on each objective by the farmer.

Mate selection algorithm

A systematic strategy for mate selection is required to optimise expected progeny performance of the next generation as illustrated in Figure 1. Rows are bulls and columns are cows. The intersection of one row and one column represents the mating value (π) of the mating from bull *i* and cow *j*. Each bull can be potentially mated to any of the *c* cow candidates restricted to a number of matings for that bull, and each cow can be potentially mated to any of the *b* bull candidates restricted to usually one mating per cow.

FIGURE 1: Representation of a mating table for the application of mate selection algorithms.

		Cow number			
		1	2	. . .	c
Bull number	1	π_{11}	π_{12}	. . .	π_{1c}
	2	π_{21}	π_{22}	. . .	π_{2c}
	:	:	:		:
	b	π_{b1}	π_{b2}	. . .	π_{bc}

To select *d* mating pairs from *b* bull and *c* cow candidates, with *k* cows per bull and *s* and *d* bulls and cows to be selected, the total number of mating sets (*ms*) is given by the following combinatorial expression (Hayes *et al*., 2002):

$$ms = \frac{\binom{b}{s}\binom{c}{d}c!}{k!^{b}}$$

where $\binom{b}{s} = \frac{b!}{(b-s)!\,s!}$, $\binom{c}{d} = \frac{c!}{(c-d)!\,d!}$

and ! = factorial of the number

Different algorithms can be used to find a mating set that has the optimum value of expected performance of the progeny, including linear programming (Jensen & Wilton, 1985), exchange algorithm (Kinghorn & Shepherd, 1994) and evolutionary algorithms (Kinghorn & Shepherd, 1999). In this study, mate selection was performed using an evolutionary algorithm called Differential Evolution (Price & Storn, 1997) that has previously been used for mate selection in beef cattle (Kinghorn *et al*., 1999).

Mate selection schemes

Selection and mate allocation of bulls and cows were considered simultaneously in seven different schemes under the constraints that a bull could be mated to no more than 25% of the herd and that only 75% of the cows were required to leave progeny from these bulls (308 cows): 1) bulls and cows were randomly selected and allocated, 2) bulls and cows were randomly selected and allocated but only matings with less than 3% inbreeding were allowed, 3) bulls and cows were randomly selected and allocated but only matings with less than 6% inbreeding were allowed, 4) mate selection was applied to maximise the expected BW of the progeny, 5) mate selection was applied to minimise the expected inbreeding level of the progeny, 6) mate selection was applied to maximise expected PW of progeny, and 7) mate selection was applied to optimise a multiple objective to maximise PW and minimise inbreeding level of the expected progeny with relative weights 1 to 1.

RESULTS AND DISCUSSION

Table 2 shows the expected means and ranges of proportion of Holstein-Friesian genes, inbreeding coefficients, BWs and PWs for the different mate selection schemes to select 308 matings from 411 cows mated to 20 bulls. Selection and mate allocation of bulls and cows at random produced crossbred and straightbred progeny with average PW of \$94, BW of \$166 and inbreeding level of 1.70%. Restricting random matings to less than 3 and 6% of inbreeding reduced average inbreeding level to 0.90 and 1.30%, respectively but averages of BW and PW were not significantly reduced. In agreement with the findings of Weigel & Lin (2000), the control of inbreeding by restricting matings to threshold values of inbreeding did not have significant effects on the expected genetic merit of progeny. Maximisation of genetic gain and control of inbreeding in the long term will require changes in the procedures for selecting parents of young AI bulls. Computerised mate selection programs to maximise genetic gain in a population subject to a constraint on the rate of inbreeding using contribution theory (Meuwissen, 1997 ; Bijma, 2000) have been applied in sheep (Amer *et al*., 2002) and dairy cattle (Weigel & Lin, 2002) breeding programs. Long-term control of inbreeding is also a feature of Livestock Improvement's strategy to generate young bulls.

Results of single objective optimisation show the competitive nature of the objectives, which is particularly apparent when comparing the maximisation of PW with the minimisation of inbreeding (Table 2). Mate selection applied to maximise PW yielded a mating set with an average PW of \$181 and an average inbreeding level of 2.07%. Conversely, the minimisation of inbreeding selected a mating set with average PW of \$65 and average inbreeding level of 0.03%. A way to optimise these contrasting objectives is through a multiple objective optimisation. Weighting these single objectives in a ratio of 1:1 (PW to inbreeding), the mate selection algorithm selected a mating set with an average PW of \$176 and an average inbreeding level of 0.44%. Comparing results of single-objective to multiple-objective optimisation, it is possible to measure the tradeoffs between objectives when entered into a

TABLE 2: Mean, minimum and maximum values of breed composition, inbreeding coefficient (%), breeding worth (BW; $) and production worth (PW; $) of expected progeny from 308 matings selected from a crossbred herd of 411 cows and a team of 10 Holstein-Friesian and 10 Jersey bulls under different mate selection schemes.

	Proportion of HF[1]			Inbreeding (%)			BW ($)			PW ($)		
Mate selection scheme	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Random mating	0.49	0.00	1.00	1.70	0.00	19.38	166	119	215	94	-166	226
Random mating with <3% inbreeding	0.52	0.00	1.00	0.90	0.00	3.00	166	119	215	88	-166	226
Random mating with <6% inbreeding	0.50	0.00	1.00	1.30	0.00	5.99	166	119	215	91	-166	226
Maximise BW	0.58	0.00	1.00	1.16	0.00	13.93	181	156	214	75	-138	215
Minimise inbreeding	0.64	0.13	0.91	0.03	0.00	0.21	168	121	214	65	-156	209
Maximise PW	0.27	0.00	0.69	2.07	0.00	14.14	178	144	212	181	157	220
Maximise PW and minimise inbreeding[2]	0.29	0.00	0.69	0.44	0.00	1.75	173	133	208	176	131	226

[1] HF=Holstein-Friesian.
[2] Weights of the multiple objective function were 1:1 for PW and inbreeding, respectively.

multiple-objective framework. PW was reduced from $181 (single-objective optimisation) to $176 (multiple-objective optimisation) and inbreeding level was increased from 0.03% (single-objective optimisation) to 0.44% (multiple-objective optimisation). Dairy farmers can give different weightings to the objectives in the multiple-objective optimisation for desired tradeoffs between PW and level of inbreeding. Similar results were obtained by Tozer & Stokes (2001) for sire selection using multiple objective programming; a model with equal weights on each objective resulted in an increase of 3% in average inbreeding and a decrease of average Net Merit by US$170 from the single-objective optima.

Application of mate selection algorithms to optimise expected performance of progeny of the next generation should consider production worth rather than breeding worth because production worth includes the effects of heterosis which are not passed into future generations. Single-objective maximisation of BW selected a mating set with a high proportion of Holstein-Friesian genes in the progeny (0.58) and low average PW ($75). In contrast single-objective maximisation of PW selected the mating set with the lowest proportion of Holstein-Friesian genes (0.27) and the highest PW ($181), but the highest inbreeding level (2.07%).

Several types of restrictions can be imposed in the mate selection algorithm. For example, restrictions on the expected breed composition of the progeny can be included as part of the restriction set to achieve systematic crossbreeding systems, such as two-breed rotational or upgrading to one of the breeds. In this study, all matings were considered regardless of breed composition of the progeny, cows or bulls. Some farmers would prefer to use a mate selection algorithm as a tool for the definition of systematic crossbreeding system.

The computerised mate selection program described here is an example of how current technology and knowledge can be used to solve a practical problem. Implementation would require automating methods to prepare input data and consideration of how to deliver the output. For example, output could either be delivered using either web-based technology or hand-held computers.

CONCLUSIONS

This study demonstrates a computerised mate selection program with a multiple-objective optimisation algorithm that allows dairy farmers to reduce inbreeding and increase farm profit of the expected progeny for the next generation. The relative size of the tradeoffs between inbreeding and farm profit is determined by the weights the dairy farmer places on each objective.

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