OPTIMAL ALLOCATION OF TEST FUNDS IN SELECTION FOR GENETIC GAIN

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INTRODUCTION

When contemplating investment in a selection scheme it is important that the breeder has some understanding as to how the available funds should be allocated in order to maximise the benefits from this investment. Funds may be allocated in a number of ways, between more or less expensive testing methods or between males and females. The problem is to maximise genetic gain within the restriction of a budget.

This problem has, in the past, been approached by James (1966), Smith (1969), and Jackson et al. (1986). James (1966) and Smith (1969) sought to reduce costs by testing a proportion of randomly chosen individuals from the available selection candidates. Smith (1969) examined alternative methods for selecting the individuals required for breeding after testing a given proportion. Jackson et al. (1986) looked at the best way to allocate funds between the sexes in a selection program.

In breeding merinos for wool production more selection pressure is able to be applied to rams than to ewes. Because of this, more funds available for the selection program are allocated to ram testing. Often, no testing at all is carried out on ewes.

If a higher test cost is allowed for measuring a group of individuals, such as ewes, then superior candidates may be distinguished more accurately and genetic gains increased. However, this increment will diminish with increased test cost. Here, we aim to determine whether funds should be spent on testing all candidates, spending less on each, or on testing only a proportion with a higher level of accuracy. The division of funds between males and females will also be examined.

METHOD

A computer program was written in Pascal which optimises testing levels and the allocation of funds between males and females in the breeding program.

Certain parameters used in the optimisation will be fixed by the limitations of the enterprise considered. For example, the proportions of all candidates which must finally be selected in males and females, m and f respectively, and the marginal effectiveness ratio (k), which is a parameter used to describe the relationship between increasing test cost and selection efficiency, will be fixed by the production system. The amount of funding available to the testing program (T), expressed in arbitrary units per head, will be determined by the priorities of the producer and the amount of capital which is available for investment in the breeding program. The levels used for these fixed parameters in the optimisation are shown in table 1.

Table 1 Fixed parameters used in the optimisation

Parameter	Fixed levels			
k	0.3	0.5	0.7	0.9
m	0.01	0.05	0.10	
f	0.2	0.5	0.8	
T	2.5	5.0	7.5	10.0

The breeder will generally wish to maximise the revenue, in the form of genetic gains, resulting from the chosen testing strategy. The proportions of males and females tested of those available, Qm and Qf, are varied in the optimisation as are the expenses of the test method used in males and females, Cm and Cf.

Selected animals are taken from those available by two methods. In method 1, selected individuals are taken as required from randomly tested candidates and untested candidates are ignored. So, the intensities of selection used to calculate the selection differential in each sex (Pm and Pf) are determined by the proportion of tested candidates which are selected, i.e. m/Qm in males and f/Qf in females.

Using method 2, breeding individuals are selected first from candidates with measurements above the mean of those tested. If more animals are required than this number, they are chosen next from untested candidates which have an expected mean of zero. Only as a last resort will breeding individuals be chosen from those candidates which have been tested and are known to be poor performers. The selection intensity used to calculate the genetic response will be determined by the testing status of the individuals chosen, which will, in turn, be related to the final proportion required (m and f) and the proportion tested (Qm and Qf).

Both selecton methods are compared for each combination of fixed parameters. When the final proportions required for breeding are less than one half of the proportions of candidates tested the two methods are equivalent. The theory for determining genetic response is given in the appendix.

RESULTS

There is not space to present detailed results here. Instead results are presented which are relevant to a wool production enterprise. Jackson et. al. (1986) suggest that fleece weight selection in sheep has a k value around 0.7 where one unit of test cost (Cm, Cf or T) corresponds to $0.50 per head. When k=0.7, low cost testing methods have low effectiveness. Each increment in test cost will lead to increases in genetic gains which do not diminish until the test cost is larger than 8 units, or $4 per head. The dollars, as described, are nominal and do not relate to any specific recording scheme.

Table 2 gives results for two different testing budgets, $1.25 and $2.25 per head, and for two different selection intensities in rams which, if rams are used once only, may correspond to a natural breeding population (m=0.05) and one where artificial insemination (AI) will be used (m=0.01). The final proportion of ewes required (f) is fixed at 0.5 and k at 0.7. For a test budget per head of T units, Tm is the amount of funds spent on testing male progeny, Tm= Qm*Cm, and Tf on testing female progeny, Tf=Qf*Cf.

Table 2 Optimum values for Qm, Qf, Cm, Cf and Tm/Tf, when k=0.7, f=0.5 and one unit of cost=$0.50, for varying m and T

	T	funds/head($)	Qm	Qf	Cm	Cf	Tm/Tf
m=0.01	2.5	1.25	0.34	1.00	8.09	2.25	1.22
	5.0	2.50	0.63	1.00	8.73	4.50	1.22
m=0.05	2.5	1.25	0.49	1.00	6.12	2.00	1.50
	5.0	2.50	0.84	1.00	7.14	4.00	1.50

Taking the first case, where it is intended that sires be used in an AI program, a budget of $1250 is allowed to test 1000 progeny of which 500 are rams and 500 are ewes. The optimal allocation is:

Test 170 rams at $4.05 per head	$ 687.65
Test 500 ewes at $1.13 per head	$ 562.50
TOTAL TESTING OUTLAY	$1250.15

Although method 2 is the more efficient selection technique, it is always optimal to test more than twice as many candidates as are required for breeding. When this is the case the methods are equivalent.

DISCUSSION AND RECOMMENDATIONS

It is difficult to draw specific conclusions from the trends in the overall results. Due to the number of factors influencing the optima, often no consistent pattern can be discerned. In order to obtain a useful result a specific case must be examined. The optima cannot be predicted simply using an equation. Different proportions tested and test costs must be tried and compared in order to find that combination giving the greatest genetic gain.

For the example shown the greatest genetic gain will result from testing all ewes using a cheap testing method, such as greasy fleece weight. In rams, a more comprehensive test, such as clean fleece weight and fibre diameter, should be carried out on 1/3 of the candidates. The rams chosen for testing may be drafted off at random or chosen for other qualitative or quantitative characteristics. If selected for testing on other characteristics, the situation will be one of two-stage selection and responses may be influenced. Further work is being carried out for optimal procedures when two-stage selection is used.

The optima suggest that it is wise to test a higher proportion of females than males unless funds are unlimited, in which case all candidates should be tested. The only time when it is optimal to test rams only is when the test budget is very restricted and the attainable selection intensity in females is low.

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APPENDIX 1 THEORY

Following the procedure of Jackson et al. (1986), the relative accuracy of selection is assumed to be related to test cost by the diminishing returns equation,

$$F(c) = 1 - k^{c} = \frac{r_{IH}}{r_{max}} \qquad (1)$$

where, $F(\infty) = 1$ and $F(c)$ describes the relative accuracy of selection, k is the marginal effectiveness ratio, c is test cost, r_{IH} the correlation between the index under selection and the breeding value, and r_{max} is the maximum possible correlation between the selected character and breeding value. It should be noted that the real costs of selection rise in steps rather than as a smooth function.

It is assumed that the total cost of the selection program is described by T = (qmcm + qfcf)/2, where T is the cost per head in arbitrary units when equal numbers of males and females are available for selection.

The response to selection using a selection index in one sex can be shown as,

$$R_H = i \, r_{IH} \sigma_H \qquad (2)$$

where σ_H is the standard deviation of breeding value, i is the standardised selection differential, and R_H the response in breeding value. (James 1982)

From this basis we can derive an equation for annual genetic gain from selection in two sexes. If, $r_{IH} = r_{max}(1-k^{c})$, then,

$$R_H = \frac{[i_m r_{max}(1-k^{cm}) + i_f r_{max}(1-k^{cf})]\sigma_H}{Lm + Lf} \qquad (3)$$

where i_m and i_f are standardised selection differentials in males and females respectively, and Lm and Lf are average ages of males and females at the birth of progeny.

Some factors which do not vary during the optimising process can be removed from the equation as the constant, A, where,

$$A = \frac{Lm + Lf}{r_{max}\sigma_H} \qquad (4)$$

Standardised selection differentials are calculated in the computer program using a converted form of the ALNORM function described by Hill (1973).

Relative genetic gain is calculated using the equation,

$$AR_H = \frac{Pm*qm*i_m(Pm)*(1-k^{cm})}{m} + \frac{Pf*qf*i_f(Pf)*(1-k^{cf})}{f} \qquad (5)$$

where Pm and Pf are the proportions of tested candidates which are actually selected for breeding. Using method 1, Pm=m/Qm and Pf=f/Qf.

Using method 2 the values will depend upon a number of variables. Looking at one sex, if m<0.5*qm all selected candidates will contribute to genetic gains thus Pm=m/qm, as with method 1. If m>0.5*qm and m<((0.5*qm)+(1-qm)) then half of the tested animals will be selected and will contribute to genetic gains, so Pm=0.5. Untested candidates will have an expected mean of zero. If m is greater than the sum of the proportion of tested animals measuring above the mean and the proportion of untested animals i.e m>((0.5*qm)+(1-qm)) then, Pm=(m-(1-qm))/qm.