Bull selection strategies using genomic estimated breeding values

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Summary

Several strategies for selecting bulls in an artificial insemination (AI) stud under Canadian conditions using genomic estimated breeding values (GEBV) as the selection criterion were compared for genetic response in the cow population and cost of operation using stochastic simulation of AI stud operations over 55 years. A constant population size of 1 million cows and an AI stud currently testing 400 young bulls per year were assumed. Correlations between GEBV and true breeding values (TBV) were varied between 0.4 to 0.8. Different numbers of young bulls to be genotyped were varied from 500 to 4000 per year. Scheme A selected young bulls for progeny testing on the basis of GEBV. Scheme B assumed that young bulls with GEBV could be used immediately as sires of sons based on their GEBV. Other variations between Schemes A and B were also compared. Results showed that use of GEBV increased genetic gains in the population regardless of the correlation between GEBV and TBV. Using young bulls with high GEBV at one year of age to sire the next generation of young bulls gave greater genetic responses in the cow population at almost 1/4 the cost of the traditional progeny test program. Initially, AI studs will likely continue with progeny testing, but may use young bulls with high GEBV at one year of age to sire a portion of the new young bulls. Once producers are comfortable with GEBV, then the AI stud could switch entirely to Scheme B. Turnover rates of bulls in the AI stud will be more rapid when GEBV are used than in PT.

***Key words**: Single nucleotide polymorphisms, Simulation model, Genome-wide selection schemes.*

Introduction

Panels of thousands of single nucleotide polymorphisms (SNP) spread approximately evenly over the genome are available for genotyping of dairy cattle. Each SNP location in the genome has three possible genotypes, and attempts are made to estimate the effects of each genotype at all locations on the genome simultaneously using estimated breeding values (EBV) or de-regressed proofs of bulls as the observations. Different methodologies have been proposed and are being used for this purpose. Estimates of the SNP genotype (or haplotype) effects can be summed together based on the genotype of the animal to give a genomic estimated breeding value (GEBV). The GEBV can have accuracy equal to or greater than a parent average (PA) derived from EBV of parents. The primary advantage of the GEBV is that it can be obtained shortly after an animal is born (or possibly even in an early stage of embryonic development) such that selection decisions can be made early. In a progeny testing (PT) scheme, young bulls wait for their progeny-based EBV until they are six years of age.

The objective of this study was to use simulation to compare bull selection strategies for a typical AI stud under Canadian conditions that use GEBV for young males, in terms of genetic gain in the cow population and costs of operation for the AI stud. Various possible alternatives were compared.

Simulation model

Progeny testing assumptions

A population of 1 million cows serviced by a single AI stud that currently tests 400 young bulls per year was assumed. In any year, 50 proven sires were used to breed the population of cows, and the best 20 sires were used as sires of the next generation of young bulls. Dams of young bulls were randomly chosen from the top 5% of the cow population based on their EBV having an assumed reliability of 0.50.

Young bulls were assumed to have enough matings to provide 100 daughter records in their first progeny test proofs. Proven sires were differentially mated to the remaining population based on their EBV. The top 10 bulls had 20% of the matings, the next 10 had 50%; the next 10 bulls had 20%, and the last 20 bulls had only 10% of the matings. Every 12.5 matings resulted in a daughter record for proven bulls.

Bull calves were purchased at birth, test mated at one year of age, and proven at 6 years of age during the PT program. Cost of purchasing a young bull for PT was $10 000. At proof time, all newly proven bulls plus the current group of 50 proven sires were ranked on their EBV, and the best 50 kept for the next year, with the top 20 being sires of sons for the next generation. Cost of keeping a bull in the stud for one year was $6 000. All dollar figures were kept constant over the simulation period of 55 years.

A single trait, representing an overall index, was simulated having a heritability of 0.30. A total of 55 years of operation was simulated, with the first 20 years being the same for all schemes compared in this study. Changes in selection strategy began in year 21. Thus, comparisons were for years 21 to 55. One hundred replicates were run for each scenario.

Genome-wide selection schemes

The cost of genotyping an animal was $300. The correlation of GEBV with TBV was assumed to be constant over time. In reality the correlation is expected to decrease, if the SNP genotype estimates are not updated. Thus, the assumption was made that research and methodology will at least keep the correlation constant over time. Another possibility would be that research could increase the correlation over time, but that would make the results better than reported here. The correlation was varied from 0.4 to 0.8.

Scheme A – GEBV to select young bulls for progeny testing

In this scheme, a number of young bulls from top dams were genotyped and a GEBV computed with a reliability equal to the square of the correlation between GEBV and TBV. From this group the best were kept to enter the PT program. The number of bulls genotyped was varied from 500 to 4 000, and the number kept for PT was varied from 100 to 400. The purchase price was still $10 000 per young bull.

Scheme A would be used when producers do not trust the reliability of GEBV, and still want to see daughters in lactation before they decide to use a bull. The cost of Scheme A will be at least the same as PT, but there will be the additional costs of genotyping young bulls.

Scheme B – Using young bulls with GEBV as proven sires

Scheme B would be used if there were complete confidence in the reliability of GEBV, and animals with a GEBV were considered "proven". The AI stud genotypes a number of young bulls at birth and calculates their GEBV. The young bulls are purchased and brought into the stud if their GEBV is greater than the minimum proof of the current "proven" sires, up to a maximum of 50 young bulls per year. The cost of buying these young bulls was assumed to be $20 000 instead of $10 000. If a young bull was in the top 20, then that bull was used as a sire of sons at one year of age.

Scheme B was less costly than Scheme A because fewer young bulls were purchased per year, and fewer bulls were in the stud. Scheme B should give better genetic gain than Scheme A because the genetically superior bulls are used at one year of age instead of waiting until they are 6 years old.

Scheme C – Between Scheme A and Scheme B

An AI stud has a big investment in facilities for handling a large number of young bulls per year plus the labour force to make it run. Thus, converting from PT to Scheme B in one year would be very disruptive. Also, some producers will be reluctant to use young bulls as proven sires. Thus, there could be an intermediate plan that progeny tests young bulls chosen on their GEBV, and the AI stud could use a portion of those young bulls as sires of sons. As producers accept GEBV bulls, then fewer young bulls could be progeny tested, and a greater percentage of young bulls could be used as sires of sons. Eventually, Scheme A would evolve to Scheme B. The number of young bulls chosen for PT was reduced from 400 to 200, and the number of young bulls used as sires of sons was either 5 or 10. Young bulls chosen as sires of sons were only used for one year, then returned to the PT. The bull could possibly return to the top 20 if its progeny test proof was very high. However, such an event was very unlikely. The cost of Scheme C would be intermediate to Schemes A and B, depending on the number of young bulls progeny tested per year. Genetic gain may be closer to that of Scheme B, because some young bulls are being used as sires of sons.

Results and discussion

Usual progeny testing gave a response of 0.26 genetic standard deviations (GSD) change per year at a cost of $18.7 M. There was a turnover of 26 bulls per year of the top 50 proven bulls or approximately one half of the top 50 bulls were replaced annually.

Scheme A

Results for 10 versions of Scheme A are given in Table 1. Schemes A1 to A4 used a correlation of 0.4 between GEBV and TBV while the number of young bulls that were genotyped ranged from 500 to 4 000. As more bulls were genotyped the genetic gain per year was increased, but also the cost of the operation was increased above that for usual PT. The turnover of bulls in the top 50 also increased to 33 out of 50 bulls being replaced annually.

Schemes A5 to A8 and A3 can be used to observe the trend due to an increase in the correlation between GEBV and TBV from 0.4 to 0.8. The increase in genetic gains were very small, while the costs remained constant at $20.0 M. The turnover rate increased from 32 to 34 bulls per year.

Schemes A9 and A10 were made to see the effect of reducing the number of young bulls that were progeny tested. Costs were greatly reduced while genetic gains were not greatly affected. Turnover of the top 50 proven bulls was slightly lower than when testing 400 bulls per year (Table 1).

Spelman *et al*. (1999) conducted a similar study where all four pathways of selection were changed by using marker information. Although the population they simulated was smaller and the number of bulls in the progeny test was only 140 per year, the results were similar to those presented here.

Scheme A does not take advantage of the fact that the genetic merit of a bull is known at birth with an accuracy better than a parent average EBV. The young bull still goes through the same waiting period to receive a progeny test EBV before it is used for general breeding in the population. The gains here are due to slightly better accuracy in picking the 400 bulls for progeny testing. Thus, increasing the number of young bulls that are genotyped increases the selection intensity amongst choices of young bulls for progeny testing. The correlation between GEBV and TBV has a very small contribution to greater genetic gains.

Scheme B

Use of young bulls as sires of sons of the next generation when they are just 1 yr of age results in bigger genetic gains than PT or Scheme A because of the advantage of having a GEBV at birth. Scheme B4 gives twice as much gain than PT, and 1.47 times as much as A4 in Table 1. The effect of number of young bulls genotyped at birth also has a greater effect than in Scheme A. At the same time, because no more than 50 young bulls are purchased per year, the costs of operation are 64% smaller

Table 1. Comparison of genetic gains and costs of operation for selecting young bulls for progeny testing using GEBV.

Label	Corr.	No. Geno.	No. PT	Turnover	GSD/yr	$$M
PT			400	26	0.26	18.7
A1	0.4	500	400	28	0.28	19.4
A2	0.4	1000	400	30	0.31	19.6
A3	0.4	2000	400	32	0.34	20.0
A4	0.4	4000	400	33	0.36	20.6
A5	0.5	2000	400	32	0.34	20.0
A6	0.6	2000	400	33	0.34	20.0
A7	0.7	2000	400	34	0.34	20.0
A8	0.8	2000	400	34	0.35	20.0
A9	0.6	2000	200	32	0.35	10.8
A10	0.6	2000	100	28	0.34	6.1

(B4 versus PT). The effect of increasing the correlation between GEBV and TBV offers more gain than in Scheme A, but this is a small effect. Turnover of bulls is higher than for Scheme A (Table 2).

Scheme C

Scheme A makes minimal use of GEBV at an early age, and Scheme B uses GEBV immediately to select future sires of sons. Both gains and costs are improved greatly by using GEBV. AI studs, however, have a large investment in facilities and labour that are no longer needed with Scheme B. From a management and human relations viewpoint, switching to Scheme B in one year would not be possible. Two scenarios were examined. Both scenarios assumed a correlation of 0.6 between GEBV and TBV, genotyping of 2000 young bulls per year, and progeny testing only 200 per year instead of 400, as in Scheme A6. In addition, the best 5 or 10 young bulls were used as sires of sons along with the current proven bulls. After being used as a sire of sons the young bulls were returned to the PT program.

The genetic gains were 0.43 GSD per year for 5 young bulls as sires of sons, and 0.46 GSD per year for 10 young bulls. The cost of each sheme was $10.1 M per year. Therefore, Scheme C would be 1.23 times better than Scheme A9, 0.83 times less than Scheme B6, and 1.65 times better than PT.

Advantages of Scheme C are that it accommodates producers that will hang on to the proven bull concept, and also the producers that want to be aggressive in their genetic improvement program. The AI stud is positioned to switch entirely to Scheme B when the time is appropriate, and the costs of operation are reduced from the current PT scheme.

Genotyping females

As with bull selection, genetic gains are going to be greatest when genotyping females at birth and selecting them as dams of sires and dams of future cows at birth before they are old enough to be bred. The reliability of GEBV on females should be just as accurate as they are for males. Also, GEBV on females should be free of the effects of preferential treatment that commonly affect EBV of dams of sires. AI studs may have to help finance the genotyping of prospective dams of sires, and may need to have different kinds of contracts with producers to prevent costs of new young bulls getting too high.

Table 2. Comparison of genetic gains and costs of operation when young bulls are used as sires of sons at one year of age.

Label	Corr.	No.Geno.	Turnover	GSD/yr	$$M
B1	0.4	500	29	0.44	3.1
B2	0.4	1 000	32	0.47	4.0
B3	0.4	2 000	34	0.50	5.1
B4	0.4	4 000	37	0.53	6.7
B5	0.5	2 000	35	0.51	5.4
B6	0.6	2 000	36	0.52	5.8
B7	0.7	2 000	38	0.53	6.4
B8	0.8	2 000	40	0.55	7.3
B9	0.6	500	31	0.45	3.5
B10	0.6	1 000	34	0.49	4.5
B11	0.6	4 000	39	0.55	7.5

Producers are concerned about AI studs having knowledge about their cows' GEBV that they may not have. Thus, Canada is planning for a public distribution of GEBV to all industry members. GEBV will be combined with EBV by Canadian Dairy Network, and the combined values will be released to the public. Exact rules and regulations around this ideal still need to be determined.

Problems will arise as SNP panels will likely change over time, and there could be several competing panels existing at one time. Associated with that will be the estimation of SNP genotype effects for each SNP panel.

Inbreeding

Rates of inbreeding were not included in this study, but the anticipation is that inbreeding rates could increase faster than with PT. The turnover rates of bulls will be greater, as in Scheme B, and this could lead to greater rates of inbreeding. However, the number of sons per sire of sons should be evenly distributed. If large numbers of young bulls are genotyped per year (2 000 - 4 000 bulls), then these could represent a larger group of dams in the population, and might help keep inbreeding rates low. Female bloodlines not commonly used in PT might be discovered.

If animals are genotyped, then a comparison of their genotypes would give an indication of their relatedness, and then the mating could take place or be avoided. Inbreeding rates could be kept low by close monitoring of matings.

Conclusions

GEBV will become the primary tool for bull and cow selection in the future. The genetic potential of an animal will be known at the animal's birth with reasonable accuracy, such that the animal will be considered "proven" without having made a record or having any progeny. Progeny testing will become obsolete as a tool for genetic improvement in dairy cattle. Nearly all animals that are born will be genotyped for a large number of SNP.

Molecular genetics will continue to make advancements, such that SNP will be replaced with the actual genes. Thus, GEBV will become more accurate over time. Genes with large effects will become known for many traits. However, there is still a lot of work to be done to make these ideas successful.

List of References

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