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AN INTRODUCTION TO THE USE OF SIMULATION IN THE STUDY OF GRAZING MANAGEMENT PROBLEMS

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SUMMARY

This paper presents an introduction to the use of simulation as a research technique. An example of its application to agriculture is given in the study of grazing management problems.

The idea of simulation is first clarified by reference to two examples. The concept of a Monte Carlo simulation is then introduced. Grazing management is analysed into its most fundamental form and round this a basic Monte Carlo simulation model is built. The principles of its operation are introduced and explained. An expanded model is then put forward and the place of electronic computers in association with this is noted. Consideration is given to the advantages and limitations of a simulation approach to grazing management. Conclusions are then drawn.

SIMULATION

AS SIMULATION is not a word with which we are normally familiar, consideration will first be given to an explanation of this term.

It is probable that most readers will be aware of the game of Monopoly. This game centres on a board which has a series of properties, each bearing the name of a prominent place or street in London, set out around its perimeter. Play proceeds according to the fall of two dice. Properties are bought and sold, rents are paid, fines levied, and houses built. In fact a miniature business situation is envisaged, and, guided by the fall of the dice, business proceeds. This miniature representation or parallel of real life is termed a simulation.

The second example of a simulation is a well-known one: the field experiment. Here a suitable example is the fertilizer trial. In this, a small area is marked out, fertilizer applied, and in due course the result observed. The small area studied represents a larger area such as a complete soil type. The experiment is thus a small-scale parallel of the larger real-life situation and is also an example of a simulation.

From these examples it can be seen that a simulation may be defined as: "Any process or activity which parallels an actual situation without achieving reality itself". Thus a simulation has no set form or shape in which it must necessarily appear. Rather it takes a form which most adequately represents the object or activity being simulated.

Monte Carlo Simulation

When Monopoly was considered as an example of simulation, it was noted that play was governed by the fall of two dice. If these dice are considered fair, it can be said that a random element is thereby introduced into the game. This leads to the recognition of a particular type of simulation, that involving random elements. Any simulation which contains one or more random elements such as those introduced by the dice in Monopoly, is termed a "Monte Carlo Simulation".*

THE SIMULATION OF GRAZING MANAGEMENT

Once the ideas of simulation and Monte Carlo simulation have been established, consideration can be given to the application of these to grazing management.

Grazing management involves making decisions about equating pasture feed supplies to livestock carried. Both short-term, day-to-day, and longer-term seasonal considerations are involved. One item of information which farm managers would like to have when making these decisions is some estimate of how well any series of decisions will work out in the long run, that is, over a whole season. The farmer is, in fact, anxious to evaluate his short-term, day-to-day grazing management decisions in terms of the outcome taken over a whole year. Simulation appears to have some place as an aid to evaluating this problem.

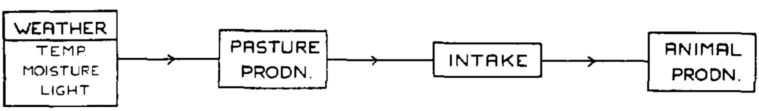

Fig. 1: Basic simulation programme.

When a grazing management programme is studied closely, an underlying pattern or sequence of activities is apparent. The essential features of this pattern are illustrated in Fig. 1. The weather, indicated by the three more important indexes, temperature, moisture and light, in-

* The term Monte Carlo in this context was originally derived from the association of Monte Carlo city, with the random outcomes of the many gambling games for which that city is renowned.

fluences pasture production. Pasture is eaten by grazing animals and from this an animal product is produced.* This sequence provides a basis on which a simple Monte Carlo simulation can be built.

A BASIC MONTE CARLO SIMULATION

Basically a Monte Carlo simulation of grazing management involves the setting up and the operation of a sequence of the type in Fig. 1, on paper. The sequence of events, weather to pasture growth to intake and production, is set down exactly as in Fig. 1. Values of these four parameters appropriate to the system under study are collected. By means of mathematical equations and logical rules of procedure, the links between these phases are defined. Insertion of specific values for each of the parameters in the sequence then allows estimates of output to be made.

The process of selecting specific values for insertion in the simulation can be done in one of two ways. If the value which a parameter takes is known with certainty, this value can be inserted directly. If, however, the parameter can take one of a range of possible values, then a more elaborate selection process is required.

The range of values which might occur in reality is first defined. A frequency distribution for this is then drawn up.

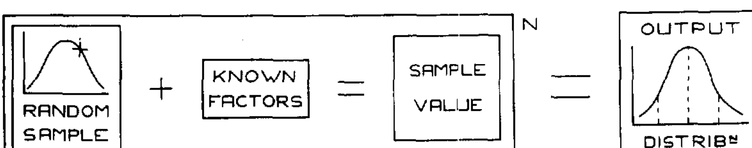

Fig. 2: Simulation process.

From this a random (Monte Carlo) sample is drawn, using a random selection process.

An example of a variable requiring this second type of selection for simulation is temperature. It may, for instance, be observed that temperatures for the month of February range from 65°F to 90°F in a frequency distribution similar to that illustrated on the left of Fig. 2. For simulation purposes, only one value from this range is required. Accordingly a random sample is taken. This value

* It must be emphasized that Fig. 1 is a greatly simplified representation of the grazing management situation. The writer is only too well aware of the complexity associated with grazing management studies but finds this simplification helpful for the explanation and understanding of a grazing management simulation.

is then used along with the "known factors", factors which can be specified with certainty, to calculate output. This process is represented by the left-hand side of Fig. 2.

Now, as the random sample value used for temperature in these calculations was only one of a range of possible values, the output value calculated from using this value in the simulation cannot be considered representative. In order to achieve a representative estimate of output, the process of random selection and calculation must be repeated a large number of times. This part of the process is represented by N outside the left-hand side section of Fig. 2.

The result of this iterative process is a range of output values which, together with a record of their frequency of occurrence, can be arranged in the form of an output distribution. This is shown on the right of Fig. 2.

From a study of this final distribution, its mean and variance, conclusions may be drawn about the production and stability of a management system.

Information to aid in farm management decision-making comes from comparison of two or more plans evaluated in this way. Study of the mean values of the distributions indicates which plan gives the higher overall yield, while study of the variances of the distribution will indicate which of the plans is more stable.

Expanded Model

Expansion of the basic model to more realistic proportions is only a question of increasing the number of variables and sequences of the type in Fig. 1. Each new variable may be included in Monte Carlo fashion, if this is desirable,

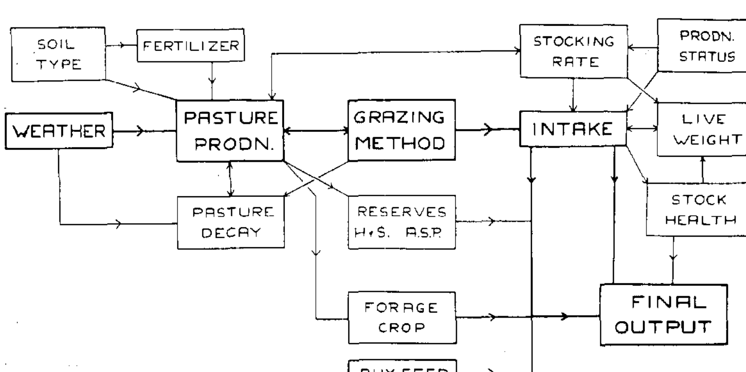

Fig. 3: Expanded simulation programme.

or it may be made subject to certain set rules of operation, if this is more appropriate.

Obviously a complete simulation programme for grazing management is a very complex thing. This will readily be appreciated from a glance at Fig. 3. This endeavours to present a more complete picture of the number of factors and interactions involved in grazing management. Evaluation and operation of a simulation of this size presents certain problems, but basically the method is the same as that described; programming the set rules and random sampling the processes not known with certainty.

With a large model like this, computation becomes a prominent feature of the simulation. Many calculations have to be made, and many random samples taken. For this reason there is little point in starting on a large-scale simulation unless electronic calculating equipment is available. However, now that this equipment is becoming increasingly available in New Zealand, this phase of simulation presents little problem. On the contrary, in fact, with this facility available several advantages accrue to simulation as a research method.

An obvious advantage is that simulation on this scale now becomes possible. Prior to this the thought of having to run a simulation on a desk calculator has been more than sufficient to preclude further work on the subject. Now, with machines that operate at the rate of thousands of calculations per minute, large-scale simulations are clearly possible.

The speed of operation of modern electronic computers also means that a great many seasons can be simulated in a very short time. When it is considered that a large computer can simulate 500 growing seasons in a matter of hours, and this is compared with the twelve months taken to conduct a field experiment on grazing management, the value of a fully representative grazing management simulation is seen. The field trial yields only one set of results applicable to only one season, whereas the simulation takes into account a wide range and a large number of seasons.

ADVANTAGES

Apart from the advantages in computation, there are also a number of other advantages in a simulation approach to grazing management. These may be divided into two groups, namely:

(1) Contributions to our thinking and understanding of the grazing management problem;
(2) Advantages in the method itself and the way it approaches problems.

1: Contributions to our Thinking and Understanding of a Problem

(a) In formulating a simulation model, a pattern of actions and interactions, as illustrated in Fig. 3, is set up. This helps to clarify our ideas about grazing management and how it works.
(b) In endeavouring to operate a simulation, a data problem is frequently encountered. Questions such as "Do we have the information we require?" "Do we have enough information?" arise. These pinpoint gaps in our knowledge and also indicate possible lines for research.
(c) Once a simulation is operating, it gives a display of how a management plan operates. From this, ideas on which variables are important and which are not, can be discerned.
(d) Finally, the simulation presents a representative answer; a distribution of output values as in Fig. 2. Mean values are used to provide information on the relative outputs of different plans and variance estimates indicate the stability of the different plans. A range of information rather than a single answer is provided.

2: Advantages in the Simulation Method Itself

(a) First, the method treats the problem in its entirety. More is considered than just the pasture growth or just the animal intake. The entire process is studied from start to finish. In this way all variables are considered simultaneously and the chances of any important interactions between factors being omitted are reduced.
(b) The method provides for the incorporation of variables which cannot be specified with certainty. These are the Monte Carlo variables. Weather, one of the most important influences in grazing management, falls into this category and its incorporation in a simulation has been illustrated. Similarly, the intake of feed, for a given pasture availability, can be treated as a statistical variable using some variance based on current measurements in physical experiments.

(c) Thirdly, simulation is a method which proceeds step by step, providing a logical development from beginning to end. With a model of this type only a minimum of idealization is necessary to enable the model to be used. By this it is meant that the number of corners which have to be cut off the real problem, the number of things which have to be overlooked and neglected in order to use the model, is a minimum.

(d) The step-by-step procedure is a logical one which lends itself to the incorporation of logical decisions. It may, for example, be desirable to include a decision relating to the closing of an area for hay in the simulation. This can be done by including a simple question such as "Is there an excess of pasture building up?" A fork is built into the simulation process and one or other branch is followed according to the answer to the question. Results reflect the decision at this point.

(e) Time is another factor which simulation is set up to handle. Time intervals, such as pasture recovery time, production lag, and lactation lengths, are important in grazing management. Simulation offers scope to incorporate these factors too. Time periods, such as a fortnight or a month, can be specified and simulation of these intervals can proceed with or without reference to other time periods. Timing of events can thus be taken into account.

From these points it will be readily seen that simulation offers considerable scope for grazing management investigations. However, as with other research methods, simulation, too, has its limitations.

LIMITATIONS

The first of these limitations is that of model accuracy. Although every simulation is formulated to represent reality as closely as possible, there is a risk that the model drawn up does not represent the real situation as accurately as it should. There are no formal tests for model adequacy, though, of course, the assumptions underlying a simulated management system which gave 600 lb of butterfat per acre as the average outcome, would naturally be very carefully examined. Only improved knowledge of the real system will ameliorate this condition. It is, therefore, important to realize that a simulation is only our best representation of reality, a guide to our thinking — not reality itself.

Secondly, there is a lack of theoretical background on several statistical problems. This is concerned mainly with methods of generating random numbers, the merits of pseudo random numbers and variance reduction. These problems need not be discussed further in this paper, but it is as well to be aware of problems in this sphere of simulation.

Thirdly, simulation must be clearly identified as an enumerative method. It studies a problem by putting figures into a model and seeing what happens. It is essentially a cut-and-try procedure. The use of any such method is inefficient research, if a more sophisticated method of study is available. Therefore, if an alternative analytical method becomes available for studying part or all of our grazing management problems, it should be used.

The fourth limitation is that of data. It will be appreciated that the operation of a simulation of grazing management requires much factual information. Already a considerable quantity of data relating to the basic components of grazing management — weather, pasture production, intake and output — has been accumulated. The question, however, is: "Is what we have enough?" Present study has not yet provided any definite answer to this question, but, from experience to date, it is thought that the quantity of detailed information available for use in simulation may be the most significant limitation to the simulation of grazing management in New Zealand.

CONCLUSIONS

(1) Though evidence and examples of simulation are widespread, the use of simulation as a research technique is relatively new. It is not without its problems and limitations, both theoretical and practical.

(2) A simulation approach applied to grazing management appears to have considerable merit. This arises because the method:

- (a) Tackles the problem as a whole,
- (b) Incorporates variables which cannot be specified with certainty,
- (c) Takes time into account,
- (d) Can be adapted to make logical decisions,
- (e) Adds to our knowledge through the descriptive type of model it employs,
- (f) Is extremely flexible, and is particularly useful when no other method is available.

Finally, it is emphasized that this paper has been prepared as an introductory paper on the simulation of grazing management. Many of the ideas and points put forward are still subject to evaluation in the New Zealand situation. Simulation has produced some very useful results overseas and work in its application to grazing management in New Zealand is proceeding.

ACKNOWLEDEMENTS

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DISCUSSION

P. B. LYNCH: The main difficulty in using simulation techniques in problems of this type is that of securing adequate data for the various parameters involved. In many cases the information required is not available, and it would need much experimentation to provide it. The second difficulty arises when we are dealing with concepts such as "grazing method" or "soil type" which cannot be defined precisely. Estimates of pasture production are themselves subject to complex interactions with cutting technique, grazing method, and many other factors such as pasture species and climate.

Certainly the direct experimental approach is likewise affected by these factors but at least it gives an estimate of output for a specific (if limited) set of conditions.

P. L. ARCUS: The provision of adequate data for use in simulation *may* be a limiting factor. However, I find it difficult to agree that this *is* so until some reasonably exhaustive investigation leads to this conclusion. Recent research has provided some information on most of the phases of simulation proposed in Fig. 3. This may well be sufficient to operate a simple simulation from which useful information may be obtained.

Definitions do present problems and emphasize our lack of knowledge in certain fields. It is one of the incidental benefits of the Monte Carlo approach that it forces us to define, fairly closely, what we mean by such terms as "rotational grazing".

The direct experimental approach is, of course, complementary to, and indeed a prerequisite to, the Monte Carlo approach.

Q: *Can the "random elements" in such a simulation as this have a different value at different times of the year? For example, can allowance be made for the difference in productive value of one pound of pasture D.O.M. grown in early lactation and a similar amount grown when stock are not lactating?*

MR ARCUS: Yes, different values of the various parameters applicable to different times of the year can and should be incorporated in a Monte Carlo simulation. In fact, if the simulation is to be truly representative, it is essential that this be done. The mean and variance for the rainfall variable, for instance, should vary from month to month.

Q: *Has this technique been used overseas to estimate input-output relationships with animals?*

MR ARCUS: As far as I am aware, simulation has not previously been applied to situations involving livestock. Most overseas experience on record has been concerned with the application of simulation to business, industry, and war.

DR A. H. CARTER: The speaker is to be congratulated on a difficult task. To be effective, simulation methods must reproduce realistic conditions. This requires knowledge of underlying mechanisms, including distributions and interrelationships of causative factors. Even knowing or simulating these causative factors, chance processes enter into the final outcome. The value of the deterministic models employed seems, therefore, open to question. Simulation methods have been profitably used in genetic studies, where the basic mechanism, that of Mendelian gene segregation, is essentially a "Monte Carlo" process. Could Professor Rae indicate some of the recent applications overseas in this respect?

PROFESSOR A. L. RAE: Simulation techniques are being used quite widely in the study of the effects of selection and of population size on the genetic composition of populations. In general, two types of approach are in use. In the first type of study, chromosome pairs, each with a specified number of genes, are set up in the programme, and the random segregation and combination of genes is simulated. This type of programme is useful in the study of the effects of limited population size, linkage and non-additive gene effects on expected progress from selection. The second type of study is concerned with the sort of model used in animal breeding work where variation in a character is partitioned into an additive genetic component and environmental variation (both permanent and random). This method is being used in studying the efficiency of selection indexes in a wide variety of postulated conditions.