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Potential benefits from new reproductive technologies in commercial dairy herds; a case study simulation

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ABSTRACT

New reproductive technologies may provide the possibility to derive the egg component of embryos for dairy cow replacements from only an elite proportion of the dairy herd, or from heifers or calves, thereby creating opportunities for greater genetic gain. Using modeling, four possible selection strategies in two case study herds were compared over 10 years at annual replacement rates of 15, 20 and 25%. In the different strategies, replacement calves were bred from: (1) AB bull + all herd cows, 'status quo' vs (2) AB bull + only the top 25% of herd cows vs (3) AB bull + the top 100% of maiden heifers vs (4) AB bull + the top 100% of heifer calves. Assumptions used included (1) an average bull breeding worth (BW) of $135, gaining by $5 per year. (2) A 'high BW herd' average BW of $62 (almost in the top 10% of all New Zealand herds). (3) A 'low BW herd' average BW of $32 (nearly in the bottom 10%). The model predicted that rate of herd genetic gain increased with replacement rate. The low BW herd gained more than the high BW herd using any of the strategies because it started from a lower base. The BW of the 2 herds converged over 10 years and this effect increased with selection pressure. After 10 years, BWs of 150 and 149 were predicted for the high and low BW herds respectively by using eggs from calves as in Strategy 4 above. This compared with Strategy 1 where herd BWs at year 10 were 130 and 120 respectively.

Keywords: reproductive technologies; dairy; cows, simulation; modelling, breeding worth

INTRODUCTION

Recent progress in the manipulation of cattle reproduction via embryo transfer, cloning, sexing of embryos etc, (Thompson *et al.*, 1998) has created new opportunities for selecting replacement animals. In the dairy industry, replacement calves are currently derived from either natural mating or (predominantly) artificial breeding (AB) using semen from highly selected bulls (Anon (a), 2000). Usually, selection on the dam side is limited because the AB semen is typically inseminated into whichever cows come on heat on any particular insemination day. The only selection that occurs on the dam side is when the farmer carries out a production cull near the end of the milking season.

The new reproduction technologies mean that potentially, replacement eggs for subsequent embryo production could be derived from only an elite proportion of the commercial dairy herd or even from the heifers or calves. Multiple egg removal from individual animals, and subsequent embryo production and pregnancy in surrogate dams would create opportunities for achieving greater rates of genetic gain (de Boer *et al.,* 1994; Van Vleck, 1981).

As part of an assessment of these opportunities, the following modeling study was carried out to simulate and measure the potential size of the benefits that might arise from using the new technologies. The effects of these on herd breeding worth (BW), as defined by Harris *et al.,* (1996), were compared with the status quo selection system over a 10-year period.

MATERIALS AND METHODS

A simulation model was developed using Visual Basic on an Excel spreadsheet. Data from a case study herd of 160 in-milk cows was used to predict the change in that herd's BW over a 10-year period using the different strategies for selecting replacement heifers that might be possible with the new reproductive technologies.

The four strategies tested were:

(1) a status quo mating strategy using Livestock Improvement Corporation's 'bull of the day' AB service (Anon (b), 2000) with cows from the herd selected, effectively at random, as they came on heat until the farmer deems enough have been mated to generate the required number of replacements;

(2) a new strategy where replacement heifers were generated from the AB 'bull of the day' and the top 25% of the milking herd;

(3) same as (2) but where the females used for mating came entirely from the maiden heifers (rising 2-year-olds);

(4) same as (2) but where females for mating came entirely from the rising 1-year-old calves.

Strategies (2), (3) and (4) assumed the necessary technologies were available to make them feasible.

Assumptions in the models included the following:

- Progeny BW is very close to the average of the sire and dam BWs (Brumby, pers. com)
- The average BW of the 'bull of the day' in spring 2000 was $135 (Anon (b), 2000)). Average Bull BW in each year was assumed to have a standard deviation (sd) of $7 based on the range in Anon (b) (2000)
- An average increment in bull BW of $5 units linear gain per year. This was slightly conservative compared to estimates of $6 elsewhere (Anon (a), 2000; Garrick & Lopez-Villalobos, 1998; Lopez-Villalobos & Garrick, 1997)
- Annual herd replacement rates of 15, 20 and 25% consisting of 5, 10 and 15% production culling respectively, of the lowest BW cows, and 10% random culling due to deaths, sick and empty cows. This compared with reported average replacement rates of 21.6% (Simmonds, 1998) and 18.2% (Anon (a), 2000) and 'expected' planned culling rates of 10% (Macmillam *et al.*, 1998). For simplicity, BW was used for production culling decisions in our model whereas, in

practice, most farmers use production worth (PW). This discrepancy was not considered serious as the correlation coefficient between BW and PW is approximately 0.75 (Harris *pers. Comm.*)

The 4 strategies were tested, in terms of herd BW change over a 10 year period, using a case study herd which, on a BW basis, lay within the top 10% of herds in New Zealand (Anon (a), 2000). The herd data were copied from the herd owner's database programme ('DairyWin 32' – leased from LIC) into the model. A few minor manipulations were required to get the base herd data into a suitable format. Steps in the simulation of each strategy then included the following:

(1) Determine counts, average BWs and standard deviations of cows, heifers and calves at the start of the year
(2) Selection of random culls using random numbers
(3) Selection of production culls by sorting the cows on BW
(4) Creation of the next year's calf crop by the average of the dam (or donor) BW and the bull BW, sampled within the standard deviation range described above
(5) Aging of all stock by one year and creation of a next year herd list including heifers and calves
(6) Calculation of counts and average BWs and standard deviations of retained animals for the start of the following year
(7) Repeating the cycle for 10 years and summarizing the results.

A second case study herd was created by subtracting 30 BW units from every cow in the above herd. This new herd had an average BW which placed it in the bottom 10% of herds in New Zealand (Anon (a), 2000).

Tests of statistical significance were carried out using analyses of variance (Genstat 5 Committee. 1993) on the results of the 20 simulations at year 10 but it is not appropriate to report them. This is because, with a simulation model, it is easy to keep running simulations until any difference is significant. Similarly, standard errors of means can be made arbitrarily small by simulating more samples. Instead, therefore, coefficients of variation associated with the model predictions are presented to give a measure of how much individual simulations varied from the mean predictions.

RESULTS AND DISCUSSION

A sample output of one of the selection strategies over time for one of the 20 runs of the simulations described above is shown in Figure 1. Here the low BW herd was subjected to selection Strategy (4) in which a 25% replacement rate was achieved by mating 'bull of the day' semen to calf eggs. The figure shows that the model predicted considerable selection progress over the 10-year period of the strategy although most progress was made in the first few years. This type of response has been well documented previously (Clarke, 1992; Bichard, 1971). The coefficient of variation of the herd BW means of the 20 runs at year 10 was 2%. This variance ratio was low. It can be partially explained by the fact that the standard deviation in this instance was calculated from between-herd averages rather than between cow values. It could also be due to the fact that the model did not fully account for all the sources of variation that might occur in the 'real world'. Further research is warranted to fully identify all these sources of variation to provide a more realistic idea of the likely ranges in herd BW that could occur after 10 years.

FIGURE 1: Simulated average BW, within stock age or class, by year for the low BW herd subjected to strategy (4) in which a 25% replacement rate was achieved by mating 'bull of the day' semen to calf embryos.

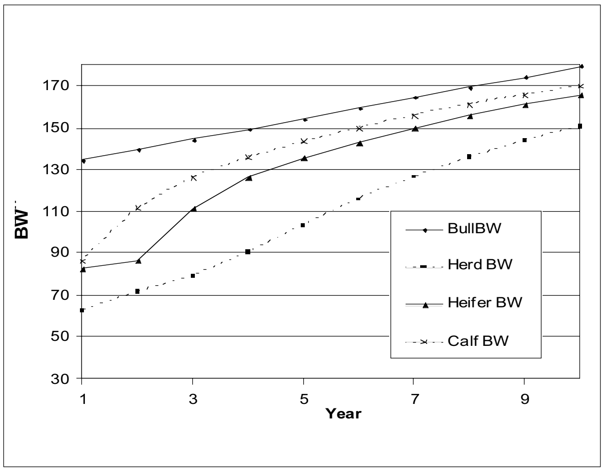


Figure 2 shows progress over time for the different selection strategies for the high BW herd again at a 25% replacement rate. The results show the extent of the genetic gain possible, over 10 years, with selection pressure (Strategy 4 vs Strategy 1 is the extreme comparison) or as the age of the egg donor decreased. Again, the coefficient of variation of the mean herd BWs was only 2%. Not shown, but worth noting was that herd age after 10 years was also affected by strategy. Strategies that produced the greatest BW gain resulted in the youngest herds. For example, in Figure 2, average herd age at year 10 was about 3.8 years for Strategy 1 and 3.7 years for Strategy 4. Selection of donor eggs from the top 25% of cows (Strategy 2) was very little different from selecting eggs from all the heifers –the same number of donor animals were involved in each case (Strategy 3, Figure 2).

The simulations showed genetic gain was greater for the herd starting from a lower base (Figure 3), especially when selection pressure was higher (Strategy 4). This is a logical outcome given that progeny BW is the average of

FIGURE 2: Progress in herd BW over time for the different breeding stategies for the high BW herd: 'Status quo', Strategy 1; 'Top cow', Strategy 2; 'Ex heifer', Strategy 3; 'Ex calf', Strategy4.

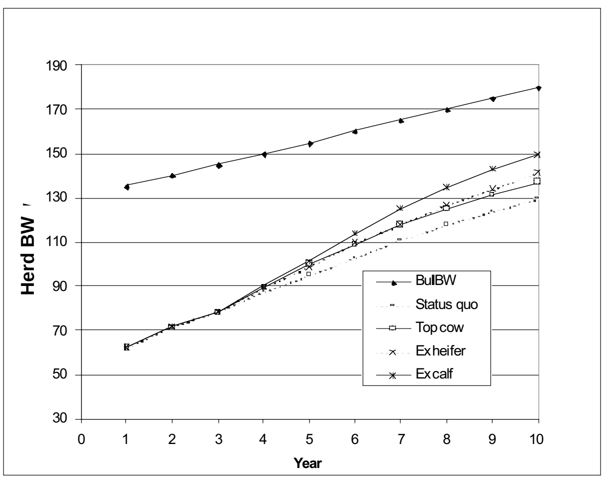


FIGURE 3: Progress in herd BW over time for 2 selection stategies (1 and 4) in herds starting from a low and a high BW base. The coefficient of variation of herd BW at Year 10 for 20 simulations was 1 to 2%.

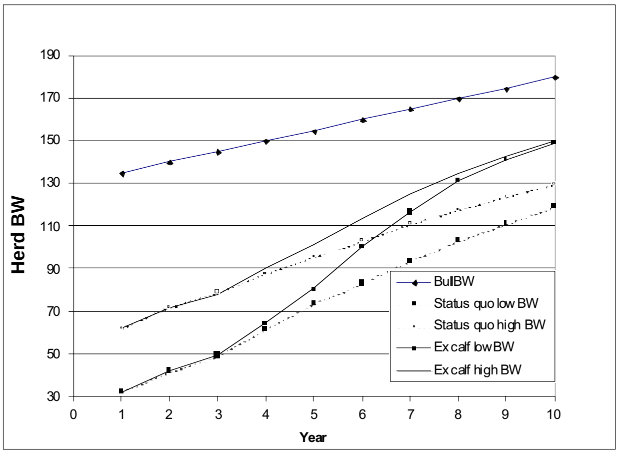
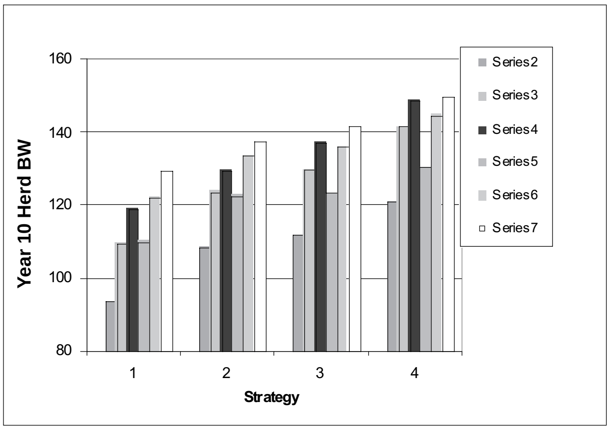


FIGURE 4: Herd BW at year 10 as affected by initial herd BW, replacement rate and selection strategy. Coefficients of variation of herd BW for 20 simulations ranged from 1 to 2%.
Key to Figure:
Series 2: 15% replacement rate, low initial BW
Series 3: 20% replacement rate, low initial BW
Series 4: 25% replacement rate, low initial BW
Series 5: 15% replacement rate, high initial BW
Series 6: 20% replacement rate, high initial BW
Series 7: 25% replacement rate, high initial BW



the dam and sire BW so that, other things being equal, genetic gains will always be greater for poorer herds. Figure 4 summarizes all the above effects for year 10 and includes the effects of selection rate. It indicates that, for a herd owner contemplating use of these new reproductive technologies, greatest gains will be achieved for herds starting from a low base, by obtaining donor eggs from calves and by selecting a high replacement rate. The simulations showed (Figure 4) that a producer using all these combinations (Strategy 4, 25% replacement rate) would increase their herd BW by 55 over 10 years compared to using status quo technology (Strategy 1, 15% replacement rate).

All selection programs eventually reach an equilibrium stage at which point genetic gain (BW in this case) in the dam (herd) tracks parallel to, and below that of the bull (Bichard, 1971; Clark, 1992). This 'lag' is twice the generation interval. New reproductive technologies as demonstrated by our models acted in 2 ways in respect to this equilibrium lag. Firstly, they indicated that equilibrium would be achieved more quickly, and secondly, their continued use (Strategy 4 in particular) would reduce the size of the lag. Unfortunately, if the herd selection policy reverted back to the status quo strategy, the lag would widen back out to that strategy's equilibrium. The implication is that the greatest benefits to the new technologies may lie with strategic use as a rapid 'catch up' system as observed in Figure 3 in which the low BW and high BW herds were compared. Whether owners of low BW herds are likely to be enthusiastic about adopting these new technologies is a subject for further research. Decisions by producers will also require thorough knowledge of the financial implications of available strategies. Cost-benefit analyses and end-user acceptance studies are planned as the next phase of this research programme.

CONCLUSIONS

Our models show that new reproductive technologies as described will increase the rate of gain of herd BW over a 10-year period. Gains are greatest for herds starting from a low BW base where producers are willing to choose high replacement rate systems with donor eggs selected from young animals (calves). Herds starting from higher initial BWs will still benefit but the gains will not be quite so large. This project has identified the likely average gains that could be made but variance was probably underestimated. Further research is required to accurately predict all the sources of variation that may occur.

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