4.3 The Value of Genetic Gain

\[ r = \frac{i}{a} \]

where \( r \) is the standard deviation of the selection index, the economic value of the genetic gain per year, \( a \) is the accuracy of the evaluation, and \( i \) is the selection intensity.

6.3 Principles of Selection Index

6.1 Introduction
As already noted, many of the studies that have considered MAS are quite pessimistic. In certain breeding programs gains obtained by information on specific genes will be minuscule. Like any other investment, genotyping must be considered in terms of potential gains vs. costs. Genetic gain is unlike all other investments, in that gains due to breed improvement are eternal and cumulative. Unlike investment in new machinery, genetic gain never is "used up" and never has to be replaced. Unlike introduction of a new treatment or process, which must be continually applied, once genetic gain is obtained, no further investment is required to maintain this gain. The annual rate of genetic gain in most domestic species is from about 1 to 5% of the mean (Lande and Thompson, 1990; Weller and Fernando, 1991). Although these numbers seem small, they represent increases in economic value, as is demonstrated below.

The calculations that follow are based on the calculations of Weller (1994) for the value of gains from breeding to the national economy. Consider an ongoing breeding program with a nominal genetic gain of \( V \) each year. The cumulative discounted returns, \( R \), will be a function of the nominal annual returns, the discount rate, the profit horizon and the number of years from the beginning of the program until first returns are realized. \( R \) is then computed as follows (Hill, 1971):

\[
R = \frac{V}{(1-r)^2} \frac{1}{1 - r} \sum_{t=0}^{T} \left( \frac{1}{r} \right)^t
\]

where \( r = \frac{1}{1+d} \), \( d = \) discount rate, \( T = \) profit horizon, and \( t = \) years to first returns. For \( d = 0.08 \), \( T = 20 \) years, and \( t = 5 \) year, \( R = 32.58V \). That is, the cumulative returns are equal to 33 times the nominal annual returns. For an infinite profit horizon, Equation \( \{6.7\} \) reduces to:

\[
R = \frac{V}{(1-r)^2} \frac{1}{d^2(1 + d)^t-2}
\]

We will now compare the value of nominal annual genetic gain to annual costs of a breeding program, assuming a fixed nominal cost per year. Costs, unlike genetic gain are not cumulative. Thus, assuming first costs in the year after the base year, \( C \), the net present value of the cost of the breeding program, is computed as follows:

\[
C = \frac{C_c r(1 - r^T)}{1 - r}
\]

where \( C_c = \) annual costs of the breeding program. Using the same values for \( T \), and \( d \), \( C = 9.82C_c \). Thus, net profit is positive if \( V > 0.31C_c \). For an infinite profit horizon, \( C = 12.5C_c \), and profit will be positive if \( V > 0.1C_c \).

Thus, a MAS breeding program will be profitable even if the nominal annual costs are several times the nominal annual genetic gain. For example, we will consider the US dairy cattle population, which consists of about 10,000,000 cows. Annual genetic gain is about 100 kg milk/yr. The value of a 1 kg gain in milk production has been estimated at \$0.1 (Weller, 1994). Thus, the annual value of a 10% increase in the rate of genetic gain (10 kg/yr) is:

\[
V = (10 \text{ kg/cow/yr}) \times (\$0.1/\text{kg}) \times (10,000,000 \text{ cows}) = $10,000,000/\text{yr} \quad \{6.10\}
\]

The cumulative value with a profit horizon of 20 yr and an 8% discount rate would be $330 million, and break-even annual costs are $32,000,000/yr. Thus, it would be profitable to spend quite a lot for a relatively small gain.

These calculations are based on the gain to the national economy. Brascamp et al. (1993) considered the economic value of MAS based on changes in returns from semen sales for a breeding organization operating in a competitive market. In this case a breeding firm that adopts a MAS program can increase its returns either by increasing its market share or increasing the mean price of a semen dose. Although the value of a semen dose will be less, the increase in the market share of a semen dose can increase the firm's returns more than the increase in the market share of a breeding organization operating in a competitive market. In this case a breeding firm that adopts a MAS program can increase its returns either by increasing its market share or increasing the mean price of a semen dose.

The calculations are based on the gain to the national economy. Brascamp et al. (1993) considered the economic value of MAS based on changes in returns from semen sales for a breeding organization operating in a competitive market. In this case a breeding firm that adopts a MAS program can increase its returns either by increasing its market share or increasing the mean price of a semen dose.
The male generation intervals are usually much longer than the biological minimum. Bulls
are used for breeding because they have a higher genetic gain than the females, but this can be
offset by a shorter generation interval. The genetic gain per generation for path x, and Lx = generation interval for path x.

Where:

- a affect some of the traits included in the breeding objective. We will define m as the “net genetic gain for the population,
- d decreases as the heritability increases. Assume that marker information is available for QTL affecting some of the traits included in the breeding objective. We will define m as the “net genetic gain for the population,
- G = genetic gain for the population, γ is computed as follows:

\[ \gamma = \frac{d \cdot \mu - 1}{d} \]

\[ \gamma = \frac{d \cdot \mu - 1}{d} \]

Introgression will be at the expense of selection within the breed. Visscher et al. (1997) simulated introgression for a nucleus swine population under selection for a quantitative trait with a heritability of 0.25. They found that the reduction in genetic gain for individual selection through MAS can be quite significant. RE computed for selection based on half-sib or full-sib records are much less. With half sib selection, the maximum gain possible, as p tends towards unity, is \( 2[(1-h^2/4)/(1+2h^2)] \). For \( h^2 = 0.5 \), maximum RE = 1.58. (1966) defined five type of “economic” heterosis.

The relative efficiency, RE, of two different indices is defined as the ratio of their expected genetic gains. The RE of a selection index including marker information to a selection index based only on trait values for individual selection is computed as follows:

\[ RE = \frac{\sum b_i^2}{\sum b_i^2 + \sum b_m^2} \]

where \( b_i \) represents the index coefficients for the quantitative trait records, and \( b_m \) represents the index coefficient for m.

Different breeds are sometimes crossed to produce a population with increased genetic variation. Crossbreeding is often more profitable than selection within a single line. Moav (1958) defined five type of “economic” heterosis.

(1) utilization of heterosis, (2) increased genetic variation, and (3) introgression. The three main goals of crossbreeding are:

- Improved uniformity of young stock by the use of purebred parents.
- Increased yield or superior market qualities of the hybrid stock.
- Reduced costs of production by utilizing superior genotypes.
...
MAS was obtained for all loci after 10 generations. Response to trait-based selection was higher for two-trait selection, as compared to single trait selection. Two situations were simulated: a single known quantitative locus, and 10 identified loci accounting for all the genetic variance. Results are presented in Table 6.1. The advantage of MAS was greater when the traits were negatively correlated. Selection efficiency of marker-assisted selection (MAS), relative to traditional selection index with heritability of 0.2 was 1.24. Similar results were found by de Koning and Weller (1994) for high heritability traits. For low heritability traits the relative efficiency of MAS was even higher, for a single trait selection objective, relative to trait-based selection. The genetic correlation was -0.4, the environmental correlation was 0, and heritability of the two traits were equal, for the two-trait simulations. Results are the means of 10 replicates.

In future breeding programs, MAS will probably be combined together with other new technologies affecting reproduction, such as embryo transplant, sexed semen and cloning. Georges and Massey (1991) considered the theoretical possibility to grow, mature and fertilize prepubertal oocytes in vitro. This procedure could reduce the generation interval of cattle to maybe as little as 3 to 6 months, as compared to the normal biological minimum of two years. By using in-vitro fertilization of fetal oocytes by selected, progeny-tested sires, annual responses in milk yield could be doubled compared to conventional progeny testing. They found that genetic response was greater via MAS in the early generations, which results in less genetic gain in later generations. Although this term selection cannot be solved analytically, all of these studies are based on simulation, and studies have also looked at the expected long-term effects of MAS. Since the effect of long-term selection is generated during the course of the breeding program, the difference between selection index and MAS becomes critical. Even though Lande and Thompson (1991) maintain that term selection for a single trait. The genetic correlation was -0.4, the environmental correlation was 0, and heritability of the two traits were equal, for the two-trait simulations. Results are the means of 10 replicates.

It is possible to combine MAS with germ-line manipulation. Although spontaneous oocyte maturation and ovulation do not begin until puberty, for cattle this is at the age of close to one year, waves of oocyte growth are seen in utero. Activation of primordial follicles starts at 140 days of gestation. Georges and Massey (1991) considered the possibility of combination of MAS with germ-line manipulation. This procedure would involve the possibility of in vitro maturation and fertilization of prepubertal oocytes. In their breeding scheme, MAS is followed by germ-line manipulation. A shift from single trait selection to two-trait selection could lead to more genetic response. By using in-vitro fertilization of fetal oocytes by selected, progeny-tested sires, annual responses in milk yield could be doubled compared to conventional progeny testing. They found that genetic response was greater via MAS in the early generations, which results in less genetic gain in later generations. Although this term selection cannot be solved analytically, all of these studies are based on simulation, and studies have also looked at the expected long-term effects of MAS. Since the effect of long-term selection is generated during the course of the breeding program, the difference between selection index and MAS becomes critical. Even though Lande and Thompson (1991) maintain that term selection for a single trait. The genetic correlation was -0.4, the environmental correlation was 0, and heritability of the two traits were equal, for the two-trait simulations. Results are the means of 10 replicates.

Table 6.1  Relative efficiency of MAS with all QTL known for a two trait or single trait selection objective.

<table>
<thead>
<tr>
<th>Generation</th>
<th>Single Trait</th>
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Two traits: Single trait

- 0.05 0.10 0.20 0.30 0.40
- 0.50 1.00 1.50 2.00 2.50
- 3.00 3.50 4.00 4.50 5.00

Table 6.2  Relative efficiency of MAS with all QTL known for a two trait or single trait selection objective.

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Two traits: Single trait

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- 0.50 1.00 1.50 2.00 2.50
- 3.00 3.50 4.00 4.50 5.00

Table 6.3  Relative efficiency of MAS with all QTL known for a two trait or single trait selection objective.

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Two traits: Single trait

- 0.05 0.10 0.20 0.30 0.40
- 0.50 1.00 1.50 2.00 2.50
- 3.00 3.50 4.00 4.50 5.00
2. Selection of fetal "bull dams" based on genetic markers.

3. In-vitro fertilization of fetal oocytes with semen of elite sires, selected by breeding values based on records of female relatives and genetic markers.

4. Selection among juvenile male calves based on genetic markers.

5. Selected young sires at age of 1-2 yr are mated to cows of commercial population.

Step 3 of this protocol is not possible at present, but until very recently, it was generally considered impossible to clone mature mammals.

6.11 Summary

Again we must emphasize that a little bit of genetic gain can have a huge economic value. Thus, relatively large costs in genotyping can be justified to increase rates of genetic gain by only a few percent. It is not possible to consider within a single chapter all scenarios for MAS, and radically different results can be obtained depending on the breeding scheme and the assumptions employed. There does seem to be a consensus emerging that application of MAS could result in rather significant genetic gains, at least for several generations. Consideration of ten or more generations does not seem very relevant since profit horizons are at most 20 years, and breeding objectives tend to change over time anyway. In addition, with normal rates of spontaneous mutation, it does not appear that fixation of desirable alleles after a few generations of MAS is a serious problem.

References


305-328.

