Supporting the
land-based industries
for over a century

SAC

LAND ECONOMY WORKING PAPER SERIES

Number 11. Modelling Agricultural Systems: Applications to Livestock Breeding

Corresponding Author:

Caroline Hattam
Land Economy Research Group
Research Division
SAC Edinburgh
EH9 3JG

Tel: 0131-535-4418
E-Mail: Caroline.Hattam@sac.ac.uk

Modelling Agricultural Systems: Applications to Livestock Breeding

Caroline Hattam
Land Economy Research Group, Research Division, Kings Buildings, SAC,
Edinburgh, EHG 3JG

Abstract

Traditionally the evaluation of animal genetic traits has focused primarily on production traits and the construction of selection indices. Selection indices, however, fail to consider the effect of management practices and the environment on productivity. Non-production traits are either under-valued or not valued at all. Given the changing demands placed on agriculture and the increased understanding of the effects of agriculture on the environment, this approach can be considered myopic.

While techniques are available to link economic and biophysical/environmental models, little has been applied in the context of genetic trait evaluation. This paper therefore explores the potential for integration and the development of methods that capture not only breeding objectives, but also non-production traits. Such an approach should provide greater understanding of the implications of breeding choices and reflect not only the interests of farmers, but of society as a whole.

Keywords: A*nimal genetic traits; economic weights; biophysical models; breeding objectives.*

1, Introduction

Agricultural systems have been modelled in a number of ways and the character of each model varies enormously (Swinton and Black, 2000). The scale of modelling ranges from the subcellular to the agroclimatic, studying processes as diverse as the biophysical and the economic. These models also differ in time, being either static in nature or running for hundreds or thousands of years, and may simulate or estimate the predicted outcomes. Classifying and reviewing models is therefore not a straightforward task.

Using the livestock-breeding sector as an example, most models have been developed to assist with farmer decision making. In this case, decisions correspond to the improvement of production and functional traits such as milk yield, growth rate and feed efficiency. Given fluctuating markets, the changing objectives of consumers, the increased awareness of the provision of public goods via agriculture and the prospect of climate change, this approach seems somewhat myopic (Olesen et al., 2000). This paper therefore reviews the potential for modelling approaches developed for the livestock sector that combine decisions taken on production and livestock improvement together with environmental objectives and the development of non-economic traits.

This paper begins by describing the need for modelling breeding systems and defining the economic value of genetic traits (section two). It then describes the methods commonly used in building such models (section three). Following this, the inclusion of environmental factors and linkages to environmental process models are explored, together with brief descriptions of a number of biophysical models that have been used in agricultural research (section four). The paper closes with a summary of the key issues brought up in the discussion (section five).

2, Modelling breeding systems and valuing genetic traits

Breeding systems should be developed to integrate the objectives of the farmer and how the changes introduced in the livestock will impact upon the overall efficiency of the farm (Olesen et al., 2000). Valuation of livestock genetic resources is commonly achieved through the construction of selection indices. Based on index theory, combinations of estimated genetic progress (or breeding value) are compared and weighted according to breeding goals (Walsh and Lynch 2000). This is an iterative process that estimates a set of weights until a desired scenario is obtained, the weights from which are then selected and may be interpreted in economic terms. The appropriate weighting scheme for future scenarios of husbandry, society and market can then be inferred.

Breeding value is commonly calculated using the best linear unbiased prediction method (BLUP). This is a simultaneous measure of the phenotype of the animal, based on the genotype, environmental effects and other residual effects, combined with the effects of this on the animal's performance (Mrode, 1996). Economic weights are then calculated using a variety of methods, as described below.

The majority of analytical methods developed to model these construct economic values for a particular trait or groups of traits and, depending on the frequency of expression, weight them with respect to resource efficiency. As mentioned such methods have focused primarily on production and functional traits with little consideration for environmental, social or ethical concerns. A linear relationship is assumed between increased expression of a trait and profit, irrespective of breed and farming system (Neal and Fulkerson, 2006). This is despite the knowledge that management practices and environmental factors influence productivity. Ignoring interactions with the management and wider, policy constraints, information asymmetries and even factors such as hybrid vigour may mean that production traits are over-valued, while non production traits remain under-valued or not valued at all.

Societal concerns over public good provision are often considered insufficient to stimulate the adoption of a specific trait in breeding goals (Brascamp et al., 1998). Producers respond more readily to prices, but it has long been understood that these do not perfectly reflect the demands of society. Reliance on market signals means that breeding goals have had the tendency to focus on short-term objectives often leading to unwanted side effects, with the wider, often non-economic effects failing to be taken into consideration.

Before introducing measures that consider, for example, environmental effects, it is important to be sure of the probability of being able to influence a problem through breeding. This needs to be achieved without negatively influencing other aspects such as production and functional traits such as calving ease or feed use efficiency. It is therefore important to understand what can and cannot be achieved through breeding. A better chance of success will occur when fewer genes are involved and the interaction between traits is less (Olesen et al., 2000).

Valuing traits that incorporate environmental, ethical and social needs, however, is not problem free. Production and functional traits are valued in monetary terms and are therefore exchangeable on the market. It remains questionable whether such a strategy is adequate for non-market traits; however, weighting between conflicting concerns is increasingly becoming a necessity. There needs to be tradeoffs between long-term and short-term goals (e.g. breeding may reduce milk yield in the short term, but this could be offset by greater disease resistance in the long run), especially as the importance of traits such as robustness and tolerance to changing environmental conditions may be particularly important in the not too distant future.

As Groen et al. (1997) comment, there is no one best methodology for valuing traits and breeding schemes, at the end of the day it depends on the objective, trait and production circumstances. The results however differ with modelling approach, definition of efficiency, planning horizon, system level under investigation, the size of the system and the objective of selection (for example, profit maximisation or maximum return on investment). Priorities need to be distinguished, such as welfare vs. profit, quality vs. price and the willingness to pay for these needs to be sufficient to transfer objectives from society to the producers (Olesen et al., 2000).

Obtaining the appropriate balance between short term productivity and the negative externalities from production is therefore a contentious issue. With the average age of farmers on the increase and greater emphasis placed on market signals and free-trade, it becomes much more difficult both for farmers and policy-makers to go against competitive pressures. Doing so may even compromise domestic production and lead to conflict with international free-trade agreements (although ‘green box’ policy interventions may be exempted). Food production is then likely to shift to low cost regions where concerns for negative externalities are lowest.

Olesen et al. (2000) advocate democratic control of the market economy to counter these problems and see a need for greater dialogue with the public over these issues. However, even if successful, balance must be achieved between conflicting goals and interest groups. For example, Stott et al. (2005) demonstrated a private gain from the inclusion of mastitis in a dairy cow breeding goal. This was only sufficient to slow the decline in mastitis associated with the negative genetic correlation with milk yield. When lameness was also included in the breeding goal some loss in mastitis benefits ensued.

3, Methods for calculating economic weights

A variety of methods have been used in the literature to infer economic values of breeding traits and animal genetic resources. The most commonly used approaches can be grouped into econometric estimation based on profit functions, simulation models involving mathematical programming methods and a range of alternative approaches permitting non-linear interactions.

3.1 Econometric estimation

Econometric estimation of the economic values of traits stems from Hazel (1943) who stated that “the relative economic value depends upon the amount by which profit may be expected to increase for each unit of improvement in that trait”. Partial derivatives of complex profit equations are calculated with respect to each trait in the objective function (e.g. profit maximisation, cost minimisation, fixed output or fixed number of animals). The derivatives are evaluated at the mean of all the other traits. The economic value of a trait is the change in profit accruing from a unit change in the genetic merit of the trait considered.

At the simplest level, these are single equation approaches and investigate the economic importance of individual traits. However, single equations may over simplify the situation (Harris and Newman 1994). Models based on a number of equations, being far more detailed and mechanistic, are considered to allow a more nuanced approach and allow for substitution effects between traits. For example, Koots and Gibson (1997) develop a bioeconomic model for the evaluation of beef production traits. Assuming profit maximisation, they identify 16 traits that may affect the costs and returns of the system. While most traits were assumed independent of each other, others were considered residual after accounting for non-linear relationships.

Econometric estimation is a theoretically sound measure of calculating economic values and is technically strong, capturing substitution effects. However, it demands good quality data. Estimating multiple demand equations is data intense and is potentially challenging (Scarpa, 1999).

Hedonic modelling has also been used for valuing type traits and relevant production traits, for example in dairy cows in Alberta Canada (Richards and Jeffrey 1996). This method assumes that the market price of a trait is related to its characteristics and the services that these traits provide. It is useful for assessing the value of the contribution of newly developed and successful varieties, and the importance of these traits to the producers. It also provides an indication of potential relative returns from further genetic resource conservation.

3.2, Decision Analysis Methods

Decision analysis models are more sophisticated, multi-equation models that can incorporate changing levels of genetic merit. They are also based on optimisation techniques but can incorporate cross effects and interactions between genetic traits. Such models frequently use mathematical programming techniques (e.g. linear programming, dynamic programming or multiple objective programming).

At the simplest level, linear programming has been applied to the calculation of economic values. Using this method, Koenen et al. (2000) investigate the effect of genetic change on liveweight and dry-matter intake in dairy herds under different production situations in the Netherlands. Economic values are calculated with respect to optimisation of labour income. A similar study by Steverink et al. (1994) calculates economic weights for a number of traits and the effects of genetic improvement on farm nitrogen loss. Differing scenarios with more stringent environmental legislation were compared. The value of body fat increased with tighter legislation, while the value of body weight decreased.

Dynamic programming is commonly used to study the interactions between performance characteristics, for example, feed efficiency, fertility and general production traits. Unlike linear programming, this method does not have an objective function, but describes a process in terms of the transition from one state to another. Beginning with an initial state, dynamic programming can be used to compare it with a new state once a decision has been made. It can be used for discrete decision problems and has frequently been used as a decision support tool. This method is commonly used to investigate optimal replacement strategies (e.g. Vargas et al., 2001) but has been used in combination with other herd submodels to estimate economic values in dairy herds (e.g. Plaizier, 1997).

In the UK it has formed the basic framework for calculating economic weights for the national dairy breeding programme since Veerkamp et al. (1997). At this point the index (now called £PLI) was expanded to include longevity as well as the production traits in the initial index (PIN). Longevity requires that the cow's expected future performance exceeds that of a replacement heifer, which is determined in part by its continued survival. By including certain type traits in £PLI, survival can be improved. Dynamic programming provides a means to assess the value of improved survival as explained by Stott (1994).

Linear and dynamic programming is limited as they only allow the decision maker to have one objective. This can be overcome by using multiple objective programming which allows the decision maker a number of different objectives, for example maximising net merit while at the same time minimising inbreeding (see for example Tozer and Stokes (2001) and their study of a Jersey dairy farm). Multiple objective programming allows the interactions and tradeoffs between the different objectives to be examined. The weighting placed on the individual objectives influence the final outcome.

3.3, Alternative methods

The above methods, while commonplace, are limited because they assume linearity in the objective function (linear programming) and linearity between transitions and combinations of stage returns (dynamic programming). In situations involving a number of non-linear interactions their use maybe restricted and their outcomes biased. Problems of non-linearity can be overcome by using a Bayesian approach and other adaptive methods, for example genetic algorithms. Such analysis can be used to investigate both continuous and ordered categorical traits, but can also be applied to linear models (van Tassell et al., 1998). However, these methods are more commonly used to understand patterns of heritability and performance, rather than for the direct calculation of economic values as such (see for example, Cardoso, 2003, van Tassell et al., 1998 and Weigel and Rekaya, 2000). Nevertheless, they may provide potential for further development.

An alternative method uses Markov chain methodology to understand the dynamics within the herd or flock. This component of the model is then associated with an economic component to estimate the economic values and weights. Conington et al. (2003) take this approach, combining it with gross margin analysis of the whole farm to calculate economic values for sheep traits. As the economic values of several traits are considered non-linear, many were calculated marginal values. Wolfová et al. (2005) use a similar approach, simulating life-cycle production using Markov chains, then calculating economic values as marginal economic values of the traits for a number of production scenarios (e.g. a beef pasture system and a dairy milking herd). Economic values are calculated as the first derivative of a profit function with respect to the trait of interest. To account for variation in the expression of different traits in different production systems, a gene flow method is used (using the ZPLAN software), allowing for discounting over the investment period.

4, Linkages with environmental models

To date few models include the economic evaluation of traits that are likely to have a positive effect on the environment or other public goods, such as animal welfare and biosecurity, nor traits that will assist compliance with environmental policies and regulations. Notable exceptions include Scarpa et al. (2003a, b), Drucker et al (2001), Baumung et al. (2001), Kanis et al. (2005) and Santarossa et al. (2004); however, with the exception of Santarossa et al. (2004) and Baumung et al. (2001), these models have taken a less quantitative and more subjective approach.

Of these methods, two main approaches appear in the literature related to valuing animal genetic resources: choice experiments and contingent valuation methods. Neither method derives economic values by direct calculation, the justification for which is insufficient knowledge, but they can easily incorporate non-economic traits, the importance of which can differ with individual perception.

These approaches model the preferences of the decision-maker for individual breed traits. They focus more strongly on the desires of the individual, inferring economic values of genetic traits as opposed to direct calculation of them. An interesting example of which is Scarpa et al. (2003a). Using this method and modelling the outcome using random utility models and multinomial logit analysis, Scarpa et al. provide an estimate of the economic value of certain indigenous pig attributes in the Yucatan (e.g. resistance to high temperatures and disease resistance). A similar approach has also been applied to valuing indigenous cattle breeds in Kenya (Scarpa et al., 2003b).

Contingent valuation methods differ slightly by investigating the willingness to pay for non-economic traits or willingness to accept payment for conservation of such traits by the decision maker, allowing the direct elicitation of non-use values. This method can be used to transfer the desires of society back to the individual breeders/producers and investigate the willingness of producers to fulfil societal needs. As demonstrated for potato production in Peru (Brush et al., 1992) this method can be extended to consider option values and the opportunity costs of maintenance of off-farm diversity.

The benefits foregone in the present can be considered a measure of the cost of maintaining the option to switch to other varieties at a later date. This can be considered a type of 'insurance' approach and portfolio choice models[1] can be applied here. Individual genetic traits are not valued as such, just their use or potential use value. This idea bypasses the need to investigate the cost or benefit of genetic traits to society and can be linked to the producer's production function in terms of costs and income generated (Drucker et al 2001).

Groen et al., (1997) state that these methods are particularly useful for pig and poultry breeders as it is common practice for producers to compare the performance of their own stock with that of their competitors. For cattle and dairy production, where the construction of trait indices is more common, alternative approaches are necessary. If however, the objective of trait evaluation is to understand what farmers want and why, and estimate use and non-use values, these methods may provide great potential, especially in light of the difficulties associated with valuing environmental characteristics.

4.1, Bioeconomic models

Bioeconomic models allow a more detailed understanding of the underlying processes of a farming system. A growing number of them incorporate the environmental impacts of production decisions, although not breeding goals. Given that models exist examining the impact of genetic traits on production and investigating the impact of production on the environment, it seems reasonable to suggest that the two approaches can be combined. It is frequently commented upon in the literature that this is an important avenue for future research (Brascamp et al., 1998 and Olesen et al., 2000). In what follows, methods of incorporating environmental effects into economic evaluation models are presented.

---

[1] Originally applied to financial decisions, portfolio choice models are used to explain choices under risk. They assume choice among assets is guided by the risk and return of the assets and individual risk aversion.

According to Brown (2000), on the one hand there are models that are biological process models which include an economic component. The economic component is usually incorporated as a set of accounting equations, tabulating the costs and benefits associated with a particular management strategy. One such example is the DAFOSYM (Dairy Forage System) model (Rotz et al., 1989), designed to evaluate the long-term performance of different dairy farming systems. This whole farm model covers aspects of crop production, feed use, manure use, harvest and storage and animal performance. It includes a submodel specific to the dairy herd. It has since been updated to allow more detailed analysis of, for example, manure handling (Harringan et al., 1996), feeding systems (Soder and Rotz, 2001) and to include a beef herd submodel (Rotz et al., 2005).

On the other hand are economic optimisation models that include components from biophysical models. Environmental aspects are simply considered activities among various choices for optimisation. This type of approach is limited by its ability to model the agro-ecological processes. At the most basic they optimise farm income and include a component which measures biological or ecological sustainability of the system being modelled. This may be some biological equivalent of the economic accounting equations mentioned above.

More sophisticated versions however, may allow for multiple objectives and include an agro-ecological simulation component (Brown, 2000). Examples include the SOLUS model (Bouman et al., 1999) designed to quantify biophysical and economic trade-offs in regional land use (from field to regional level). It investigates labour use; NPK balances in the soil, the environmental impact of pesticide use and quantifies input and output use among other issues.

In the middle of these two extremes are integrated systems. These are perhaps the most complicated as they attempt to capture the interactions between the biophysical and economic components and so have characteristics of both model types described above. They are designed to capture multiple attributes of the objective function and the trade-offs between them while at the same time capturing the dynamics of biological processes. All of these models are data intensive and compromise is often necessary between level of detail and scale of coverage as environmental and economic systems are often studied at differing scales.

4.2, Linking biophysical and economic models

The common method for integrating economic and biophysical models is to take the outputs of one model component and to use them as the inputs of another (e.g. the output from crop or livestock models may be fed into economic models which in turn are entered into environmental process models). If the data are statistically representative of the land units or population of decision-makers, the results can be aggregated to understand the trade-offs at a certain regional level (Antle and Capalbo, 2001).

Following Antle and Capalbo (2001) there are three main methods for combining economic and biophysical models. The first method utilises representative farm programming models to estimate optimal distribution of resources. For example, Barbier and Bergeron (1998) create a recursive dynamic bioeconomic model investigating natural resource management in Honduras. They combine a linear programming model of smallholder farmers and ranchers (focusing on both crop and livestock production) with the EPIC biophysical model, designed to understand land degradation issues. Kaiser et al. (1993) using a similar approach, use a representative farm model to understand the effects of climate change on Minnesotan agriculture.

Reliance on a representative farm, however, restricts their usefulness, as they cannot take into consideration spatial differences between farms and variation in economic behaviour and environmental situations. A second approach is based upon econometric models explaining observed outcomes. These use reduced-form functions of economic situations and biophysical characteristics of the environmental units. However, because they do not represent the relationship between productivity and the environment, they cannot be linked to biophysical models of crop and livestock production.

The third approach uses econometric methods to estimate production, cost and profit functions. As they can be estimated and simulated using site specific data they can represent spatial variation in the environment and economic data. Biophysical condition can also be explicitly included. However, data availability restricts the degree of spatial and temporal variation this approach can simulate. Discrete choices are also complicated to estimate. An example of such as model is Kaufmann and Snell (1997) who investigate the implications of climate change on corn yields. Antle and Capalbo (2001) also develop a model investigating land use and management decisions linked with biophysical crop growth and environmental processes that does capture continuous decisions.

4.3, Biophysical models

Given the level of sophistication and variety of economic valuation models of genetic traits, it therefore appears a logical step to include biophysical processes within them. Once a decision is made on which economic approach to use for the evaluation of genetic resources, the question remains as to which biophysical model to incorporate? A number of biophysical models are available to the analyst and a short description of a number available over the Internet are presented below:

4.3.1, EPIC (Erosion Productivity Impact Calculator) model[2]

This model was designed by the USDA Agricultural Research Service to assess the effects of field level soil erosion on productivity. It models the effects of management decisions on soil, water, nutrient and pesticide movements, investigating their impact on soil loss, water quality and crop yields. It assumes homogeneous management approaches and soil (although these can be divided into up to ten layers) within the area under investigation.

It contains a number of subcomponents including ones for weather generation, surface runoff, percolation, N and P mineralisation, pesticide fate and transport, crop growth, crop rotations, tillage waste management among others. The data for which can be supplied with the model. It can be run to simulate one to 4000 years and has been used in over 60 different countries.

---

[2] http://www.brc.tamus.edu/epic/

4.3.2, APEX (Agricultural Policy/Environment Extender) model[3]

Developed from the EPIC model, APEX provides a tool for managing whole farms or small watersheds with the objective of maximising production efficiency and maintaining environmental quality. It contains the same subcomponents as the EPIC model, but places greater emphasis on water flows, sediments, nutrients and pesticides.

4.3.3 WOFOST (World Food Studies) model[4]

WOFOST simulates crop growth under specific conditions, based on equations simulating basic plant physiology and soil processes. The driving processes are light and CO2 assimilation, with optimum management practices assumed. Although it is one-dimensional and site specific, it can be applied to regions by aggregating representative points. This model requires site-specific data on soil and crop management. It has been used in a number of different scenarios to estimate crop production for a number of crops from grains to potatoes to sunflowers, indicating yield variability and evaluating the effects of climate change and soil fertility changes.

4.3.4, APSIM (Agricultural Production Systems Simulator)[5]

APSIM was developed as a decision support tool to simulate biophysical processes in farming systems, especially the economic and environmental outcomes of management practices. It contains three main modules: one each for plant, soil and management processes. Includes a number of crops, pastures and trees, and can simulate N and P transformations, soil pH and management controls. It was developed from need to accurately predict crop production in relation to climate change, genotype, soil and management factors and general sustainability.

This model has been used on a number of occasions, reference to a large selection of which can be found at the Agricultural Production Systems Research Unit of the Australian government. An example of note is the use of APSIM in assessing the value of traits of food legumes (Robertson et al., 2000).

---

[3] http://www.brc.tamus.edu/apex/index.html
[4] http://www.wiz.uni-kassel.de/model_db/mdb/wofost.html
[5] http://www.apsru.gov.au/apsru/

4.3.5, DSSAT (Decision Support System for Agrotechnology Transfer)[6]

This is a group of models developed under the framework of IBSNAT-DSSAT (the international benchmark site network for agrotechnology transfer project decision support systems for agrotechnology transfer) whose goal is to standardise model building to enhance suitability for use in any site. Use of these models has been wide spread and an enormous amount of experience exists regarding calibration and data requirements.

DSSAT models can be divided into two main groups: -GRO models and CERES (crop estimation through resource and environment synthesis) type models. –GRO models developed from SOYGRO, a decision support tool for irrigation and pest control. It simulates the yield, growth and development of soybeans as a function of soil, weather and management variables. Since its inception it has been developed and is no longer location-specific or environment-dependent. Has been extensively validated in the US and Europe and can be easily modified for site-specific information. The purpose of CERES models was to generate yield estimates by modelling factors considered relevant to yield determination (e.g. plant growth and development, soil water and nutrient status). Pest and disease infestation not considered.

4.3.6, GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) (Leaonard et al., 1987)

This is a field-scale model that can be used to investigate agricultural management practices on the chemical processes in the root zone of the soil. It contains components investigating hydrology, sediment, pesticides and erosion and has since been modified to include complex climate-soil-management interactions. It has been used on a number of occasions and validated in many regions of the world looking at the impact of management decisions such as planting date, cropping, irrigation, tillage on chemical movement.

---

[6] http://www.icasa.net/dssat/index.html

4.3.7, SWAT (Soil Water Assessment Tool)[7]

Both GLEAMS and EPIC have contributed to the construction of this model. It has been used to predict the impact of land management practices on water, sediment and agricultural chemicals in large complex watershed with varying soils, management condition and land use over long periods. Is a continuous time model and water balance is the driving force. It has been used to model agricultural cropping systems on a number of occasions, although linkages have not been made to livestock systems.

5, Summary

Changing political and natural environments present a clear case for the inclusion of environmental factors and other aspects of societal concern into breeding goal objectives. Calculation of economic values and weights to assist farmers and breeders in understanding the implications of these choices is therefore a necessity. A number of approaches already exist for the calculation of economic weights and values, ranging from econometric estimation to simulation models to non-linear approaches allowing ever more realistic descriptions of the farming system.

Increasingly farm level production models are incorporating biophysical processes, but such linkages are few with models estimating economic values of animal genetic traits. Other more subjective methods are available, such as contingent evaluation and choice experiments, but rigorous theoretical and structural models are few and far between. Existing bioeconomic models are skewed in their approach, however, favouring either the biophysical processes or the economic activities. There is a definite need to construct more integrated approaches that can capture the multiple attributes of the objective function and the necessary trade-offs between them in a dynamic manner.

To date, linkages between economic and biophysical models occur in three formats: first using representative farms, second using reduced-form econometric models and third using econometric estimation of production, cost and profit functions. Only the

---

[7] http://www.brc.tamus.edu/swat/

first and third can be linked to biophysical process models, with the third option presenting the greatest potential.

A number of biophysical methods are available to the analyst and can potentially be incorporated into farm level models. The common method for doing so involves taking the output from the biophysical models and including it in the production function of the economic component. The model components are therefore considered exogenous to each other. To date few biophysical models have been included in livestock models, the exception being EPIC. However, APSIM has been used to value legume genetic resources and so may also be a contender for valuing animal genetic resources.

While the objectives of breeding goals must reflect the interests and needs of the producer, increasingly they must reflect society and address potential changes in future conditions such as more stringent environmental policy and climate change. Breeding goals must therefore take a long-term focus, but make clear what can be achieved via breeding and what must be achieved through other means, such as alternative management approaches. Furthermore, given the variety of objectives among decision-makers and the diversity of production systems it must be recognised that there is no one best solution and economic values should be estimated from a range of models and analytical tools. The outputs must also be presented to stakeholders in such ways as to ensure dialogue. This should achieve greater balance between conflicting interests and objectives, and the development of more sustainable animal breeding programmes and agricultural systems as a whole.

References

Antle, J. M. and Capalbo, S. M. (2001) Econometric-process models for integrated assessment of agricultural production systems. *American Journal of Agricultural Economics.* **83**(2): 389-401.

Barbier, B. and Bergeron, G. (1998) Natural resource management in the hillsides of Honduras: Bioeconomic modeling at the micro-watershed level. EPTD Discussion Paper No. 32. Environment and Production Technology Division, International Food Policy Research Institute, Washington, USA.

Baumung, R., Sölker, J., Gierzinger, E. and William, A. (2001) Ecological total merit index for an Austrian dual purpose cattle breed. The 4th NAHWOA Workshop, Wageningen, 24-27 March 2001.

Bouman, B. A. M., Jansen, H. G. P., Schipper, R. A., Nieuwenhuyse, A., Hegsdijk, H and Bouma, J. (1999) A framework for the integrated biophysical and economic land use analysis at different scales. *Agriculture, Ecosystems and Environment.* **75**(1-2): 55-73.

Brascamp, E. W, Groen, A. F. de Boer, I. J. M. and Udo, H. (1998) The effect of environmental factors on breeding goals. Proceedings of the World Conference on Genetics Applied to Livestock Production, p. 129–135, January 1998, Armidale, Australia.

Brown, D. R. (2000) A review of Bio-economic models. Paper prepared for the Cornell African Food Security and Natural Resource Management (CAFSNRM) Program.

Cardoso, F. F. (2003) The value of hierarchical Bayes models on genetic evaluation of multiple-breed beef cattle populations. Available at: http://www.bifconference.com/bif2003/BIFsymposium_pdfs/BakerEssayCardoso.rtf

Conington, J., Bishop, S. C., Waterhouse, A and Simm, G. (2003) A bioeconomic approach to derive economic values for pasture-based sheep genetic improvement programs. *Journal of Animal Science* **82**: 1290-1304.

Drucker, A. G., Gómez, V. and Anderson, S. (2001) The economic valuation of farm animal genetic resources: a survey of available methods. *Ecological Economics*, **36**: 1-18.

Groen, A. F., Steine, T., Colleau, J. J., Pedersen, J., Pribyl, J. and Reinsch, N. (1997) Economic values in dairy cattle breeding, with special reference to functional traits. Report of an EAAP-working group. *Livestock Production Science*, **49**: 1-21.

Harris, D. L. and Newman, S. (1994) Breeding for profit: Synergism between genetic improvement and livestock production (a review). *Journal of Animal Science* **72**: 2178-2200.

Hazel, L. N. (1943) The genetic basis for constructing selection indexes. *Genetics* **28**: 476-490.

Kaiser, H. M., Riha, S. J., Wilks, D. S., Rossiter, D. G. and Sampath, R. (1993) A farm-level analysis of economic and agronomic impacts of gradual climate warming. *American Journal of Agricultural Economics*. **75**: 387-98.

Kanis, E., de Greef, H. K., Hiemstra, A., and van Arendonk, J. A. M. Breeding for societally important traits in pigs. *Journal of Animal Science* **83**: 948-957.

Kaufmann, R. K. and Snell, S. E. (1997) A biophysical model of corn yield: integrating climatic and social determinants. *American Journal of Agricultural Economics*. **79**: 178-90.

Koots, K. R. and Gibson, J. P. (1997) Economic values for beef production traits from a herd level bioeconomic model. *Canadian Journal of Animal Science*. **78**: 29-45.

Koenen, E. P. C., Berentsen, P. B. M. and Groen, A. F (2000) Economic values of live weight and feed-intake capacity of dairy cattle under Dutch production circumstances. *Livestock Production Science* **66**(3): 235-250.

Leonard, R. A. and Knisel, W. G and Still, D. A. (1987) GLEAMS: Groundwater Loading Effects on Agricultural Management Systems. *Trans American Society of Agricultural Engineering*. **30**(5): 1403-1418.

Mrode, R. A. (1996) Linear models for the prediction of animal breeding values. CAB International.

Neal, M. and Fulkerson, B. (2006) "One size fits all"? – The relationship between the value of genetic traits and the farm system. Murray Darling Program Working Paper: M06#1. The University of Queensland, Australia.

Olesen, I., Groen, A. F. and Gjerde, B. (2000) Definition of animal breeding goals for sustainable production systems. *Journal of Animal Science*. **78**: 570-582.

Plaizer, J. C. B. , King, G. J., Dekkers, J. C. M. and Lissemore, K. (1997) Estimation of economic values of indices for reproductive performance in dairy herds using computer simulation. *Journal of Dairy Science* **80**: 2775–2783.

Richards, T. J. and Jeffrey, S. R. (1996) Establishing indices of genetic merit using hedonic pricing: an application to dairy bulls in Alberta. *Canadian Journal of Agricultural Economics* **44**(3): 251-264.

Robertson, M. J., Carberry, P. S., Wright, G. C. , and Singh, D. P., 2000. Using models to assess the value of traits of food legumes from a cropping systems perspective. Proc. International Food Legumes Conference, Sept 1997, Adelaide, 279-288.

Rotz, C. A., Buckmaster, D. R. and Comerford, J. W. (2005) A beef herd model for simulating feed intake, animal performance, and manure excretion in farm systems. *Journal of Animal Science* **83**: 231-242.

Rotz, C. A., Mertens, D. R., Buckmaster, D. R., Allen, M. S. and Harrison, J. H. (1999) A dairy herd model for use in whole farm simulations. *Journal of Dairy Science*. **82**(12): 2826-2840.

Santarossa, J. M., Stott, A. W., Wooliams, J. A., Brotherstone, S., Wall, E. and Coffee, M. P. (2004) An economic evaluation of long-term sustainability in the dairy sector. *Animal Science* **79**: 315-325.

Scarpa, R. (1999) Revealed preference valuation methods for farm animal genetic material: Principles, strengths and weaknesses. In: Economic valuation of Animal Genetic Resources: Proceedings of an FAO/ILRI Workshop held at FAO Headquarters, Rome, Italy, 15–17 March 1999. Available at: http://dad.fao.org/en/refer/library/reports/valuatn.pdf

Scarpa, R., Drucker, A. G., Anderson, S., Ferreas-Ehuan, N., Gómez, V, Risopatrón, C. R. and Rubio-Leonel, O. (2003a) Valuing genetic resources in peasant economies: the case of 'hairless' creole pigs in Yucatan. *Ecological Economics* **45**: 427-443.

Scarpa, R., Ruto, E. S. K., Kristjanson, P., Radeny, M, Drucker, A. G. and Rege, J. E. O. (2003b) Valuing indigenous cattle breeds in Kenya: an empirical comparison of stated and revealed preference value estimates. *Ecological Economics* **45**: 409-426.

Soder, K. J. and Rotz, C. A. (2001) Economic and environmental impact of four levels of concentrate supplementation in grazing dairy herds. *Journal of Dairy Science* **84**: 2560-2572.

Steverink, M. H. A., Groen, A. F. and Berensten (1994) The influence of environmental policies for dairy farms on dairy cattle breeding goals. Livestock Production Science **40**(3): 251-261.

Stott, AW (1994) The economic advantage of longevity in the dairy cow. Journal of Agricultural Economics. **45**, 113-122.

Stott, A.W., Coffey, M.P. and Brotherstone,S. (2005) Including lameness and mastitis in a profit index for dairy cattle. Animal Science **80**, 41-52.

Stott, A.W., Lloyd, J., Humphry, RW and Gunn, G.J., (2003) A linear programming approach to estimate the economic impact of bovine viral diarrhoea (BVD) at the whole-farm level in Scotland. Preventive Veterinary Medicine, **59**, 51-66.

Swinton, S. M. and Black, J, B. (2000) Modeling Agricultural Systems. Staff paper, Department of Agricultural Economics, Michigan State University.

Tozer, P. R. and Stokes, J. R (2001) Using multiple objective programming in a dairy cow breeding program. *Journal of Dairy Science*. **84**: 2782-2788.

Van Tassel, C. P., van Vleck, L. D. and Gregory, K. E. (1998) Bayesian analysis of twinning and ovulation rates using a multiple-trait threshold model and Gibbs sampling. *Journal of Animal Science* **76**: 2048-2061.

Vargas, B., Herrero, M. and van Arendonk, J. A. M. (2001) Interactions between optimal replacement policies and feeding strategies in dairy herds. *Livestock Production Science* **69**: 17–31.

Veerkamp, RF, Hill, WG, Stott, AW, Brotherstone, S. and Simm, G. (1995) Selection for Longevity and Yield in Dairy Cows Using Transmitting Abilities for Type and Yield. Animal Science, **61**, 189-198.

Walsh and Lynch (2000) Theory of Index Selection. Available at: http://nitro.biosci.arizona.edu/Nordicpdf/WLChapter23.pdf

Wolfová, M., Wolf, J., Pribyl, J., Zahradkova, R. and Kica, J. (2005) Breeding objectives for beef cattle used in different production systems: 1. Model development. *Livestock Production Science* **95**: 201–215.

Weigel, K. A. and Rekaya, R. (2000) A multiple-trait herd cluster model for international dairy sire evaluation. *Journal of Dairy Science* **83**: 815-821.