The broad range of applications for using simulation in animal breeding is surveyed. Six areas are identified where simulation studies can help the animal geneticist: data analysis; rates of genetic change; selection indices; gene action, animal genotypes and phenotypes; and complex economic systems.

With economic applications, the evaluation of investment opportunities (Investment Marketing Packages), breeding objectives and return on investment in breeding are considered and inter-related. Electronic spreadsheet deterministic models which collate knowledge about characteristics of breeds, and their crosses, with financial considerations would be of benefit to farmers, their advisors, and to bankers.

Simulation provides an excellent tool for the integration of quantitative knowledge from a variety of disciplines. The exercise of defining the model, forces an evaluation of the key factors influencing the outcome. This can help identify those areas which require further experimentation or extension to industry.

INTRODUCTION

Before discussing the evaluation of beef breeding programs the following factors must be defined (A) the target market: veal, prime beef, or old bullocks; (B) the management system: pure beef, terminal crossing, or dual purpose, intensive versus extensive and the level of investment. I will later refer to the combination of (A) and (B) as the INVESTMENT MARKETING PACKAGE.

Next, one must consider from whose viewpoint the simulation is done: for the farmer, the AB stud, or for the country. Simulation itself can take many forms, from a simple sum on a scrap of paper, to electronic spreadsheets and complex computer models.

I will review the areas where simulation has had a bearing on beef breeding and then offer some further ideas.

Data Analysis and the Role of Simulation

Simulation can be used to answer two main types of problems associated with data analysis:

(1) What is the best model for the analysis of field data?
(2) Knowing the model, what data structure is optimal?

In the case of (1) there has recently been considerable use of simulation to define better models which:
* Remove the effects of weaning weight selection on final weight assessments. Pollock and Quaas (1981a) evaluated multiple trait models using simulated data.

* Remove the effect of non-random mating of cows and sires. Hudson and Schaeffer (1984) compared the efficiency of four models under three culling and mating programs. They concluded that an 'animal model' was superior to the other approaches such as the 'sire-maternal grandsire model'.

* Remove the bias due to genetic trend. Pollock and Quaas (1981b) used a variety of models to analyse animal growth traits in eight simulated generations.

The choice between models to use for field data analysis is often an arbitrary balance between the appeal of a low cost, simple model and its ability to produce estimates which come close to those generated by a more exact, expensive model. One way of assessing the ability of a particular computing shortcut to adequately and cost-effectively obtain Estimated Breeding Values (EBVs) is to take a file of field data and generate simulated measurements (Y) with known biases, while retaining the incidence matrix (X), i.e. the animal and herd structure.

The second problem (2) is really one of experimental design; how can one restructure the breeding program to reduce the degree to which the field data is unbalanced. There has been some work specific to beef breeding to illustrate preferred patterns of reference sire use for achieving adequate linkage between herds (Foulley and Clerget-Darpoux, 1978). The geneticist must resist the temptation to recommend data structures which sacrifice accuracy of sire assessment for the ability to extract components of variance. While this is usually not an issue in the beef industry, where extensive use of AI is practised, it must be considered.

As computer hardware becomes cheaper, the use of more and more exact models becomes affordable. The appearance of cheap microcomputers has greatly reduced the cost of simulating large data sets both for testing ranking procedures and for testing procedures for variance component estimation.

Just as the gap is narrowing between the theoretically best models and what could be afforded in practise, the cost of automatic data capture equipment is showing signs of falling. One consequence of developments in automated data measurement equipment is the availability of much larger numbers of measurements per individual, with a consequent increase in the complexity of the computer software.

**Prediction of Rate of Change in Population Means**

In animal breeding, the most widely used types of simulation involve the Rendel and Robertson (1950) or the Dickerson and Hazel (1944) methods of predicting steady state rates of change in population means. Parnell et al. (1984) give a review of the development of the theory over the following three decades which covers methods for dealing with overlapping generations and complex (realistic) population structures.

In one of the more recent papers, Alenda et al. (1982) examined the effectiveness of progeny testing following a performance test and concluded that for a heritability of 37% and a herd of 200 cows, progeny testing was inferior to a simple one-stage selection on own performance. Morris et al.
(1980) concluded that within-herd progeny tests were less desirable than performance testing, but that progeny testing, via a Sire Reference Scheme (SRS), of the top bulls in co-operator herds (selected on own performance test) maximised progress. The SRS concept relies on AI which allows greater selection intensities. Of course, with the appearance of BLUP models, the issue of progeny versus performance testing is irrelevant when one simply picks the best animals on EBV.

Baker and Morris (1981) presented various options for straight and crossbreeding plans, and provide estimates of the gain expected when breeding for yearling weight with various age structures and mating policies. They too highlight the need for rapid turnover of both males and females. Various crossbreeding strategies were examined to test which method could be recommended to New Zealand farmers. The three-way rotational crossbreeding program was favoured, particularly when the straightbred bulls used were generated from herds using an SRS. Their primary proviso was that genetic gain for yearling weight will generate a corresponding change in carcass weight. It was also assumed that the increased carcass weight would not be completely offset by an increase in costs associated with the herd such as changes in dystocia, feed requirements or fertility.

Parnell (1985) has developed the ideas of Bulmer (1980) and of Johnson (1977) to predict changes in population means, variance of response and inbreeding levels year by year in beef herds, using a deterministic model. The farmer can relate more easily to models which illustrate what he can expect to happen on an annual basis rather than to what is predicted to happen when the program reaches equilibrium.

**Simulation of Animal Genotypes and Phenotypes**

The simulation of individual animals within a herd was popularised by the computer program COWGAME (Willham, 1971). Indeed this model has been used to test evaluation methods (Pollak and Quaas, 1981a,b). The program was rewritten (and called ECHO) to incorporate a single trait BLUP procedure for the evaluation of the five multiply correlated traits in simulated herds (Middleton, 1982). A more complete system (BGEN) based on COWGAME and ECHO has been produced (Tier et al, 1984). This version uses Quaas' Reduced Animal Model for multiple trait evaluation of the simulated data. Undoubtedly, there is a distinct advantage in offering a teaching tool which exactly matches the evaluation method used for the analysis of commercial field data (Nicol et al, 1985).

Russell (1985) has used simulation to illustrate the effect of culling beef cows for failing to reproduce, using four culling policies. He confirmed that although True Breeding Value on the underlying scale improved, calving rate changed less predictably. For traits with low heritability the use of BLUP could assist in obtaining better rates of progress in True Breeding Value.

Parnell (1986) used stochastic simulation based on the BGEN model to compare classical index selection and BLUP over 20 years. As expected, he found only small improvements in the rates of gain using a within-herd BLUP evaluation. However, the rate of inbreeding of simulated animals was about 20% higher than expected from a deterministic prediction of inbreeding rate. Of course the real impact of BLUP is the effect it has on producers by providing a logical basis for discussing breeding.
Selection Indices

Selection index theory (Hazel, 1943) provides a mathematical model which can predict the accuracies of various combinations of measurements and their relative usefulness in a breeding program. This type of deterministic simulation provides the key information needed in the economic modelling of selection programs. These economic models should balance the cost of measurement against the added benefit which results from the inclusion of this data in the index. With the more widespread use of BLUP, the index is simply a function of the animal's EBV for each trait, obtained from a multiple trait BLUP.

Simulation has been used to test the robustness of the selection index to the effects of incomplete knowledge about genetic parameters (Sales and Hill, 1976a,b). Selection indices calculated after eight generations using William's simulation model, had a correlation with True Breeding Value which was only two-thirds of expectation. The primary weakness of selection indices in practice is, of course, that they do not correctly remove fixed effects: the expression of a phenotype from a contemporary group mean also removes a genetic component due to genetic trend. The multiple trait mixed model corrects this problem.

Simulation at the Gene Level

The basis of genetic variation has been simulated extensively. In the case of beef cattle, Davis and Brinks (1983) reviewed the relevant papers in this area. In their simulation they examined variation in the phenotypic response to inbreeding under three methods of mating, with eight modes of gene action (additive, additive by dominance etc.) for 64 loci. They concluded that, for traits with low heritability, at the phenotypic level, there was considerable variation in the response to inbreeding.

McClintock and Hammond (1981) have shown how stochastic simulation can clarify what happens in a systematic back-crossing program where deterministic prediction is not trivial. There is considerable variation in the percent of the genome contributed by the new breed at each generation - the idea that an animal comprises 75% of one genome should be presented with caution since its makeup may be between 66% and 84%, in the case of cattle.

Stochastic simulation was also used by McClintock (1981) to illustrate how factors such as herd size, female culling rate and chance influences the probability of transferring the pollen gene from one breed to another.

Simulation of Animal Phenotypes

The TAMU simulation model, developed at Texas A&M, simulates phenotypically the growth and fertility of a herd of beef animals. The model, described by Cartwright (1978), has been modified and used by various authors, but the basic method involves updating each simulated animal's growth and energy status at monthly intervals, according to the availability of ME during that time period. The effect of feed availability on weight, fatness, milk and fertility can then be analysed by separate economic analyses. For straightbreeding it was found that the genotype of an animal can be defined in terms of its mature size, maturing rate and milk production potential.

The general approach can be used to realistically simulate various crossbreeding systems because the ancestry and paddock location of each individual is stored. There would be a large number of predictive equations which would need validation for crossbreds (Cartwright, pers. comm).
Simulation at the Regional Level

Economic models which simulate the competition between different farming enterprises are used at the national and regional levels to find out if resources (land, labour, capital) are being used effectively. These models incorporate expected levels of efficiency factors (such as calves sold per cow), costs of fertilisers, returns from various commodities and elasticity of prices (Reeves, 1981). They can predict possible shifts in the profitability between beef, sheep or grain. At a crude level, these models could provide assistance in defining relative economic weights and could indicate the prospects for investment in a breeding program. Will there be a beef industry in the future? If so, what approximate characteristics will the beef animals have to exhibit?

DISCUSSION

It seems that it is the economic aspects, in particular, of breeding programs which now require the application of simulation techniques. Perhaps the best starting point is when the financial planning of a new farm is taking place.

If a decision is taken to invest in a cattle enterprise then the logical course would be to draw up business investment plans showing how a return on the investment (ROI) is to be obtained. Alternative plans would be examined to find the most appropriate one. Such alternatives would explore options such as:

- Invest more or less capital?
- Aim at different markets?
- Integrate several compatible enterprises?
- Use a different breed or crossbreeding system?

Let us define a particular plan, in which the market(s) and the level and use of capital are defined, as being an Investment Marketing Package (IMP). There is usually a quantum difference between these packages in the major factors which limit profitability. Examples of changes in the IMP would be: A switch from dairy to beef farming, where the requirement for machinery and labour is quite different; or a switch from selling pedigree breeding stock to selling crossbred commercial animals. Changes in the IMP can be at the national level. For example, Norwegian market forces dictate that dairy cows in Norway serve as the primary source of beef. The production system (IMP) involves a rapid replacement of the female herd with culled animals being used for beef; so this must be recognised when the calculations are done on the relative importance of beef, milk and stayability in Norway.

It is not sufficient to merely compare different IMPs. It is necessary also to ask the question "For any given IMP, would a change to certain attributes of the animal lead to more ROI? For example, what would be the profitability of a total farming enterprise if animals conformed to an altered set of characteristics?" This might involve substituting a new breed, or it might mean a small change in the proposed management.

Examples of factors to include in an IMP evaluation are:

- Estimates of numbers sold by age/weight/fat class,
- Weight/fat/conformation targets,
- Capital appreciation of assets,
- Land,
Buildings,
Purchased feed cost,
Fertiliser and fuel costs, and
Tax interest and inflation.

Having defined the IMP in detail, including the breeds which will be used, it is then necessary to ask "Should I make genetic changes to these animals so as to make the overall farming enterprise more profitable?" In other words, given a particular population with known genetic parameters, how do we best change it towards a more desirable type of animal. This problem must be attacked in two stages:

1. What is a change in the animal's genotype worth?
2. What will it cost to operate a selection program?

The answer to (1) must involve an assessment of what increase in returns can be expected from a unit change in each component of the breeding objective, with all other components remaining constant and with the IMP remaining fixed.

The answer to (2) involves an assessment of the cost of measuring, the cost of record processing and the projected returns from the investment in the breeding program per se. It is necessary to know the economic weights to predict the returns from any particular combination of measurements. Selection index theory can provide a prediction of the relative benefits (accuracy) of different combinations of measurements. Simulation of the absolute costs and returns is required to give a perspective on which strategies (measurement, mating and culling) can maximise ROI.

Recently it has been shown by Brascamp et al. (1985) that the problems raised by Moav (1973) are overcome by using the concept of a normal profit. Providing a normal profit is built into the cost part of the profit function, the relative economic weights are comparable whether calculated per unit of investment, per breeding female, per individual, or per unit of product.

Smith et al. (1986) have extended this concept and clearly show that it is essential to include all costs, both fixed and variable, in the simulation of what a unit change in a trait is worth. They further show that the profit per unit of product sold which can be expected when the whole enterprise is expanded, should be subtracted from the apparent profit associated with a unit of genetic change in the trait. In other words if an IMP provides an overall return (R) and a cost (C) per unit of product sold then only genetic changes which provide a profit of more than (R-C) should be regarded as having a real economic value.

The example chosen by Smith et al. involves only one product being sold from the enterprise, although several traits contribute to economic merit. In practise several products are usually sold (veal or prime beef and cull cows, stud animals and cull cows), and each will have different markets, and prices, so it is better to calculate R and C at the IMP level rather than the unit of product level. Absolute levels of each trait are recognised as important and this emphasises the need to define the IMP accurately.

It is possible that where an animal has been matched perfectly with its IMP due to careful initial choices of breed and system, any change to a trait like growth rate could reduce the overall (R-C) of the IMP. However, it is probable that there will be genetic variability associated with (R-C).
Decisions which concern large sums of money usually involve bankers or business consultants. It is important, that this group be given the tools to make rational decisions, i.e. a guide to how different beef genotypes perform under particular production systems. Such a guide would include the expected performance in a commercial herd using:

- Rotational crossing with particular breeds,
- Random mongrelisation,
- Straightbreeding with a particular breed, and
- AI from a source committed to a particular program.

CONCLUSION

It is well recognised by those who have used simulation (for example Cartwright, 1978) that it provides an excellent framework for the integration of quantitative knowledge from a variety of disciplines. The exercise of defining the model forces an evaluation of the key factors influencing the outcome. This helps the recognition of those areas which require further experimentation or extension to industry.

Stochastic simulations, in particular, have much to offer at the applied level since they are easier for producers to understand than the abstract differential formulae of a deterministic model.

Electronic spreadsheet deterministic models which collate knowledge about characteristics of breeds, and their crosses, with financial considerations would be of particular benefit to farmers, their bankers and advisors.

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