# MEASUREMENT OF EFFICIENCY IN ANIMAL BREEDING RESEARCH

## Die Messung der Efficienz von Zuchtprogrammen

## Mésure de l'éfficacité dans la sélection animale

W. G. HILL *

* Institute of Animal Genetics, West Mains Road, Edinburgh EH9 3JN, Scotland, U.K.

INTRODUCTION

There are several ways in which the title of this paper could be interpreted, so firstly I shall explain what I propose to discuss. These will be methods of measuring progress in an animal breeding programme, not in the sense of partition of environmental and genetic trends, but of evaluation, often in monetary terms.

Genetic improvement made at present, either by selection between populations such as breeds, or by selection within populations, is likely to last indefinitely, or at least as long as the same traits are desired. Yet on most people's scale of values, something obtained now is more desirable than the same thing obtained in some years time. This scale of values can be quantified if we consider money, for that earned now can be reinvested and should produce more than that earned later. Thus the practice is to compare money obtained in different years by discounting that in a future year ($t$) to the present using a factor $1/(1 + d)$, where $d$ is the interest (or discount) rate. This procedure of investment appraisal was first used in an animal breeding context by POUTOUS and VISSAC (1962), and subsequently by many others, such that it is often used now when comparing alternative breeding programmes, and many examples could be given. Whilst it is obviously a very powerful method, the use of discounting (or discounted cash flow analysis) is subject to a lot of problems or pitfalls, and these I wish to review. Although it might be desirable for the animal breeding applications to be discussed by an economist, most of the practitioners in this field have been geneticists rather than economists.

In principle, the discounting analysis of a breeding programme requires estimates of the following parameters: the size of the market for improved stock (this may be the total production of a country), the monetary value of a unit change in performance, the parameters, such as heritability, necessary to enable computation of genetic progress, the cost of alternative schemes and finally the discount rate. Let us discuss some aspects of these.

*Monetary value of changes in performance and market size.*—The values of changes in performance are also required when calculating selection indices, and it is usually possible to obtain good estimates for the more important traits. The main problem is in predicting how they will change in the future. This is exemplified, for example, in dual purpose cattle populations, where the relative prices of beef and milk have changed in recent years and may well continue to do so.

It is usually more difficult to predict the size of the market for the improved stock. This differs according to who is financing it. In national schemes, with money coming directly or indirectly from the consumers, the market may be the nation's whole population of that species of livestock. For a self-financed commercial breeder the market is the number of stock he sells. Therefore in a national breeding scheme, such as that of the English Milk Marketing Board, the market for the final product, milk, and indirectly for the breeding stock is fairly constant. Thus it is possible to predict what the returns from a unit improvement in the breeding programme are likely to be in the industry as a whole by multiplying the number of animals by the value of change in each. However, if we are concerned with an individual breeder, say a large commercial company breeding chickens or pigs, it may be quite unrealistic to assume a linear relationship between performance and returns. It seems more likely that the fundamental relationship is sigmoid: if the breeder's stock is much poorer than that of his competitors, his sales are likely to be very small, if much superior, very large; while over the range of his competitors' performance, he is likely to obtain a large increase in sales for a small change in performance. Of course this idealistic viewpoint will not hold exactly, as selling expertise, for example, will reduce the impact of performance on sales. Even on a national basis, we should not be too willing to asume that a breeding programe has a fixed market, for stock may be imported from competing programmes run in other countries, in which case there may be zero real returns from the breeding programme of the importing country.

These problems of predicting future market size and value are likely to be more critical in species with long generation turnovers, where it may be many years before improved stock are used in large numbers and the breeding programme breaks even. This has been exemplified by HINKS (1971) and HILL (1971) for milk and beef improvement, respectively, in cattle.

A related problem is where we consider new breed evaluation. If the tested breed is found to be superior it will then be substituted for the old. In most societies such a substitution can not be imposed on the farming community and therefore it will be very difficult, if not pure speculation, to predict the rate and final

extent of substitution of the new breed for the old. These will have a very large effect on the discounted returns likely from any breed testing programmes.

*Discount rate.*—Interest rates have risen markedly in recent years, such that programmes likely to produce early returns are predicted to be more profitable. This has some anomalous consequences, which are well illustrated using some results of JAMES (1972).

If the total number of animals that can be tested each generation is fixed, but the breeder can vary the number of animals selected, then the more intensely he selects the more rapid the initial rate of response, but the smaller the effective population size, and therefore the more quickly will the population run out of genetic variation. There must therefore be an optimum selection intensity. Values for this were obtained by JAMES, using the usual discounting assumptions. He showed that the critical parameter was the discount rate per generation, which can be very high. For example, with an annual discount rate of 10 % and a five year generation length as for cattle, the discount rate per generation is roughly 50 %. This implies that returns obtained after two or three generations are discounted to a very low value, so the optimum programme would have a very high selection intensity with most variation lost after this time.

The consequence of this argument is that there would be no genetic variation left for future generations of *breeders* to utilize. We would be taking an extremely short term view, much more so than most breeders would be willing to take. Thus most breeding programmes have some minimum rate of inbreeding restriction imposed on them, presumably with future generations in mind. Similarly, if a high discount rate is used, it may be difficult to justify any programme of storage of germ plasm resources until some unknown date in the future, and without any certainty that that the material would ever be used.

A less *ad hoc* method of avoiding these very short term consequences of the discount method is to adopt a *social* discount rate (PREST and TURVEY, 1965). We argue that current interest rates produce consequences that are socially unacceptable, and thus adjust the rates to lower values. We have little guidance as to what rates should be used however, and presumably a social rate is more applicable to a national than private breeding programme.

There are alternative methods of comparing different programmes: one is to fix a test discount rate and see which schemes yield the greatest margin of discounted returns over costs, another is to find which schemes have the highest internal yield, or discount rate at which they break even. It is for economists, not a geneticist, to say which is preferable; my own preference is to do both: find the profit for the test rate, and check the robustness of the scheme by showing it has a high internal yield.

Although one measure of safety against risks in a scheme is a high predicted internal yield, other methods can be used. One useful technique is to divide the returns into those which seem reasonably certain and those on which there is a high degree of risk, and then find the net profit or yield in the relatively risk-free situation. More sophisticated alternatives require predictions of the probability distribution of returns, but these seem to require knowledge of too many parameters. In any event, it is necessary to undertake some kind of sensitivity analysis of the predicted returns from the programme, if only to identify the critical assumptions.

*Costs of schemes; genetic parameter estimates.*—I do not want to discuss these in detail, primarily because they seem to introduce much less uncertainty into predictions of net returns than do the parameters of market size and value of product discussed earlier. Further problems of genetic parameter estimation are being discussed elsewhere in this conference.

From these arguments it will appear that I am somewhat sceptical of the value of the discounting procedure, despite being one of its practitioners. The problem is that so many parameters have to be estimated that, with adequate skill, there is a fair chance that the conclusions which were desired from the outset can be proved in the analysis. (This seems the usual outcome of any economic analysis in which there are inevitable political overtones!) Nevertheless, I consider the method useful and think it has had one important impact on our thinking as animal breeders, in that it has focussed attention on short term as opposed to long term gains. This has always been a concern of commercial companies who have firstly to worry about short term survival, but perhaps not of national organisations. For example, we see that it is desirable to undertake breed comparisons over a few rather than many years and publicise results immediately; and in a dairy cattle improvement programme to emphasize the use of bulls directly for breeding cow replacements rather than through the path «bulls to breed bulls», when only grand-daughters of the selected animals yield returns to the industry. But as I have mentioned previously, even the short term view must be held with reservation.

## PREDICTION OF SHORT TERM RESPONSE WITH OVERLAPPING GENERATIONS

In populations in which generations overlap, particularly dairy cattle where animals may reproduce over many years, selection practised now does not immediately improve all animals in the population by the same amount. Initially only progeny are affected, then grandprogeny and so on, and it is very many years before all animals in the population have approximately the same relationship to the group of animals selected in any year. This has been well illustrated by HINKS (1971), and rather differently by McCLINTOCK and CUNNINGHAM (1974). Thus, after a single year's selection, the mean performance of the population fluctuates considerably before finally settling down at a value equal to $\Sigma S / \Sigma L$, where $\Sigma S$ and $\Sigma L$ are the sums of selection differentials and generation intervals over the four pathways (males to males, etc.) of genes. This increment is equal to the rate of response in a continuing programme, as derived by RENDEL and ROBERTSON (1950). However, this classical rate is reached asymptotically, and so we need some formulation for predicting the response before the asymptotic rate is reached. This is relevant to our present discussion, because when returns are discounted it is those obtained in early years, while the discount factor is still large, that are most important and the asymptotic values may not feature significantly in our calculations.

Several methods have been developed to enable computation of these short term responses, in all of which track has to be kept of the mean performance of animals born each year (e. g. SEARLE, 1961; HINKS, 1971). Recently the methods have been formalised using matrix analysis (HILL, 1974; J. M. ELSEN, personal

communication). This comprises specification of a matrix, $P$, in which the element of the $i$th row and $j$th column defines the proportion of genes in animals of age-sex class $i$ at time $t$ which come from animals of age-sex class $j$ at time $t$-1. In a dairy cattle population in which bulls survive up to say 12 years and cows up to 15, the matrix would have to be of dimension 27 or so. As a more compact example, consider a beef herd in which bulls have equal numbers of progeny when 2 and 3 years of age, and cows have, on average, 20 % of their progeny when 2 and 5 and 30 % when 3 and 4 years of age. Thus the row definition and elements of $P$ are as follows:

$$
P = \begin{pmatrix}
0 & 0.25 & 0.25 & 0 & 0.1 & 0.15 & 0.15 & 0.1 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0.25 & 0.25 & 0 & 0.1 & 0.15 & 0.15 & 0.1 \\
0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 1 & 0
\end{pmatrix}
$$

corresponding to

| Sex: | Males | | | Females | | | | |
|---|---|---|---|---|---|---|---|---|
| Age: | 1 | 2 | 3 | 1 | 2 | 3 | 4 | 5 |

There are two rows in $P$ corresponding to reproduction, and the rest to the passage of genes due to ageing. We also require another matrix, $Q$, which defines the passage due to ageing only, and so equals $P$ with the two rows defining reproduction set to zero. Consider selection in a single year. We define a column vector $s$ of the same dimension as $P$, whose elements are the genetic selection differentials applied to the specified age-sex class in that year. Letting $r_{(t)}$ be the vector of responses obtained $t$ years later, it can be shown that

$$r_{(t)} = (P^t - Q^t)\, s \qquad [1]$$

(HILL, 1974).

The initial responses are erratic, but we find that $\lim_{t \to \infty} Q^t = 0$ and that $\lim_{t \to \infty} P^t$ has all rows the same. The elements of a row, $v'$, of this limiting matrix are proportional to the reproductive values, which are the fraction of genes contributed by age-sex class $i$ in the remainder of its life, starting with a value of 0.5 for new-born individuals. Thus in our example,

$$v' = (0.5 \quad 0.5 \quad 0.25 \mid 0.5 \quad 0.5 \quad 0.4 \quad 0.25 \quad 0.1)$$

The final response is the same for all age groups and equals

$$v's/L = \Sigma v_i\, s_i/L,$$

where $L$ is the generation interval, averaged over all paths of genes, and equals 3 years in our example. This is just a more formal way of expressing the classical response formula of RENDEL and ROBERTSON (1950), and also shows that it is approached asymptotically.

Considering now monetary responses, we require a further vector $w'$, whose elements are proportional to the undiscounted monetary returns from a unit improvement in the selected trait taken over all animals marketed, or yielding milk say, of that age group. Thus the undiscounted returns at time $t$ are $w'r_{(t)}$, and the total returns up to time $T$, discounted to present value, from one year's selection are

$$y_T = \sum_{t=0}^{T} (\frac{1}{1+d})^t \, w'r_{(t)}$$

$$= w' \sum_{t=0}^{T} [(\frac{1}{1+d} P)^t - (\frac{1}{1+d} Q)^t] \, s$$

using (1). Taken to infinity this becomes

$$y = w' \, [(I - \frac{1}{1+d}P)^{-1} - (I - \frac{1}{1+d}Q)^{-1}] \, s \qquad [2]$$

(HILL, 1974). Standard computer matrix routines can be used to calculate the formulae.

As an illustration, chosen for simplicity rather than relevance, consider the cattle programme defined previously. Assume males are selected for live weight at one year of age, with a genetic selection differential of 24 Kg, with no selection on females, so $s' = (24\ 0\ 0 \mid 0\ 0\ 0\ 0\ 0)$. The responses $r_{1\,(t)}$ among young males (equal to that in young females assuming no interaction) are given below, together with the discount factors $1/(1+d)^t$, for $d = 10\,\%$:

| $t$ | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | $\rightarrow \infty$ |
|---|---|---|---|---|---|---|---|---|---|
| $r_1\,(t)$ | 0.000 | 6.000 | 6.000 | 2.100 | 4.500 | 4.035 | 3.915 | 4.127 | 4.000 |
| $1/1.1^t$ | 0.909 | 0.826 | 0.751 | 0.683 | 0.621 | 0.564 | 0.513 | 0.467 | 0.000 |

Even in this example, where breeding animals are retained for only five years, the initial response, when the discount factor is high, is irregular. To show how the vector $w$ is calculated, assume the population is of size 5000, with 2000 males and 1000 females being slaughtered each year, half by one and half by two years of age, and that each Kg extra live weight is worth £0.20, net over food costs. Then $w' = (200\ 200\ 0 \mid 100\ 100\ 0\ 0\ 0)$ and the discounted returns to infinity given by (2) turn out to be £22070. In a real life example we would discount for a shorter period, and, of course, try and ensure the breeding stock was multiplied over a wider market.

Whilst these techniques for overlapping generations are easy to apply, we still have to bear in mind the reservations attached to the discounting method. The matrix techniques were invented with discounting in mind but are probably of more value in demonstrating the structure of populations in which generations overlap.

296

## SUMMARY

Breeding programmes can be evaluated solely in terms of expected genetic progress, but it seems necessary to include economic criteria and also to discount both costs and returns to a fixed time. While discounting is a well established procedure in animal breeding research there are many problems in its use, and these are discussed. In particular we usually have very inadequate knowledge of the expected market for improved stock, even in a national programme. Generally, discounting procedures have usefully focussed our attention on the short term; but if this approach is carried to the extreme and net returns using a high discount rate are the sole criteria for choice of programmes, we would select so intensively that little genetic variance would be available to enable progress in the future.

A matrix method is described which enables prediction of responses to selection and discounted returns in the first few years in populations with overlapping generations.

## ZUSAMMENFASSUNG

Zuchtprogramme können nach dem zu erwartenden genetischen Fortschritt bewertet werden, jedoch erscheint es wüschenswert, ökonomische Kriterien in die Planung mit einzubeziehen und Kosten und Nutzen auf einen bestimmten Zeitpunkt zu diskontieren. Obwohl die Diskontierung eine gebräuchliche Methode in der Tierzuchtforschung geworden ist, wirft ihre Anwendung viele Probleme auf, die hier diskutiert werden. In erster Linie ist das Wissen um die Marktaussichten für das verbesserte Tiermaterial im allgemeinen unzureichend, was sogar für nationale Zuchtprogramme zutrifft. Diskontierungsmethoden haben sich für kurzfristige Voraussagen im allgemeinen bewährt. Bei extrem langfristigen Prognosen verlieren sie jedoch ihre Gültigkeit. So führt bei hohem Diskontsatz die ausschließliche Bewertung von Zuchtprogrammen nach den Nettogewinnen zu einer so hohen Selektionsintensität, daß die genetische Variation und damit der weitere Selextions erfolg reduziert wird.

Eine Matrizenmethode wird beschrieben, welche die Vorausschätzung des genetischen Fortschrittes und des diskontierten Selektionsgewinnes für die ersten Jahre eines Zuchtunternehmens gestattet, und zwar für Populationen mit überlappenden Generationen.

## RESUME

Les programmes d'amélioration génétique peuvent être évalués uniquement en termes du progrès génétique attendu, mais il semble nécessaire d'y inclure des critères économiques et aussi d'escompter les dépenses et les recettes à un temps fixe. Alors que l'actualisation est un procédé bien établi dans la recherche génétique, il y a de nombreux problèmes, qui sont discutés, dans son utilisation. En particulier, nous avons habituellement une connaisance inadequate du marché attendu pour un bétail amelioré, même dans un programme national. Generalement, les procédés d'actualisation ont utilement concentré notre attention à court terme, mais si cette approche est portée à l'extrème et si les recettes nettes utilisant un

haut taux d'actualisation sont les seuls critères pour le choix des programmes nous sélectionnerions si intensivement qu'une petite variance génétique serait disponible pour permettre des progrès dans le futur.

Une méthode matricielle, qui permet le prévision des réponses à la sélection et l'actualisation des recettes dans les premieres années d'exploitation des populations avec des generations qui se cheauchent, est décrite.

## REFERENCES

HILL, W. G. (1971): Investment appraisal for national breeding programmes. *Anim. Prod.*, 13:37-50.

HILL, W. G. (1974): Prediction and evaluation of response to selection with overlapping generations. *Anim. Prod.*, 18:117-139.

HINKS, C. J. M. (1971): The genetic and financial consequences of selection amongst dairy bulls in artificial insemination. *Anim. Prod.*, 13:209-218.

JAMES, J. W. (1972): Optimum selection intensity in breeding programmes. *Anim. Prod.*, 14:1-9.

McCLINTOCK, A. E., and CUNNINGHAM, E. P. (1974): Selection in dual purpose dairy cattle: Defining the breeding objetive. *Anim. Prod.* (In press.)

POUTOUS, M., and VISSAC, B. (1962): Recherche théoretique des conditions de rentabilité maximum de l'épreuve de descendance dex tauraux d'insémination artificielle. *Ann. Zootech.*, 11:233-256.

PREST, A. R., and TURVEY, R. (1965): Cost benefit analysis: a survey. *Econ. J.*, 75:683-735.

RENDEL, J. M., and ROBERTSON, A. (1950): Estimation of genetic gain in milk yield by selection in a closed herd of dairy cattle. *J. Genet.*, 50:1-8.

SEARLE, S. R. (1961): Estimating herd improvement from selection programs. *J. Dairy Sci.*, 4:1103-1112.