
THE PROCEEDINGS OF THE
NEW ZEALAND SOCIETY
OF
ANIMAL PRODUCTION
VOLUME 62 2002

The role of systems research in animal science

D.G. McCALL, G.W. SHEATH, A.B. PLEASANTS

AgResearch; Whatawhata Research Centre, Private Bag 3089 Hamilton, New Zealand.

ABSTRACT

This paper presents challenges to the way we conduct experimentation in animal science. The theme of the paper is to show the benefits of using systems research methods in both our basic and applied animal science. The need for more accurate prediction of biological processes to achieve future breakthroughs in animal production is postulated. The use of systems research using dynamical systems models in our basic science to better understand and predict the outcome of complex biological processes is discussed. In the applied science context, difficulties in translating basic (component) research results into recommendations for improved farm performance are emphasised. Equally, difficulties in designing interpretable farm system experiments are acknowledged. Finally, examples are given of the benefits of using whole farm models to integrate component results and create a link between component research and improved farm system, field, experimental approaches.

Keywords: modelling; dynamical; basic; applied; experimental design; farm.

INTRODUCTION

This is a review article which is designed to bring to the attention of animal scientists many points that are well known in systems research. It considers the way we conduct experimentation in animal science and questions the way we develop technologies for use on farms.

Most animal technologies developed in New Zealand are designed to be implemented on farms. Within this context a specific technology may be aimed at meeting diverse goals such as increased production, enhanced farmer lifestyle, minimal environmental impact, or more highly specified animal product. This broad context means that specific animal technologies may interact with a wide range of components in both the biological and socio-economic environment. For example, animal technologies interact with the needs of both the pasture and the farmer.

The farmer deals with a system which is much broader than that commonly viewed by technology developers. In particular, issues such as the economic implications from taking on new technology are important (Robinson, 1974). This is clearly evident in New Zealand where historical gains in animal production have been closely linked to subsidies which reduced the financial risk of intensification (McCall and Sheath, 1993). The question then is: how best should animal scientists conduct their experimentation in order to develop technology which meet farmer needs?

Research to establish farmers' needs in relation to technology development (eg McRae, 1993) is an important first step, but is addressed by other papers in this contract. While acknowledging that in many cases appropriate animal science processes should flow from social research knowledge, we make observations on the role of other system research methods based on experience in developing technology for farmer use.

Various definitions exist for experimental approaches in animal science. Within the categories of basic and applied research we view applied animal science as ultimately dealing with problems at the whole farm level. Underpinning the applied science is a number of levels of basic science where a mechanistic understanding of the biological processes of a farming system are sought. The benefits of systems research tools in both basic and applied research provides the theme of this paper.

We will discuss two sets of systems tools. The first is the use of mathematical modelling in understanding biological mechanisms at the basic levels. The second is the use of farm system models and field experimentation to create an information link between component research and the knowledge and confidence needed to implement a technology on farm.

Basic Animal Science

Functional levels of basic science

It is helpful at the outset to further define what we mean by basic animal research. Basic research occurs at a number of levels. Currently there is a large emphasis on achieving major physiological breakthroughs in production from improved animals (Fennessy 1990). Targets include susceptibility to disease, limits to reproduction rate, partitioning of food to lean tissue growth and efficiency of nutrient use. At one end of the scale, approaches to these objectives include transgenic animals. At the other end, genetic markers and direct intervention technologies such as ovulation enhancers are sought.

A second emphasis in animal science is to pursue farm goals through better management of the compromises between plant and animal requirements. This is the approach that has been followed in developing improved grazing systems. The same approach will be required for answering sustainability questions.

The major difference in research required between the two approaches is the functional level at which understanding is required. In the former, manipulation of animal physiology obviously requires basic research at the physiological level. In the latter, basic research is required at the ecological level, that is, at the level of the animal's response to quantity and quality of available feed in relation to it's physiological state and behaviourial characteristics. At both levels, basic research seeks an understanding of how the individual components work and how they fit together and influence each other. The complexity of interrelationships between components does not necessarily increase or decrease between levels. Each natural level of organisation has it's special characteristics whose complexity demands that they be understood at that level (Seligman 1993). The appropriate functional level for study (chemical, physiological, ecological, socio-economic) depends on the purpose for which understanding is required.

Systems research tools in basic animal science

Systems research tools help the researcher understand how the individual components fit together and influence each other. Component experiments contribute to the understanding required to improve system behaviour by providing information about relationships between biological processes, whether we are concerned with the reproduction system, the individual animal or the grazing system. However, a concern with the component approach relates to it's reductionist nature. By removing confusing feedbacks to understand how a component behaves in isolation, we miss out on knowing the consequences of changes to the component when it is part of a system where feedbacks operate.

A systems research tool that can be of considerable assistance to basic animal scientists is called 'dynamical systems modelling'. Mathematical modelling that uses a dynamical systems approach (sets of differential or difference equations) provides a useful mind-set for component biologists (Wake 1992). It offers component research the means to develop a systems understanding of the behaviour of biological processes (Wake 1992).

To illustrate the dynamical systems modelling approach, let us consider the following. Assume we want to know the level of progesterone in the female blood stream at various stages of the oestrous cycle in order to manipulate the timing of ovulation. A dynamical systems approach would seek to describe the major variables affecting the rate of release of progesterone into the blood and those damping the release rate. These would be described as a series of differential equations. The amount of progesterone in the blood at any time during the oestrous cycle would be calculated by solving the differential equations. This contrasts with the approach of taking experimental snapshots of the amount of progesterone in the blood and piecing together a description of the amount of cycling progesterone from amounts actually measured.

Obviously not all animal science technologies require the use of dynamical systems modelling for their development. Certainly not in the initial descriptive stages of an investigation, nor where there are limited interactions that affect outputs. For example, important reproductiion technologies such as the CIDR and understanding the best time for artificial insemination have been developed without the need for a dynamical systems model of the hormone events controlling oestrus and ovulation. Development of these technologies has been possible because the female reproductive system responds usefully to manipulation at a coarse level.

The benefit of mathematical modelling is not dependant on the level (eg physiological, ecological) at which the basic studies occur. It really depends on the accuracy of prediction of a process required and the complexity of the process. The level of accuracy required will depend on the particular problem to be solved or the biological purpose to be achieved. Complexity chiefly depends on the number and the importance of interactions and feedbacks on the component's behaviour, plus the degree of non-linearity in relationships between variables.

In complex systems, accurate solutions may only be obtained by taking into account non-linearities and complex feedbacks that occur between components. Hence there is a greater need for a dynamical systems modelling approach if accurate solutions are to be achieved. This will certainly be the case in studying sustainability issues where understanding the evolution of a system through time is important. Equally it may be necessary to go to this level of predictive accuracy in reproduction research as the technologies involved in manipulating female reproduction become more ambitious, for example through seeking a greater level of efficiency.

The three main steps in dynamical systems modelling are formulation, solution and interpretation of the model (Wake 1992). Formulation requires a clear statement of the behaviour of components in relation to inputs and feedbacks on the components. This process, done in conjunction with a mathematician, is the acid test on the degree of understanding of the biological process. It can be enlightening and useful in itself for focusing thoughts on the experimental data needed to develop workable theories (Ulyatt *et al.*,1976). The solution of dynamical system models is the province of the mathematicians. Interpretation of the model yields the interesting results which advance understanding about the behaviour of each component in the system. In experimenting with the model we gain confidence in our mechanistic understanding of the biology by seeing patterns emerge which we know exist in nature. For example, we can explain variation in body composition due to seasonal hormone levels (J.M. Thompson unpub) which otherwise may be ignored as unexplainable.

Applied Whole Farm Research

Extrapolation from Component Studies

In addressing the issue of applied whole farm research one might ask: why not simply conduct the relevant basic (component) research and extrapolate results to the whole farm system? Success has been achieved by contemporary animal science in understanding many phenomena by studying the components of a farm system in isolation. Examples are the successes in developing animal health technologies. However, results from component research often do not readily translate into improved whole farm performance. This again, is because we miss out on knowing the consequences of changes to the components when they are part of a whole farm system where feedbacks operate.

Exaggerated claims of potential gains in system performance arise when results from component studies are extrapolated directly into whole farm recommendations (Sheath and Bryant 1984). If all the 5 and 10% gains in production identified by component research were additive, pastoral production could probably be shown to be at least 100% greater than currently achieved. Both, Brougham (1973) and Hight (1979) noted that theoretical gains in farm system performance calculated by aggregating increased forage supply, animal number and animal performance opportunities fell well short of observed farm performance.

Let us consider component experiments designed to understand the interactions between the animal and it's feed. While these experiments may be well controlled and interpretable, they often involve artificially large differences in the experimental variable compared to that which is actually possible in the real system. For example, in dairy systems, significant production advantages may occur from high levels of pasture offered to cows in spring (eg Bryant 1980), but within a system it may not be feasible to supply these amounts of feed owing to pressures of winter stocking rate. Alternatively, interactions not considered in the component experiment, such as the future quality of pasture, are not taken into account. Another example is the over-estimation of pasture production responses due to grazing strategy. For instance, Bryant (1990) showed large differences in grazing strategy have little affect on annual milk production within a dairy system. Where pasture species with special grazing needs are being investigated, constraints from other parts of the system often mean these grazing needs can not be met and therefore potential advantages are not achieved (eg Webby *et al.*, 1990). The degree of response from altering one factor within a grazing system will depend on what feedbacks are operating and hence how quickly another factor limits production.

Difficulties in extrapolating from component grazing experiments usually arise because of the short time frame of the experiments, or because carryover effects are not part of the design. The conservative behaviour of systems, where many aspects are controlled by negative feedbacks, is the reason that ideas for system improvement need to be tested in systems studies. Negative feedbacks which occur in grazing systems through factors such as future pasture quantity and quality are the reason that marginal responses in one period are often counterbalanced by depressions in others. Another example is the buffering of milk production from cow body condition. This may be used to advantage for short term production responses but commands its price when being replenished. In the extreme, outcomes evaluated over the long term may not be sensitive to within-system manipulation of grazing, or the timing of supplementary feeding (Seligman, 1993).

Much recent interest has focused on physiological interventions to the animal in order to achieve major advances towards the goals of greater quality and diversity of product (Fennessy 1990). A concern arises here where justification for these opportunities is based on whole system benefits reasoned from a component perspective: a point noted by Fennessy 1990). For example, benefits of yearling heifer mating argued from a component perspective (Morris 1982) were found to be much less when analysed in a system context (McMillan and McCall 1991). The issue of component research focus was also raised by Robinson (1990) when he questioned whether the targets we are setting for the performance of our ruminant species are reasonable within a system context. For example, we are able to achieve litter sizes in sheep which create nutrient demands in excess of what can be supplied in pastoral conditions (Robinson 1990).

The important point to emerge is that component studies in animal production need to be planned with the real system in mind. Ideally, hypotheses about which genetic limitations represent the largest constraint to animal production systems need testing before an extensive genetic programme is embarked upon. This is most important where the expected solution interacts with feed supply. Links between component research and farm system research is needed to align the focus of component research within proven constraints in farm production systems.

Use of models in farm systems research

Farm system models can create a vital link between component and field system research in two ways. The first is in helping determine the priority foci of component research by determining the importance of various constraints on farm performance. The second is in integrating component results to develop improved farming systems.

With farm models the level of resolution is coarser than for dynamical system models because of the wide range of components impinging on the management of grassland systems. Further, precise dynamics of individual biological components may not be the most relevant aspects of farm management. The goal of producing a mechanistic model at the farm level is unrealistic because the sheer complexity of such a large model would make it as difficult to interpret as the real system. Thus, farm models often reach the stage where they use quite empirical representations of pasture dynamics, crop growth or animal nutrient partitioning. Where farm models incorporate factors as diverse as crops and labour, they are often based on linear relationships and rely on constraints to maintain the state of pasture and crops within certain bounds.

However, farm models can yield useful insight into farm behaviour. In particular, the ability to calculate optimal solutions using techniques such as linear programming can be a major benefit from using these models. Optimal solutions help the experimenter understand the sensitivity of the system to various inputs when the system is optimised to best accommodate the input. They also help to define targets for improving farm performance.

Perhaps the most important role of farm models is to integrate component research for use in developing improved farming systems. In this role they can signal likely inputs required to sustain an animal production system and provide decision rule guidelines for the management of field research to verify model predictions.

The approach described above is being used to guide the development of dairy systems in New Zealand (D.A. Clark and D.G. McCall pers comm). Current research interests centre on methods to most economically achieve large increases in production (eg 1750 kg milk solids per hectare) by removing feed constraints in seasonal dairying (Bryant 1993a). It is implicit that pasture grazing will underpin the system. A linear programming model of a seasonal supply dairy farm is being used. In this study, constraints are based on pre and post-grazing mass guidelines for optimal pasture performance. Constraints were derived independently of the model. The model is being used to create system input/output relationships for a range of supplement options such as Nitrogen fertiliser, meal or crops while maintaining the pasture management decision rules. These input/output relationships will be used to guide the design of improved dairy systems through field experimentation. Through sensitivity analysis, the model is also being used to focus on pasture and crop types which might most readily alleviate feed constraints if yields could be increased.

Because models are abstractions of the real system and their use often involves extrapolation and speculation there is no substitute for testing model predictions in the real system. In the case of empirical farm models, complete validation is an unrealistic goal because the system is too large. Rather the model should be viewed as a tool to provide useful insights into ways of better operating a farm system and into defining major animal constraints that are impeding achievement of system goals. These models can not include all factors operating in the real system. For example, effects of grazing animals on soil compaction over time and subsequent feedbacks on pasture production may be missing from a farm model. Hence these models in no way substitute for field experimentation. Field system experiments are required to refine input/output relationships for analysis of economic or environmental impact and for testing hypotheses about benefits of ameliorating animal constraints (eg reproduction rate). They also give researchers' confidence that a technology is relevant and effective within a farm context. The model's role is to help in the design of field systems experiments.

Farm systems experimentation

In the past New Zealand science has benefited from a systems approach to the development of animal production systems. The systems orientation started with the work of McMeekan (1956) and McMeekan and Walshe (1963) who studied dairy systems using self contained farmlets. The success of McMeekan's approach ensured field system experimentation has continued in dairy science (eg Bryant 1990) and in sheep and beef system development (eg Rattray *et al.*, 1978, Clark *et al.*, 1986, Webby *et al.*, 1990). However, questions have recently been asked about the effectiveness of the continued use of farm systems research for advancing animal production. Systems experimentation is viewed as only contributing to small improvements in animal production through better system organisation at the farm level . Major advances in animal production efficiency, product type and health are commonly viewed to require methods which directly manipulate animal physiology (Fennessy 1990). The need for system experiments to answer farmer's questions about economic, environmental and sociological consequences of these new technologies seems to have been lost.

Views about the relevance of farm systems research methods have not been helped by a lack of rigour in the design of some recent science programmes using so-called systems research methods (Science Review 1992). Field systems research, in particular, is very resource demanding and both a testable hypothesis and rigorous guidelines for controlling confounding of variables in the experimental system are required to obtain data which are interpretable.

Secondly, systems research require system hypotheses. Major problems occur where mixed objectives exist. Many animal production trials which are run under 'farm' conditions (eg breed comparisons, shearing strategies) fall into this category. This research often falls in a hole between component and system research, though it is often labelled as systems research. Under these conditions, criticisms that systems researchers are simply 'playing farmers' are justified. The challenge is to improve our systems research methods.

To illustrate interpretation problems, take a simple example of research designed to look at the benefits of improved lambing rate using Androvax™. A component level trial would show the advantage of extra lambs born per ewe lambing for Androvax™ treated ewes. Advancing this knowledge to a systems experiment, where treated and untreated ewes are compared at the same stocking rate, can add confusion. Androvax™ treated systems may have reduced spring pasture covers due to increased feed demand. However, summer feed quality may be better, and lamb liveweight gains greater. The weight of ewes may be less and will lead to a flow on effect of Androvax™ treatment into the next production season. Hence, final results are a measure of animal output where competing processes are integrated. They are difficult to interpret, or extrapolate to other environmental conditions.

The logical structure for a good field systems experiment is the same as for a component experiment. A testable hypothesis is required about the output of interest in response to inputs to the system. The fact that systems experiments can be difficult to execute, owing to difficulties controlling other aspects of the system, does not mean that these principles can be waived. An additional consideration with whole farm systems experiments is the importance of designing them to permit economic analysis.

An important advance in the way grazing system research is conducted is outlined by Sibbald and Maxwell (1990). They highlight the use of decision rules derived from component research to control variables in a grazing systems trial. They have used rules to control individual animal performance and pasture production and quality by controlling sward conditions on the grazed area. Sward height or pasture cover decision rules are designed to maximise the consumption by animals throughout the grazing season on all treatments by ensuring the optimum treatment of pasture. This aids interpretation of results. In our example, differences between treatments due to inputs of Androvax™ (lambing percentage), are reflected in amounts of surplus pasture released for conservation and amounts of supplementary feed required to sustain pasture cover at levels determined by the decision rules. System sustainability depends on it's ability to provide additional supplementary feed. Importantly, such designs also provide data for economic analysis. The cost of additional supplementary feed for ewes can be balanced against the extra lamb production.

The above approach gets away from the difficulties of interpreting experiments where stocking rate interacts with pasture condition causing animal performance to vary seasonally between treatments. It also allows testing of hypotheses about benefits from improved animal genotypes in farm systems.

Finally, the principle of using decision rules to control systems trials still applies where options such as conservation and supplementary feeding do not exist. For example, consider a situation where the option is to retire surplus pasture for *in situ* grazing. The output in this case will be variable animal performance dependant on the amount of surplus pasture to be removed. The important point in this type of system trial is to ensure both systems reach common pasture conditions by the time final animal output comparisons are made (Sheath and Bryant 1984). This ensures all responses are captured in an animal output and is a prerequisite for simple economic comparisons.

CONCLUSIONS

Animal scientists need to strive to ensure they are using scientific methods which have the greatest chance of producing effective technology for their clients. Often scientific progress proceeds by the development of new techniques which allow more insight into previously difficult problems. Recent advances in systems research methods provide such an opportunity. Developments in application of differential calculus offer biologists the same tools as physicists for gaining a mechanistic understanding of the component processes of their systems. The non-linear nature of biological systems will mean the road ahead will not be easy, but the foundation is laid for cooperation between biologists and mathematicians in tackling these problems.

Farm system models provide a platform for interaction between component and applied farm system researchers. Developing links between component and systems research by using whole farm models to integrate knowledge should allow a clearer focus to be maintained in the design of field system experiments. Three clear purposes exist for field systems research. The first is in quantifying system input/output relationships to allow economic analyses. Secondly, they give applied researchers' confidence that a technology is effective within the context of a farm where feedbacks may be operating to modify a technology's influence. Finally there is the testing of hypotheses about factors constraining system performance. The latter is an area which has received scant focus in New Zealand. The importance of perceived constraints has so often not been tested prior to component research.

REFERENCES

Brougham, R.W. 1973. Pasture management and production. *Proceedings of the Ruakura Farmers Conference* **25:** 169-184.

Bryant, A.M. 1980. Effect of herbage allowance on dairy cow performance. *Proceedings of the New Zealand Society of Animal Production* **40:** 50-58.

Bryant, A.M. 1990. Optimum stocking and feed management practices. *Proceedings of the Ruakura Farmers Conference* **42:** 13-17.

Bryant, A.M. 1993a. Systems for high milk solids production. Research update, New Zealand Dairy Research Corporation. December 1993 p 3.

Bryant, A.M. 1993b. Lifting our production targets. *Proceedings of the Ruakura Farmers Conference* **45:** 6-11.

Clark, D.A..; Lambert, M.G.; Grant, D.A.. 1986. Influence of fertiliser and grazing management on North Island 5. Animal production. *New Zealand Journal of Agricultural Research* **29:** 407-420.

Fennessey, P.F. 1990. Animal production in the future - a New Zealand response. *Proceedings of the New Zealand Society of Animal Production* **50:** 361-371.

Hight, G.K. 1979. Hill country. A major agricultural resource and its capacity for increased production. *Proceedings of the New Zealand Society of Animal Production* **39:** 1-12.

Maxwell, T.J.; Sibbald, A.R.; Jones, J.R.; James, E. 1986. The effects of stocking rate, nitrogen use, lamb:ewe ratio and ewe genotype on output of ewe and output per hectare. In: Efficient sheep production from grass. Occasional Symposium No 21, British grassland Society. p. 121-123.

McCall, D.G.; Sheath, G.W. 1993. Development of intensive grassland systems: from science to practice. *Proceedings of the XVII International Grassland Congress:* in press.

McMeekan, C.P. 1956. Grazing management and animal production. *Proceedings of the VII International Grassland Congress*: 146-156.

McMeekan, C.P.; Walshe, M.J. 1963. The inter-relationships of grazing method and stocking rate in the efficiency of pasture utilisation by dairy cattle. *Journal of Agricultural Science* **61:** 147-166.

McMillan, W.H.; McCall D.G. 1991. Are yearling heifer mating and more productive beef cow breeds a worthwhile use of winter feed. *Proceedings of the New Zealand Society of Animal Production* **51:** 265-269.

McRae, A.F. 1993. As applied agricultural scientists we serve...? *Proceedings of the New Zealand Society of Animal Production* **53:** 107-110.

Morris, C.A. 1982. More beef by using more productive cows and yearling-heifer mating. *Proceedings of the Ruakura Farmers Conference* **34:** 15-19.

Rattray, P.V.; Jagusch, K.T.; Clarke, J.N.; MacLean, K.S. 1978. Romneys, Coopworths and Perendales - optimum feeding levels compare. *Proceedings of the Ruakura Farmers Conference* **30:** FPP 164.

Robinson, T.J. 1974. The present status of applied reproductive physiology in animal production. *Proceedings of the New Zealand Society of Animal Production* **34:** 37-44.

Robinson, J.J. 1990. The pastoral animal industries in the 21st century. *Proceedings of the New Zealand Society of Animal Production* **50:** 345-359.

Science Review No. 8 1992. A review of science in New Zealand. Forage research. Ministry of Research, Science and Technology. 69pp.

Seligman, N.G. 1993. Modelling as a tool for grassland science progress. *Proceedings of the XVII International Grassland Congress:* (in press).

Sheath, G.W.; Bryant, A.M. 1984. Integrating the components of pastoral production: What have we learnt from grazing management experiments. *New Zealand Agricultural Science* **18:** 147-156.

Sibbald, A.R.; Maxwell, T.J. 1990. Contrasting approaches to systems research for sheep production in the hills and uplands of the United Kingdom in; Commission of the European Communities; Proceedings of livestock systems symposium, Toulouse, France, July 1990.

Ulyatt, M.J.; Baldwin, R.L.; Koong, L.J. 1976. The basis of nutritive value - A modelling approach. *Proceedings of the New Zealand Society of Animal Production* **36:** 140-149.

Wake, G.C. 1992. The symbiosis of mathematics and biology. *New Zealand Journal of Ecology.* **16(1):** 1-3.

Webby, R.W.; Sheath, G.W.; Boom, C.J. 1990. Performance of new pasture cultivars in a hill country finishing system. *Proceedings of the New Zealand Grassland Association* **51:** 151-156.