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A SYSTEMS APPROACH TO RESEARCH PLANNING  
FOR NORTH ISLAND HILL COUNTRY

A Thesis presented in partial  
fulfilment of the requirements for  
the degree of Doctor of Philosophy at  
Massey University.

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1984

## ABSTRACT

The achievement of increased production from North Island Hill Country (NIHC), through an increased research input, is currently receiving considerable attention in New Zealand. The task of planning future research and setting priorities for this work requires an evaluation of the current state of knowledge relating to hill country grazing systems, and an assessment of future research needs. A number of references have been made to the potential usefulness of systems modelling in research and research planning. The objectives for this study were to apply modelling to the development of research priorities on NIHC, and to evaluate modelling in this role.

A simulation model was constructed to assemble the available information on soil, pasture and sheep components of NIHC grazing systems. Evaluation of the state of knowledge on components of hill country systems was based on problems (data and conceptual) confronted during model construction. The model simulated pasture growth, senescence and decay from climate data. The sheep component was based on an energy balance using the metabolisable energy system.

Parameters in major components of the model were calibrated against data set aside at the start of the study. This was done in order to obtain the 'most valid' model because there were a range of values reported in the literature for many of the parameters. Statistical goodness-of-fit tests were used as an aid to decide on the structural acceptability of the calibrated model, and some issues facing the choice of appropriate statistical lack-of-fit test for models, were discussed in detail. Model validity was established by subjective judgement. The need for subjectivity arose mainly because of uncertainty about settings of some, or all, important exogenous variables in the data available for validation.

Experiments were carried out with the model where stocking rate, lambing day, length of flushing, winter and spring rotations, and the number of paddocks retired from grazing in early summer, were varied. The results were used to define decisions giving 'optimal' levels of production. Climate data from Ballantrae Hill Country Research Station were used. Five representative years were constructed to account for major variations in climate experienced at the site.

Early lambing and winter and spring grazing strategies which maximised spring feed supply were clearly shown as the most important decisions in maximising system profitability.

The 'optimal' system was used as a base from which to investigate possible benefits from adding feed in spring through the use of nitrogen fertiliser, and increasing ovulation rate by artificial means. Both the above were shown to be profitable, given some adjustments to management strategies. Finally, changes were made to a range of parameters influencing potential pasture and animal performance. Effecting some of these changes by physical, chemical or genetic means would be profitable, particularly where wool production was concerned.

Difficulties were confronted in conceiving a means of setting objective research priorities using the model. A number of information deficiencies were noted, but the reasonableness of using sensitivity analysis to rank the importance of each deficiency in an 'invalid' model was questioned. Further the problem of choosing between obtaining information to further improve the model, and developing improved systems suggested by the model, was noted. Subjective priorities were determined based on the need to demonstrate superior systems identified by modelling, and the apparent need for a greater understanding of particular components to enable improved systems to be devised. Advantages were apparent in using modelling as an aid to making these subjective judgements.

It was concluded that the process of developing a pre-research model to evaluate research needs had been valuable. The learning aspect of modelling was emphasised, though problems with validation occur where modelling is conducted in isolation from field research. The view was submitted that the modelling should be extended to become an integral part of a research programme.

## ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to Dr A. Wright and Professor R.J. Townsley for their supervision and guidance during this study. Professor Townsley made a major contribution to the statistical aspects of the study in Section 7.3.

Many other people at Massey University in MAF and DSIR helped in various ways, and can only be acknowledged collectively.

Special thanks are due to; Messrs M.G. Lambert, D.A. Clark and D.F. Chapman of Ballantrae HCRS, for their interest and generous assistance with data; and to Dr C.J. Korte for his generous assistance with data and willingness to discuss agronomic matters.

Dr Steve Black and Mr Walt Abell of the Massey University Computer Centre gave valuable assistance with computer programming problems. Mr H.U.-P. Hockey helped construct Genstat programs to analyse the simulation experiments.

The efforts of Mrs Betty Farrelly and Miss Mary Clarke in typing this thesis, Ms Pauline Hunt for help with art work, and Mr D.C. Smeaton for making critical comments on an earlier draft, are all gratefully acknowledged.

I am grateful to my employers, the New Zealand Ministry of Agriculture and Fisheries, for their financial support throughout this study, and for their enduring patience in the period in which the study ran over time.

Finally, I wish to thank Julie McCall (nee Gregson) for her support and encouragement during the course of the study.

Any deficiency in this thesis is my responsibility and is not due to those mentioned above.

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## Chapter 1

### INTRODUCTION

#### 1.1 INTRODUCTION

New Zealand's North Island hill country (NIHC) is predominantly non-ploughable land. It supports a large proportion of the nation's sheep and cattle (NZMWB, 1984a) in a variety of grazing systems, and is a source of replacement stock for lowland finishing units. It also contributes more than \$600m a year to National export earnings (NRAC, 1978). An analysis by Scott (1982) suggests that an increase in stock numbers of 128% could be achieved by adopting current technology. Other estimates suggest that the potential for increased production ranges from 50 to 200 percent above current output (Brougham, 1973; Hight, 1976, 1979). Achievement of this potential would obviously have an enormous impact.

The National Research Advisory Council published in 1978 (NRAC, 1978) a set of recommendations for the future development of hill country research. It identified a large number of research areas and asserted that greater research attention should be given to them. However, the report concluded that it was difficult to allocate priorities (para. 106) among the research areas identified, owing to the multi-disciplinary nature of the problems facing hill country. It left unanswered questions (e.g. Mooar, 1978) regarding; (1) the feasibility of accomplishing the volume of research proposed in the report, (2) the profitability of undertaking all of the research proposed, (3) methods by which the research areas identified, should be researched, and (4) questions relating to likely adoption rates of different technologies by farmers.

One reason for the above difficulty of allocating priorities is the lack of a suitable methodology to integrate existing knowledge, to provide a focus for discussion on the adequacy of this knowledge.

The systems approach appears to offer the required methodology. It is the unifying, or multi-disciplinary, concept that the systems approach seeks to achieve. A mathematical model provides a framework for describing the system precisely, within the limits of existing knowledge.

Models have always provided the basic frame of reference for thinking about systems (Wright, 1980). However in the past these models have usually been mental models. Differences in perceptions of a system, and the ability to grapple with it mentally, have given rise to difficulties in communicating these mental models. Vague language can be used inadvertently, or purposefully, to blur the communication process (Ebersohn, 1976), and hence produce an inefficient transfer of information or ideas between those concerned, especially where complex systems are involved. With a mathematical model, on the other hand, assumptions need to be stated precisely and are clearly exposed for debate. In addition, the consequences of these assumptions are reliably computed (Benyon, 1972).

The use of mathematical models in agricultural research has been receiving increased attention in recent years. However most studies have concentrated on developing mathematical models as a means of extending specific results to a wider range of environmental conditions (e.g. Smith & Williams, 1973; White et al., 1983). Those which have addressed themselves to the evaluation of modelling in terms of the wider activities covered by research (e.g. Wright et al., 1976; Miller, 1983), have reported favourably on its potential.

It has been emphasised that a modelling study requires the active involvement of specialists from a number of disciplines (Dillon, 1976; Roberts, 1976), as was done by Wright et al. (1976). However Morley (1973) considered that systems research involving the use of models is more likely to proceed from strongly motivated individuals making use of specialist colleagues.

Criticisms also exist, and are implied, of modelling studies carried out in isolation from real research programmes (Ebersohn, 1976; Baldwin & Koong, 1980; Miller, 1983). While these may be accepted in part, the important consideration must be the objective for the modelling in relation to the research programme. The usual starting point for a research programme is a review of the literature, followed by discussion with people already involved in studying the system and an intuitive assessment of research needs. An alternative approach is to develop a pre-research model and make judgements on research needs based on what is learnt from building and manipulating the model.

This study originated from a desire to apply modelling to the development of research priorities in North Island hill country grazing systems.

The major objectives for the study were:

- (i) To identify technological constraints to increased production from NIHC grazing systems by (a) integrating relevant knowledge in the form of a mathematical model, and (b) manipulating that model.
- (ii) To evaluate the systems approach, and modelling as a tool, in aiding research management.

## 1.2 PLAN OF THESIS

Part I of the Thesis comprises Chapters 2 and 3. In Chapter 2 there is a discussion on the systems concept, and agricultural research as a system, taking its place between higher and lower order systems. The former is society by which agricultural research activity is influenced and the latter is the production system that agricultural research attempts to influence. Major issues surrounding the use of production system models in the planning and conduct of applied agricultural research are then reviewed. In Chapter 3 modelling procedures are briefly outlined as a basis for discussing some of the perceived methodological problems to be confronted. The chapter concludes with a review of simulation models in the literature which are relevant to this study.

The modelling of hill country sheep grazing systems, and priorities for research into these systems, are discussed in Part II. In Chapter 4 an introduction is given to the modelling study. The choice of system boundary for the model is outlined and questions related to sources of data for the model are briefly answered. Chapters 5 and 6 are concerned with describing the relationships and assumptions used in constructing the model. Development of model structure, including calibration of major parameters, is discussed in Chapter 7 along with subsequent validation of the major components of the model. In Chapter 8 results derived from model experimentation are discussed. These results are related to production from systems employing different grazing management, and systems making use of new technology, both existing and hypothetical. Finally, in Chapter 9 an attempt was made to draw together experience gained during the modelling exercise into a discussion on priorities for NIHC sheep grazing system research, and to address the second objective.

## Chapter 2

## SYSTEMS CONCEPTS AND THE USE OF MODELS IN AGRICULTURAL RESEARCH

## 2.1. INTRODUCTION

In New Zealand, grazing systems, including those of the North Island Hill Country, have developed tremendously over the years to the point where much of the slack that existed in these systems has now been exploited, and a phase of relative fine tuning is being entered (Townesley, 1973a). Advances through the application of fertiliser, correction of trace element deficiencies, increased stocking rates, and farm subdivision, along with improved grazing techniques, have all had major impacts. There can be little doubt that agricultural research has served society and its clients, the farmer, well over this period. One ex poste economic evaluation of four New Zealand research programmes has shown relative returns in the order of 20% on investment (Dick et al., 1967).

However, questions are increasingly being asked about the relevancy and efficiency of research methods in systems where fine tuning has become important (Dillon, 1976; Ebersohn, 1976). In addition, criticisms have been levelled at the apparent lack of synthesis of research findings into usable form in these systems (Ebersohn, 1976; Miller, 1983).

The lack of synthesis by researchers may, however, be no more acute today than it has been in the past, but the synthesis task has become more difficult for the farmer for two reasons. First, the volume of information to sift is enormous and increasing rapidly. Ninety percent of the researchers who have ever worked in agriculture are working today (Williams, 1979). Secondly, with the frontiers to increased production becoming subtle interactions, as opposed to single-factor constraints, a greater level of understanding is

required on the part of the farmer in order to apply new information efficiently in his system.

The discussion in this Chapter is concerned first with showing why systems concepts are relevant to agricultural research and how the organisation of agricultural research can itself be viewed as a system. Secondly it is concerned with showing how a mathematical model of the production system may be a useful component of the research system by aiding communication and decisions about research priorities.

## 2.2 FUNDAMENTAL SYSTEMS CONCEPTS

It has been noted by Rountree (1977) that in recent years systems concepts and theory have become bound-up with models. This must in part be due to the fact that it is hard to think about a system without a model, and impossible to describe one except in model form (Spedding, 1977a).<sup>1</sup> Yet modelling represents only the technique for applying system's concepts (Dent, 1975) and a system can give rise to several models (Spedding 1977a), depending on definition of system boundary and the organisational level of its components. The danger of losing sight of systems concepts is that "we risk becoming systems people wearing blinkers, as opposed to disciplinary people wearing blinkers" (Rountree, 1977). This goes against the main objective of General Systems Theory, which is to develop a general framework to enable one specialist to obtain communication from another (Boulding, 1956).

<sup>1</sup> Models may take a range of forms, from diagrammatic to an icon of the real system. Unless otherwise stated, the models referred to in this Thesis are mathematical models, capable of being manipulated on a computer.

Systems theory is based on the rather abstract notion that the 'whole' is more than the sum of the parts. The systems approach recognises the indivisibility of the whole system (Dillon, 1976). A system may be defined as a functional unit (e.g. farm) or a conceptual unit, at a given level of organisation, made up of interacting components (Rountree, 1977). The components of a system have the following properties, defined by Dillon (1976):

- (1) Each affects the properties of the system as a whole, and
- (2) Each depends for its own properties, and its effect on the whole system, on the properties of some other components of the system.

Recognition of a hierarchy of systems, each at different levels of organisational complexity, is central to the systems concept. Organisational levels may range between the atom and the level of social interaction (Van Dyne & Abramsky, 1975). One system may therefore be a sub-system of another.

The application of systems concepts relies on recognising the purposes for which a system is to be studied (Spedding, 1975). This provides the guideline for the next step of defining a system boundary to incorporate only relevant sub-systems (levels), while ensuring that relevant linkages with other sub-systems are included. Through the above processes systems concepts provide a basis for balancing the need for detail, against generality (Rountree, 1977).

As a rule, no more than three organisational levels should be included within the boundary of a system under study (Jeffers, 1978). Within a level however, the notion of a boundary creates problems such as, which components to include, or conversely, exclude. In response to this problem Rountree (1977) has suggested that a boundary should

not be viewed as a rigid 'cut off' line but rather as a band, within which factors have diminishing effect on system behaviour.

Higher organisational levels outside the system boundary form the environment, which may often be unchanged by the operation of the system, but will provide inputs to it.

## 2.3 SYSTEMS CONCEPTS IN AGRICULTURAL RESEARCH

Before reviewing the possible uses of production systems models in agricultural research it is necessary to consider first the relevancy of systems concepts to agricultural research. Possibilities for the application of systems concepts exist at two levels. The first of these is the level of the production system in which the researchers' work is embedded. The second, is the research system (Dillon, 1976) which represents the social system in which the researcher is a component, interacting with other researchers, research administrators, and society, including farmers and their advisers.

### 2.3.1 Systems Research and the Production System

Agricultural research is primarily involved with the solution of specific problems at the farm level (Arnon, 1968) and with the identification and evaluation of opportunities for improving production (Wright, 1980). The farm therefore represents the system at which most agricultural research is targeted, and system boundaries can usually be defined relatively easily to include the relevant components of farms in a region of interest (e.g. class of sheep, pasture type or crop type).

Experiments may be performed on whole production systems or scale versions of them, as in farmlot studies. However researchers usually

draw boundaries that lie within those of the farm in order to study components of the system in more detail. For example, a detailed and specialised understanding may be required of a certain component of the system where the objective is to 'repair' or 'modify' that component (e.g. as in plant or animal breeding) (Spedding & Brockington, 1976). Yet it is essential that any change made to part of the system is studied in relation to its effect on output of the whole system, to ensure that conclusions are not made invalid by interactions with other components of the system (Morley & Spedding, 1968).

Research into agricultural systems can be conveniently classified into that involved with systems analysis and systems synthesis (Wright, 1973). Systems analysis includes research directed at gaining an understanding of the relationships between components of the system, primarily in order to understand the mechanisms underlying observed system behaviour. Systems synthesis involves the formulation of improved systems either based on hypotheses about system behaviour derived from knowledge of component behaviour gained during analysis (as in altering management decisions to improve system performance), or in the design of a new system, say by extending system boundary to include other components (e.g. introducing forage cropping to dairy systems, (Miller, 1983)).

### **2.3.2 Systems Research and the Researcher**

At the research system level the researcher and research administrator are the important components of the system with society representing the environment in which the system operates (Townesley, 1973b). A simplified research system representing one research

institution, operating on a single production system, is presented in Fig. 2.1.<sup>2</sup>

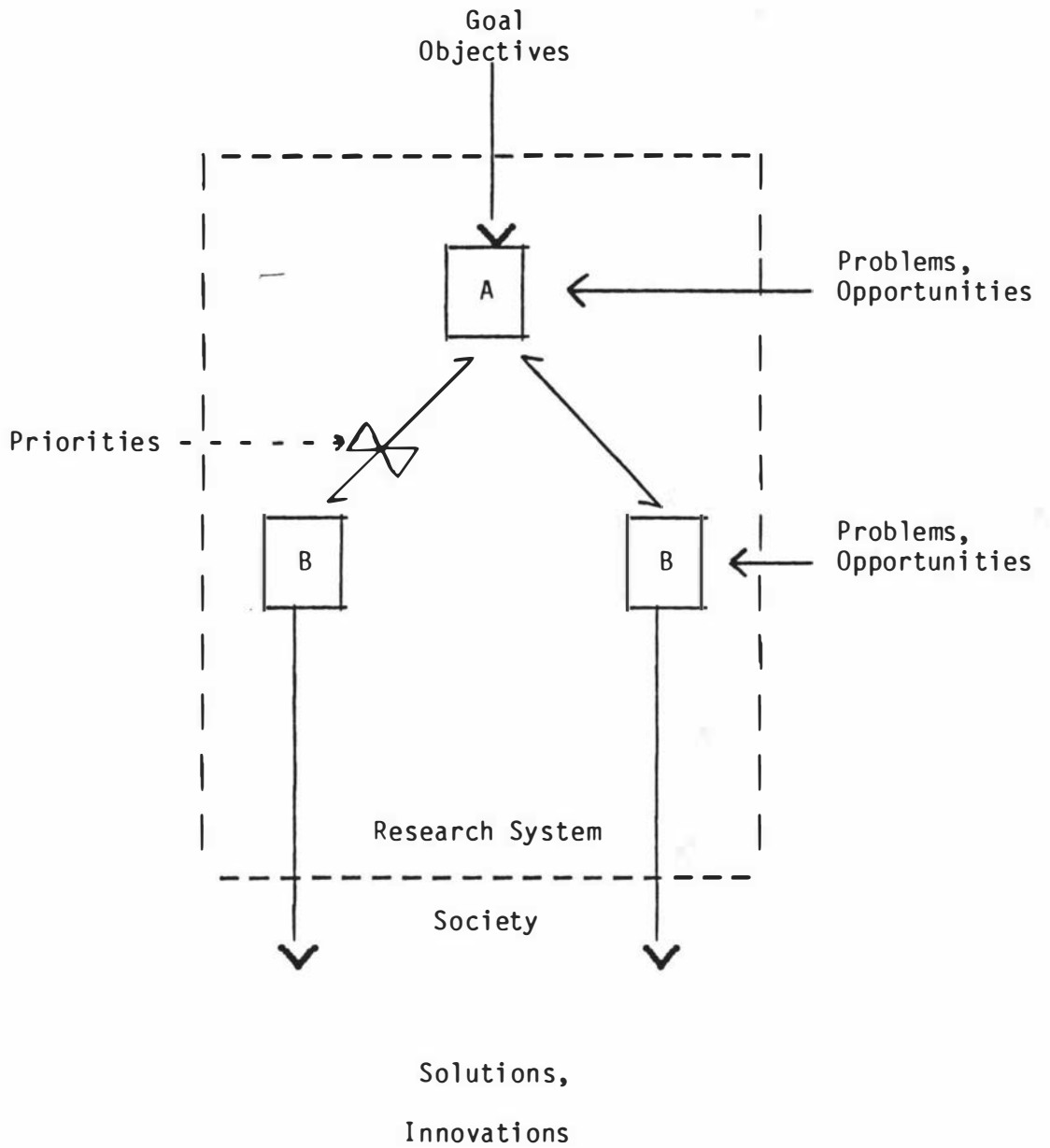
The function of the research system is primarily to facilitate research management. The important flows in Fig. 2.1, are information flows. These carry problems and opportunities for research, as well as research goals, priorities and objectives. Information also represents the major output from the system.

Greig (1981) reviewed five major functions involved in research management. These functions, and some of the requirements of the research system in relation to these functions, are as follows:

(a) Proposal Initiation: Many of the ideas for proposals originate from the researcher who through his knowledge of the production system, and perception of production system requirements, formulates researchable problems. However proposals may also be stimulated by ideas and problems posed by society either directly to researchers or to research administrators (Townsley, 1973b). An important function of the research system is to ensure the effective communication of these ideas and problems to the researcher.

(b) Proposal Evaluation: Evaluation of proposals is a prelude to the proposal being considered for selection. It is usually a two-stage process being conducted first at the researchers' level and again at the administrators' level. Evaluation can take many forms ranging from detailed economic analyses of the likely benefits arising to society (or certain members of it) should the research be

<sup>2</sup>Discussion will be confined to this system which operates on the goals set for it, and resources allocated to it, at the national research administration level.



**Figure 2.1** A simple research system consisting of research administrator (A) and researcher (B). With major inputs and outputs.

successful (Arnon, 1975), to scoring methods<sup>3</sup> or simple subjective and qualitative judgements.

In some institutions formulation of the original idea into a concrete proposal may be all the evaluation a proposal is subject to (Greig, 1981), particularly at the researchers' level. Competing ideas are often simply sifted intuitively by the researcher before one proposal is formulated.

(c) Selection: This simply involves making the choice between proposals that are competing for a limited set of resources, usually at the administrative level. There are few examples in the literature of wholly objective selection procedures being used by research administrators (Greig, 1981). This is no doubt due in part to dangers perceived in relying on the 'false' sense of objectivity engendered by scoring or ranking methods of assigning value to proposals (Arnon 1975).

In most instances final choice between proposals depends on a subjective decision made by the administrator, and is based on the evidence presented to him regarding project importance or value. A well-reasoned and evaluated proposal is likely to be viewed more favourably than one which is not.

(d) Implementation and Control of Research Project: This involves the day-to-day matters related to the conduct of a research project in the laboratory or field, including organisation and scheduling of staff, materials and equipment. It also involves making periodic reviews of project progress and direction, particularly for long-term projects, and requires appropriate judgements to be made about future project direction and termination date.

<sup>3</sup> Scoring methods (e.g. Arnon, 1975) employ relative scores based on a subjective assessment of the ability of the research to meet a number of criteria.

(e) Dissemination: Dissemination involves the communication of results. For applied research, results should be in a form that can be readily adopted by farmers. This inevitably requires synthesis of old and new knowledge into usable systems. Synthesis is generally held to be the responsibility of the researcher (Ackoff, 1962). Media for dissemination commonly include field days, conferences and published articles in popular or scientific journals. Methods of synthesising results range from intuitive synthesis to farmlet studies.

The effectiveness of research management depends to a large extent on the effectiveness of the information flows illustrated in Fig. 2.1. The common reference point for communication is the production system. Information on problems and opportunities in the production system provide the initial stimulus for research, and solutions must be fed back into it. The value of competing research proposals can only be judged in relation to likely effects of a piece of research on the production system, and hence on the farmers and society.

#### 2.4. THE USE OF MODELS IN AGRICULTURAL RESEARCH

Many of the difficulties faced in the management and conduct of agricultural research in the fine tuning phase can be attributed to the lack of a unifying language on which to base precise communication between those involved (Ebersohn, 1976). For example in the absence of a common basis on which to quantitatively evaluate likely benefits to the system of competing research proposals, the selection of proposals may be a subjective decision based on intuition. Differences between an administrator and a researcher, in the

perceived importance of a piece of research, may be the only reason for a proposal being 'rightly' or 'wrongly' discarded. Difficulties in allocating resources appear greatest where basic research proposals are involved (Walsh, 1970; Fennessy, 1983).

There appear to be three useful purposes which could be served by a model of the production system in the conduct and management of agricultural research. The first is as a focus for communicating and co-ordinating basic research needs in relation to our ability to describe the entire system. The second is as an aid to synthesis of results into improved systems, and the quantitative prediction of system behaviour under changed circumstances. The third is in communicating priorities for the allocation of research resources.

#### 2.4.1 Communication Advantages offered by Models in Basic Research

##### 2.4.1.1 Models as Hypotheses

A mathematical model really represents an hypothesis of system function, since it is composed of hypothesised relationships among variables (Innis et al., 1980). The major difference between a mathematical model and a scientific hypothesis is that the mathematical model allows the hypothesis to be extended to a 'larger slice of life', covering practical situations (Spedding, 1977b, 1980).

In the past these hypotheses about systems have been in the domain of qualitative reasoning (Baldwin & Koong, 1980), owing to the human mind's inability to trace accurately the quantitative or dynamic implications of available concepts relating to a complex system. Even with a mathematical model however, hypotheses relating to descriptions of whole systems can be so complex so as to make them difficult, if

not impossible, to test. And Passioura (1973) has argued that for this reason many ecosystem level models do not qualify as hypotheses.

The practical solution to the complexity problem has been the development of the hierarchical approach to modelling (Goodall, 1976) based on model development and testing within subsystems of the overall system. The published reports of Baldwin & Koong (1980), and Black et al. (1982) testify to the success of this approach in agricultural research.

By viewing a model as an hypothesis, or set of hypotheses, use of models in the research process can be seen to be congruous with scientific method (Spedding, 1977b; Hillel, 1977). Observation of the real system in operation is followed by formulation of an hypothesis (a mathematical model) to explain how the system operates. Next, predictions of system behaviour are obtained from solutions to the mathematical model and finally, experimentation serves to test the validity of the model's predictions.

A common feature of studies using mathematical models in agriculture is that they are conducted by multidisciplinary teams (e.g. Wright et al., 1976; Sibbald, 1981), owing to the size and complexity of the model required to encompass practical systems. One of the major benefits claimed to arise from such modelling exercises is improved interdisciplinary communication, through improved understanding of the system by those involved (Wright, 1976). A model provides an opportunity for disciplinary specialists to learn outside of their discipline (Wright, 1976) and helps foster interdisciplinary co-operation by providing a focus for each specialist on the structure, function and interdependence of his component subsystem relative to the whole system (Roberts, 1976).

The benefits of models to the disciplinary specialist are generally recognised to be highest during the conceptual and construction phases of a modelling study and to decrease at the commencement of the operational phase (Innis et al., 1980). Indeed Sibbald (1981) reported that one of the most useful modelling exercises conducted by his group at HFR0 in Scotland, had till then not produced a working computer model. The exercise had however, he claimed, led to an appreciation by those involved of the issues which needed to be resolved in order to develop more effective systems of grazing management.

A second common conclusion to many modelling efforts is that some things are well known but others deserve attention (Innis et al., 1980), and that the model construction exercise proved useful in exposing weaknesses in existing data (e.g. Wright et al., 1976). The latter is an often repeated benefit credited to model construction (Innis, 1975; Roberts, 1976; Brockington, 1979; Dent & Blackie, 1979; Spedding, 1981; Whitemore, 1981).

There can be little doubt that exposure of ignorance is an important feature of modelling studies, but it is by no means unique to modelling. For instance, any form of intensive study, such as a review of the literature related to the system is likely to yield a similar result (Wright, 1976). What is different is that a model suggests a framework which gives information about the system purpose. In many cases lack of a suitable means of using the information may have been a major reason why the information had not already been obtained. It is as a framework for the theoretical development of disciplines related to agricultural production systems that perhaps the greatest potential for models lies.

#### 2.4.1.2 Models in the Development of Theories

Because mental models have been the principal tools for guiding research and interpreting results, the tendency has been to focus on individual processes that could be easily understood and communicated (Ebersohn, 1976). Research on system components has been dominated by the law of the limiting concept, where an attempt was made to find the most limiting factor and remove it (Ebersohn, 1976). Where the effects of individual processes have been studied in isolation by minimising non-treatment variance, without regard for understanding the factors affecting absolute responses, it has been difficult to extrapolate results to other environments (Revfeim, 1980). To identify farm level factors affecting the economic performance of new technology, it may be necessary to resort to extensive farm level testing (Sanders & Lynam, 1982).

Only by assembling much of the fragmented knowledge on systems components into a sound framework of theory is it possible to spell out further component research in a coherent manner, while at the same time making provision for its application. In this context a model appears useful in helping answer the questions: can our present knowledge explain system behaviour, and what is the important knowledge required to allow system behaviour to be studied?

At this stage however there exists no generally accepted model of grazing or animal production systems, rather there have been a number of models developed by separate research teams (see Seligman, 1976; Chudleigh & Cezar, 1982).

Reluctance to use other people's models may be in part due to the large artistic, or creative, component to model construction (Baker & Curry, 1976), and the liking for one's own creation. However, in

part, the apparent reluctance may be well founded. In a purely mechanical sense difficulties arise through 'user unfriendliness', and in getting 'his program to run on my machine' (Forbes, 1981), but more important dangers are inherent in using models where the user is not fully conversant with the limitations and shortcomings of the model (Whittemore, 1981). Communication of all the detailed aspects relating to assumptions and shortcomings in a complex model, and of how to use it, is not an easy task.

It seems likely then that for some time at least, the main use of models will be to reflect personal rather than broad general theories. As such their utility in guiding component research is probably best compared with the vague and ambiguous mental images previously used (Ebersohn, 1976). However the development of personal models and the possible realisation of accepted theoretical formulations clearly requires that these models be published.

#### 2.4.2 Models as an aid to Generating System Hypotheses

A use of models which has received wide-spread acclaim is in the generation of quantitative hypotheses about the systems they describe (Spedding, 1977b; Penning De Vries, 1977; Baldwin & Koong, 1980). In this role claimed and realised applications of models include: evaluation of output from proposed systems in relation to existing systems (Wright, 1973), general exploration of systems as a means of identifying superior 'best bet' systems for field testing (Wright et al., 1976), determination of required economic conditions (input/output prices) for suboptimal systems to become relevant (Wright, 1973) and extrapolation of system effects, as shown in field

studies, over longer time (climate) sequences, and to other sites (Seligman & Arnold, 1980).

There is however the problem that a model is itself an hypothesis, and Van Keulen (1976) cautions against claiming any such benefits until the model has been verified.<sup>4</sup> This is an important point, but it must be appreciated that a model is by design a simplification of the real system, and we can not aspire to replace experimentation in the real system (Seligman & Arnold, 1980), even if experimentation is conducted solely to test hypotheses generated by the model (Spedding & Brockington, 1976).

The advantage from using a model to generate system hypotheses, compared to intuitive processes, is that reasons for improvement in the hypothesized system can, if desired, be quantitatively related to the concepts and assumptions representing our state of knowledge about system components. The 'reasonableness' of these assumptions can be more easily debated than subjective notions about reasons for hypothesised system improvement.

Having accepted that a model may be useful for the purpose of generating quantitative system hypotheses, the advantages listed initially all relate in some way to increasing the speed of the evolutionary process whereby improved grazing systems are developed. The limiting steps in this process are usually the testing of system hypotheses and our ability to reduce competing hypotheses about new, and possibly improved systems, to a manageable set.

One approach to testing these hypotheses has been the large-scale, factorial farmlet experiment comparing a number of systems (e.g. Sheath et al., 1984). Progress using this approach

<sup>4</sup>Validation and verification are discussed in Chapter 3.

can be slow though. Any more than a few of the large number of possible treatments, and a minimum number of replications, makes such experiments too expensive of physical resources. Then, once the experiment has been set up it must be run for a number of years so as to evaluate interactions between treatments and years with different climatic conditions (Seligman & Arnold, 1980). Further, comparisons may be hindered by problems of lack of homogeneity of the experimental site (e.g. McKinney et al., 1978). Difficulties also arise in deciding which data to collect to effectively monitor the system. Finally, repetition in a number of locations with, for example, different soil types, may be necessary to assess the generality of conclusions (Seligman & Arnold, 1980).

A second approach has involved the use of a single evolutionary farmlet (e.g. Townsley, 1973c; Hutton, 1973) on which an attempt is made to synthesise component information into an improved system. This approach relies on intuition in deciding on the best decisions to implement. However, problems arise in discerning cause and effect in these systems since there is no control system. Also, evaluations regarding system improvement must be made in qualitative terms (Ebersohn, 1976). While the approach already appears to be very useful for demonstrating improved systems to farmers, if theoretical cause and effect for improved system performance could be established on a model, the experimenter may be in a better position to determine critical variables to monitor in the field (Wright, 1973), thus extending the domain of such an approach into the testing of hypotheses.

There is, however, still a notable lack of reported use of modelling in the contexts described above, and hence many of the

claims remain speculative. Also attempts to evaluate these claims must of necessity be subjective since there is no way of defining accurately the course research would have taken in the absence of modelling.

### 2.4.3 Research Evaluation

The difficulty of the task of choosing between specific research projects is evident from a number of international conferences devoted to the topic (OECD, 1970; Fishel, 1971; Arndt et al., 1977).

Difficulties with ex ante evaluation of research proposals arise firstly in assessing the probability of success of the research, that is, the probability that the research will achieve the desired results. This must of necessity be a subjective judgement. Next is the problem of estimating benefits likely to arise from the research and, finally, there is the problem of estimating the probability of its adoption.

Anderson (1972) and Greig (1981) have both discussed the possible use of a model of the production system for prospective assessment of comparative returns from specific agricultural research projects conducted in one production system. A measure of benefit to the system (usually economic) coupled with some assessment of adoption rate appears quite satisfactory where production from the system is largely exported, and an increased supply of product can be assumed to have little effect on prices received.

Adoption rates of new technology by farmers are likely to be influenced by a number of factors, some of which are listed by Spharim & Seligman (1983). However the potential impact of new technology on the input/output ratio (e.g. economic benefit) of the

production system is likely to be of major importance in established farming areas (Schultz, 1971).

Two particular situations regarding the use of a production system model in evaluating research alternatives bear some comment. The first is where, following construction of a model to allow system behaviour to be studied, the model is found to be invalid. In this situation there will usually be a number of areas of ignorance represented in the model by assumptions. The current method suggested for evaluating the relative importance of various assumptions is sensitivity analysis of the change in predicted system performance, to a change in an assumption (Dent & Blackie, 1979). The greater the sensitivity, the greater is the priority to test the assumption (Sturgess, 1972). There is however a problem with this argument in that with an invalid model, sensitivity to a given assumption may be due to an incorrect assumption in another part of the model. This is discussed more fully in Section 3.4.4.

The second situation is where the model is considered valid. In this case it is possible to recognise two further types of research that a model would be useful in evaluating. The first, for which an example is provided by both Spharim & Seligman (1983), and Miller (1983), is in the evaluation of rewards for introducing innovative technology to a system. The second is in the setting of targets for new, or 'hypothetical', technology of the type referred to by Fennessy (1983), such as physically, chemically or genetically altering the physiological potential of components of the system. However in evaluating research proposals aimed at providing the technology to achieve these targets, a great deal of weight would need to be placed

on subjective assessment of the probability of success of the research.

## 2.5 SUMMARY

In this Chapter some of the basic systems concepts have been reviewed, and the possible uses of mathematical models in agricultural research have been considered.

Possibilities for the application of systems concepts in agricultural research were seen to exist at two levels. The first was the production system in which the researcher's work is embedded. The second was the research system in which the researcher is component, interacting with other researchers, administrators and society.

A model of the production system was seen to have a number of potential roles in improving the efficiency of the information flows on which the research system is based. The first was in the theoretical development of topics related to agricultural systems. Here, the model (as a hypothesis) provides a focus for communicating and co-ordinating component research needs in relation to our ability to describe the system. The second was as an aid to synthesising improved systems and the third was in establishing priorities for the allocation of research resources.

In each of these roles it was suggested that model utility may be best compared with the utility of our mental models of the system.

The next Chapter is devoted firstly, to issues facing the use of mathematical models in a research programme and secondly, to a review of some grazing system models.

## Chapter 3

### MODELLING PROCEDURES AND A REVIEW OF SOME GRAZING MODELS

#### 3.1 INTRODUCTION

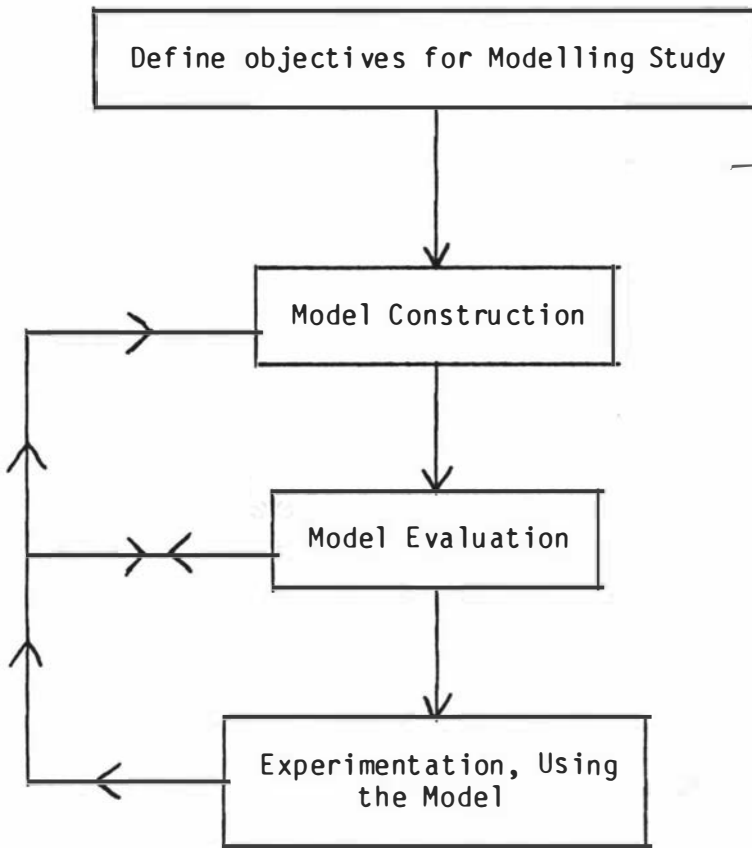
In the previous chapter it was concluded that mathematical modelling had a potential role to play in the agricultural research process. The discussion in this chapter covers some considerations related to undertaking modelling in a research programme. Then a number of simulation models relevant to this study will be discussed.

There are many reports in the literature which outline in detail procedures to be applied in conducting a modelling study (see, e.g. Dent & Blackie, 1979; Brockington, 1979). It is not the intention of this chapter to reiterate these in depth. Rather an attempt is made to highlight important decisions to be made in such a study and to develop some of the problematical issues facing the group or individual in making these decisions.

The broad sequence of events involved in a modelling study is outlined in Fig. 3.1 and it is proposed to discuss the process in this order. In practice, however, there is not always a rigid progression through to experimentation on the model. After initial construction, the modeller interacts constantly with his model and may move backwards and forwards between the stages in Fig. 3.1.

#### 3.2 DEFINITION OF OBJECTIVES FOR A MODELLING EFFORT

The need for a clear definition of objectives in a modelling study has been widely emphasised as a critical first step (e.g. Baker & Curry, 1976; Morley, 1977). Objectives are important with respect to decisions required on: level of component



**FIGURE 3.1** Sequence of events in modelling

representation, placement of system boundary and definition of an end point to model development. It is generally held that the decisions related to these are most easily made when a model is constructed in response to a specific question or problem (Brockington, 1979). However in a research context, prior recognition of all questions to be asked of a model will be difficult (Benyon, 1972). Further, tailoring a model to answer a specific question may be undesirably restrictive, especially if this precludes the model from being used to answer 'new' questions which arise in the constantly evolving research environment (Innis et al., 1980). Where models are developed with reasonably broad objectives, as most research models are, the greatest requirement is to guard against recognised risks during model development.

Four risks associated with extensive model development, outlined by Morley (1977), are: (1) pre-occupation with modelling and computer technology as ends in themselves rather than as a tool in the research process, (2) emphasis on parts of the system which are most interesting or amenable to mathematical formulation, but which may not be major determinants of the efficiency of the system, (3) distraction from field experiments designed to improve or validate the model, (4) neglect of research aimed at producing new technology such as the development of new chemical compounds to manipulate plant or animal production.

One approach which has been suggested to impose the required discipline on model development is to set a time limit (Wright, 1976). Another is to stop when the model passes certain statistical criteria (Fick, 1980).

### 3.3 MODEL CONSTRUCTION

A number of general considerations related to the construction and development of simulation models are covered by Shannon (1975). Considerations which warrant special discussion in relation to the construction and development of a simulation model for use in the research process include:

(i) The strategy for model construction

In most cases a model which is to be used in the research process will evolve over a relatively long period of time, and may be developed by a number of researchers (Innis et al., 1980). There are two general paths along which model construction and development may evolve. They are known respectively as the top-down and the bottom-up approaches to modelling (Van Dyne & Abramsky, 1975).

With the top-down approach the structure of the whole model is based on a series of initially determined objectives for the model. The coarse features of the system are modelled first with more and more detail being added as necessary. In practice the top-down approach requires that a large system be divided into a number of smaller sub-systems for firstly, ease of model development and evaluation, and secondly, where a group is involved, as a means of involving each individual group member in his area of expertise (Goodall, 1976). By dividing a system into sub-systems on a heirachial, or nested basis, Goodall (1976) has suggested that various sub-systems can be selected that lend themselves to treatment at different levels of complexity. According to the objective-centred heirarchical approach described by Spedding (1975), component sub-systems can be defined that require specification in greater or

lesser detail depending on their importance in defining a central objective.

The bottom up approach starts by an independent and detailed modelling of the individual sub-systems which are to be joined together at a later date. The advocates of the bottom-up approach suggest that it is only once the detailed sub-system models can be thoroughly validated should one progress towards a total system model (Innis et al., 1980). However this approach potentially suffers from the lack of a central purpose, and forgoes some structural organisation compared to the top-down approach. There is also the danger of individuals continually increasing the complexity of their sub-models, which may represent an inefficient use of research resources. There may also be difficulties in uniting independently developed sub-models into a total system model (Innis et al., 1980). Finally, the time required to satisfy the objective of detailed representation of all sub-models largely relegates the bottom-up approach into the realms of impracticability where the development of large system models are concerned.

(ii) Level of biological complexity

The level of biological complexity of a model depends largely on the level at which the processes making up the model, are defined. Processes are well defined when represented in chemical or physical terms (Thornley, 1976). However little is understood of most biological systems in such terms (Seligman & Arnold, 1980), and even if they were, representation of a large system in these terms would result in an extremely complex model. Practical decisions are therefore required on the choice of empirical relationships

(aggregations of basic processes), with which to represent the biological processes. Where possible it is generally advised to remain with physiologically accepted relationships (Seligman & Arnold, 1980) that have been well studied and have achieved general acceptance (e.g. photosynthesis rate/radiation intensity functions). Often, however, some relationships constructed specifically for the model will be required (e.g. many of the relationships with time).

Complexity should usually be greatest in those components of the model most important to the central objective. Increased complexity is usually associated with increased realism, although this does not automatically follow (Seligman & Arnold, 1980). Complex components will be open to feedback from other components in the model. If the feedback mechanisms are not modelled correctly the model may be less accurate than if the component was represented in low resolution (i.e. the components are treated as being insensitive to feedback from other components). Low resolution is suitable for defining peripheral components to the system (e.g. soil fertility status in a plant/animal system). The major problem with representing components in low resolution is loss of generality. Components treated in low resolution may often need to be tuned to a specific site to allow the model to perform reasonably.

### (iii) Stochasticity

An almost total disregard for the inclusion of endogenous stochastic relationships in published simulation models has been noted by Anderson (1976). Anderson argues for the need to include stochastic relationships in a model to represent uncertainty where it arises. Only in this way, he argues, can one totally reflect the present degree of understanding of the modelled system by including a

measure of the perceived risk associated with a particular mode of system operation.

A major part of the problem with deterministic models is that they are incomplete (in the deterministic sense) owing to uncertainties in the estimates of parameters and variables in the model.<sup>1</sup> The deterministic approach attempts to represent probability distributions related to estimates of a variable, or parameter, by its mean. When the premise - that the chosen mean value represents the underlying situation - is wrong, one argument is that understanding gained from using the model will not reflect the real world situation. But by using a stochastic approach (e.g. Anderson, 1976) full use may be made of information about the 'error' associated with these estimates (i.e. the quality of the information), in obtaining mean system responses.

Despite the persuasiveness of these arguments there are some important practical problems associated with the use of the stochastic approach. The first is that the inclusion of stochastic relationships in a model presupposes the existence of suitable data from which such relationships may be estimated (Miller, 1983). As well, there is the problem noted by Charlton & Thomson (1970) that inclusion of stochastic parameters and variables in a model greatly expands the number of computer runs required to determine a response with confidence. A third problem relates to the ability of most model builders to include realistic stochasticity in their already complex models of biological systems. At least Wright (1970), has advised against including stochastic features until the basic model structure has been decided upon.

<sup>1</sup>They may also be incomplete where truly random processes exist, such as the roll of a dice. These are excepted from this discussion, since it is acknowledged that such processes can only be fully explained by the appropriate frequency distribution.

A major part of Anderson's case for including stochasticity was aimed at providing complete information on risk and uncertainty for the economic decision maker. In the research context the use of stochastic modelling, except as noted in footnote 1 and in the case of exogenous variables such as rainfall, may prove distracting to the researchers' riskless conceptualisations of cause and effect. The simplification offered by the deterministic approach is appealing, while still allowing prediction of trends in system behaviour which are of interest to the researcher and must of necessity be tested in the real world.

(iv) Choice of data

Besides the problem of no available data the greatest data problem facing model construction is likely to be lack of data in a suitable form for describing the system (Wright & Dent, 1969). In many cases previous methods of data analyses and presentation, based on summaries of averages, are unsuitable for developing dynamic models describing system function (Coupland, 1979). A further problem experienced by generalists in constructing models may be ignorance of the existence of important data. This may be a reason why some models constructed by generalists are considered naive by specialists (e.g. Black et al., 1982).

Finally, data are required not only for use in estimating the values of parameters and constants in a model, but also to allow assessment of the model by validation. Since separate data are required for validation from those used for model construction, Baker & Curry (1976) advised that all relevant data sources should be

located and evaluated early in the study, with some being set aside for validation purposes.

(v) Specification of input and output

The specification of model input and output is a matter of some concern in a modelling study. Form of the input data should largely depend on objectives for model use. The more general the application of a model is to be, the more general its inputs need to be (Morley, 1977). That is, for a general grazing model, meteorological, and perhaps basic soil fertility data would be required, as opposed to potential pasture growth rates specific to a site. In some cases specification of general inputs may be tempered by the availability of the data. This was a consideration in the choice of meteorological data for input to the pasture model of Wright & Baars (1976). In their model input was confined to data which were commonly collected at most meteorological stations.

Despite the apparent numerical transparency of simulated results, in reality it is extremely difficult and time consuming to trace solutions through all of the intermediate steps that culminate in some high level output from a complex model. Choice of variables to output therefore requires considerable attention if one is to be able to understand and interpret objective function results. A feature of an experiment on a computer model however, is that it can be repeated exactly if desired, with different output collected.

In general more detailed output will be required during model development, to permit detection of departure from reality by individual components (Morley, 1977).

### 3.4 MODEL EVALUATION

Of the stages of modelling identified in Fig. 3.1 the methodology for evaluating a model was noted by Anderson (1974) as the 'least developed in terms of agreed procedures', and this appears to remain the case. The reasons for evaluating a model are clear. Since a model essentially represents an hypothesis of system structure and behaviour, its suitability for making inferences about real systems must be tested.

A model can be difficult to substantiate because it contains a large number of relationships. Also, many models are deliberate simplifications of reality, constructed for a specific purpose, and are often necessarily based on qualitative understanding about system operation (Van Keulen, 1976). For these reasons evaluation procedures have had to incorporate the notion of model acceptance in relation to the objectives for a model.

Procedures for evaluating models are reviewed in the following sections.

#### 3.4.1 Validation and Verification

The terms verification and validation have been used by many writers with respect to model evaluation (Wright, 1971; Anderson, 1974; Baker & Curry, 1976; Dent & Blackie, 1979; Spedding, 1980). There appears however to be a lack of concensus over the definition of these terms (particularly verification), and the concepts involved. One point of view represented by Wright (1971) and Hillel (1977) refers to verification in the literal sense, meaning 'proving the truth' of the model as a representation of reality. However Hillel (1977) points out that one can probably never aspire to having a

verified model in this sense, even if just for the reason that 'scientific philosophy refuses to accept any knowledge of the physical world as absolutely certain'. (Reickenback, 1951, quoted in Hillel, 1977). Spedding (1980) clarifies the above definition for practical purposes by considering verification to involve establishing that the mechanisms selected to be present in the model are correctly stated (biologically) at the chosen level.

A third position refers to verification as a procedure encompassing Spedding's definition but at a less formal level, which may simply involve a subjective assessment of the models' 'correctness', by the modeller (Anderson 1974). That is, ensuring the model behaves as expected, and intended. Under this definition verification forms part of the iterative process of model and sub-model development and testing, including debugging of the computer program (Anderson, 1974).

Validation is widely defined as the process of testing whether or not a model is acceptable, or suitable, for its intended purpose (Wright, 1971; Anderson, 1974). This definition obviously leaves scope for subjectivity in determining if a model is valid or not. In the extreme, a model could conceivably be considered valid if it satisfied the given purpose of quantifying one's mental model for the purposes of decision making, despite it not predicting the behaviour of the system with a high degree of accuracy. Usually though, acceptance relates in some way to whether the model is sufficiently accurate in reproducing data from the real system (Anderson, 1974). Discrepancies may be plainly too large to be tolerable, or they be systematic, suggesting a better fit for some variables than others. They may be cumulative, meaning that the model is sufficiently

accurate over short time periods to be judged valid, but predictions progressively worsen over a 'long run' (Hillel, 1977).

In the case of a 'black box' model (Wright, 1971), used to make decisions based on transformations of input into output from correlated responses, reasonable agreement between the model and observed data will be all that is required during validation. However in the case of a model used to guide basic research the model must behave in a similar manner to the real system for the right reasons (Benyon, 1972; Hillel, 1977). In the latter case the definition of valid can be seen to encompass verification as defined by Spedding (1980).

#### 3.4.2 Means of Comparing Model and Reality

It is generally accepted that the most rigorous means of validating a model involves comparison of a model's responses with those of the real system, when the conditions producing each are essentially the same (Benyon, 1972). Comparing output from the model and the system as a whole may not be totally satisfactory, since deviations from reality by some components of the model, may be internally compensated for by counter deviations in others (Benyon, 1972; Van Keulen, 1976). Inconsistencies may only surface at a later stage if the model is used in a different situation (Morley, 1977). To avoid these pitfalls, validation needs to be conducted by comparing small sections of the model with the corresponding section of the real system (Benyon, 1972).

Availability and suitability of data with which a model is required to agree, represent two major problems encountered in validation. One option is to use historically collected data, and in

cases where the modeller is not actively associated with a research programme, this will be the only option available.

The greatest challenge in using historical data is to guard against circular reasoning, by ensuring complete independence of validation data from that used to construct the model (Hillel, 1977). While this may seem an obvious pitfall to avoid, it is difficult to ignore data during model construction, especially where not much is available. A common trap is to allow data to subconsciously influence assumptions made in the model. The practical solution to ensure independence of data is to locate all data before construction commences, setting some aside for validation (Baker & Curry, 1976).

Other problems associated with using historical data arise through incomplete recording, or reporting of conditions that produced the results in the real system, hence preventing 'true' validation (Innis et al., 1980). Most commonly, driving variables such as rainfall or air temperature are not measured at, or near, the site of data collection. Further, incomplete specification of starting levels for state variables that influence the real system causes problems as does non specification of intermediate outputs of interest in validation.

Obviously, where possible, models are best validated against data experimentally obtained for the purpose following model construction.

### **3.4.3 Tests of Validity**

Where suitable information exists to enable validation to proceed, the next question concerns the criteria to be used for accepting or rejecting the model. Greig (1979) noted that despite the availability of statistical goodness-of-fit tests<sup>2</sup> enabling some

<sup>2</sup>See Section 7.3.

objectivity to be applied to such decisions, modellers have in general shown a reluctance to use them. One reason for this may be the problem of deciding at what stage the model should be considered valid, in other words, what degree of error should be accepted. Secondly, there is the problem of deciding at what stage a decision should be made to reject a model, as opposed to devoting further effort to improving its realism.<sup>3</sup>

Greig (1979) outlined a decision theory approach to choosing non-arbitrary significance levels for statistical testing of bio-economic models for decision making. He suggested that choice of significance level should be based on the costs and probabilities of making a type I (i.e. rejecting a valid model), or type II (i.e. accepting an invalid model) statistical error. He claimed that the level of significance chosen should aim to minimise expected losses resulting from type I and II errors.

The cost of making a type I error was assumed to equal the cost of reworking the model to gain acceptance, argued on the basis that one is unlikely to cease the modelling exercise (in which case costs would equal those already incurred) because presumably modelling was initially undertaken in the belief that benefits would outweigh costs. Assumed costs of making a type II error were those of making a wrong decision as a result of using an invalid model. On the basis that the cost of a type II error would be related to the size of the expected benefits from modelling, which should be larger than the cost of modelling (otherwise why model?), Greig provided examples to show that to minimise expected losses from type I and II errors, choice of

<sup>3</sup>This is more appropriate to bio-economic decision making models than research models.

significance level should usually be higher than the customary 5 percent level, to reduce the probability of making a type II error.

A second method of validation that has gained some acceptance, and which recognises the subjectivity of model validation, is the Turing test (Van Horn, 1971). This test involves presenting an independent expert with two (unidentifiable) sets of data, one produced by the model and the other in the real system. If the data sets cannot be distinguished, the model passes the test.

The Turing test is useful as a means for comparing time series data, such as animal liveweights. The problem of objectively comparing such data has been noted by Wright (1970). Also, where a model requires wide acceptance, such as by decision makers who may wish to use it, Turing tests are claimed to do much in fostering this acceptance (Greig, 1979). For this reason Greig recommends its use in conjunction with statistical testing.

In the foregoing discussion it has been assumed that data were available for validation. Where they are not, the best that can be done is subjective verification (the latter definition in Section 3.4.1) of model behaviour (Anderson, 1974). The logical danger in accepting a model as valid on this basis is that such a model would have doubtful utility when it came to extrapolating to regimes that were different to those already well understood by the modeller.

#### **3.4.4 Options Available if Model Invalid**

Reasons why a model may be invalid include (e.g. Hillel, 1977): (1) one or more essential variables may have been omitted from the model, (2) the effects of some variables may have been entered

incorrectly, (3) certain functional forms may be in error, or (4) there may be errors in some parameter values. In most cases there is likely to be a combination of the above errors, although the latter appears to have received most emphasis in the literature.

One approach to improving the agreement between simulated and observed results is to calibrate poorly quantified parameters to a set of observed data (Wigan, 1972; Van Keulen, 1976). The major argument against calibration is that for a model in which a large enough number of parameters are calibrated, it may be possible for the model to mimic observed data without it being structurally adequate (Wilson, 1977). However Woodmansee (1978) claims that this is an over-rated argument based on an analogy with polynomial models, which in general utilise parameters that have no biological meaning. The modeller is not at liberty to assign values to parameters which are not biologically justifiable, simply to force the model to agree with observed results. In addition, calibrated models still need to be validated against other sets of independent data to test their general applicability (Van Keulen, 1976).

The usual problem with calibration is that all available data are used up and no data remain for validation (Wigan, 1972). In these cases experimental justification must be sought for fitted parameter values.

A second approach adopted in the evaluation of an invalid model is sensitivity analysis (Van Keulen, 1976). Sensitivity analysis is claimed to help in establishing the importance of obtaining precise knowledge about different poorly quantified parameters in the invalid model (i.e. priorities for basic research (Sturgess, 1972; Anderson, 1974; Steinhorst et al., 1978). It is conducted in the absence of real

system data and the assertion is that the more sensitive the model is to changes in parameter value, the greater the need to quantify that parameter precisely (Anderson, 1974; Steinhorst et al., 1978) in order to validate the model.

A major problem with conducting sensitivity analysis on an invalid model, which has largely been ignored (an exception is Van Keulen (1976)), is that it remains doubtful whether genuine estimates of model sensitivity can be obtained using an invalid model. This is because of the possible effects of settings of other uncertain parameters on measured parameter sensitivity.

Consider an example where the values of just two parameters are uncertain. Sensitivity of model output (Y) to a change in one parameter (P1) may show the model to be insensitive to P1 when another parameter (P2) is set at its originally designated, but uncertain value (Fig. 3.2). However, if the same sensitivity analysis is conducted with P2 set at a 'changed' level, model output may appear very sensitive to changes in P1 (Fig. 3.2). It is these kind of interactions, where output sensitivity is itself sensitive to the structure of the model, or the setting of another uncertain parameter, that makes sensitivity analysis from an invalid model a possibly misleading activity.

### 3.5 EXPERIMENTATION

One of the problems with conducting experiments on a model is that unlike experiments conducted in the real system, the results are not obtained through the operation of real processes (Wright, 1973). Because of this, results must be assessed subjectively, being conditional on one's assessment of the realism of the model. The

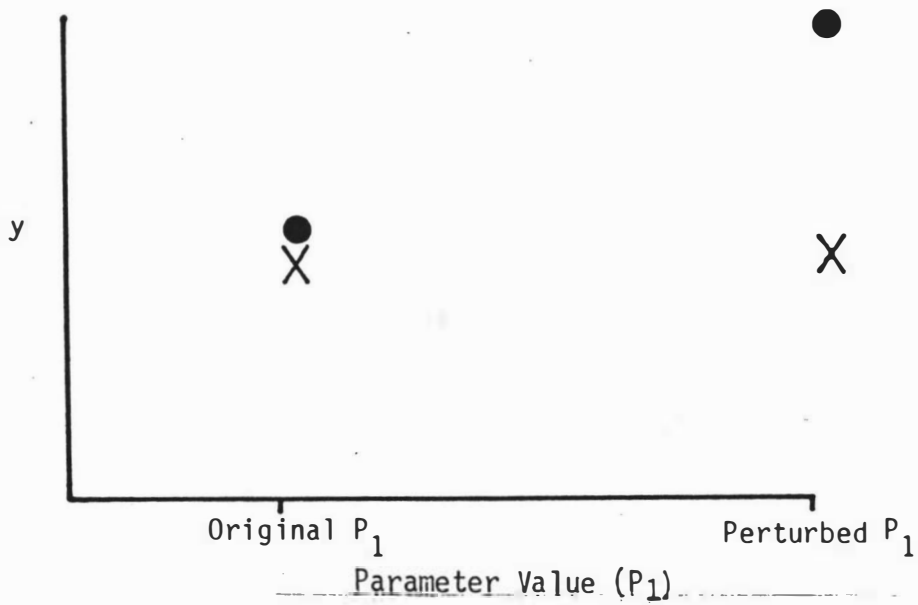


Figure 3.2 Effect of interactions between parameter settings on output sensitivity ( $y$ ) to a change in parameter value. Sensitivity of  $y$  to a perturbation in  $P_1$  with  $P_2$  at its 'original' level (X) and at a perturbed level (●).

confidence with which one moves to experimentation on a model will be influenced by the confidence gained in the model during validation.

Recognising the difficulty of making subjective judgements about the applicability of results from a model, Anderson (1974) suggested that a cautious approach to experimentation with a 'more or less' realistic model might be to conduct experiments on several versions of the model, each version containing a different form of an assumption or a different parameter setting of an uncertain parameter. This form of sensitivity analysis, while restricted by its clumsiness, may be helpful at least, in establishing the robustness of general experimental conclusions to different levels of realism, expressed in the different versions of the model.

There are two further major differences between the conduct of an experiment on a simulation model and in the real system. With a simulation model real time is compressed and the experimenter has complete control over experimental error and climate variability. The latter enables a sharpened focus on treatment differences and removes constraints imposed by climate on experimental design. A sequential approach to design (e.g. experiment, learning, rehypothesis and experiment) becomes possible, with each experiment conducted under the same climatic conditions. Apart from the above, simulation and real world experiments have much in common.

The main problems confronting similar experimentation, referred to by Anderson (1974), include; (a) the number of factors involved in most experiments, (b) the common situation of more than one response variable, and (c) the handling of stochastic elements, which may imply long simulation runs, or a large sample size. A further problem is the effect of starting states on simulation results (Wright, 1970).

Simulation experiments, whether conducted for an exploratory or optimising purpose, typically involve large numbers of experimental factors. Even considering the speed with which computer operations may be performed there will often be a need to economise on the size of the experiment to avoid inordinately large expenditure of computer time. Full factorial designs will often need to be replaced by more complex fractional factorial, rotatable, response surface, or related designs (see e.g. Hunter & Naylor, 1970).—With these designs there will necessarily be some confounding of effects. Usually high order interaction effects are confounded with main effects.

The analysis of multiple output responses such as fleece weight, lambing percentage, and lamb selling weight, for a sheep grazing system, implies a need for a multivariate analysis. In practice however, multiple responses are most simply combined into an appropriate index to produce a single response variable for analysis.

Sample size, or the number of computer runs (replications) required per treatment is only a concern when using stochastic models. The usual problem is that stochastic convergence is slow, which means that the number of runs required to obtain a suitable estimate of a mean response is high. This adds greatly to the cost of experimentation in terms of computer time.

The problem of how best to estimate the effects of climate variability is a concern with both stochastic and deterministic models. However no general consensus has been reached on the best method of doing this. It appears that choice of method has been tailored to suit the individual situation regarding availability of climate data. Alternatives include, comparison of responses in a single historical climate sequence (e.g. Wright, 1970), in a random climate sequence, in several random climate sequences, in mean climate

conditions (Anderson, 1974) or in equilibrium conditions in a number of representative good, bad and average years (e.g. Miller, 1983).

The problem with specifying starting conditions in a simulation experiment is that the initially specified states of the system may influence model performance for a period. This may occur for as long as two years with a grazing system model (Wright, 1970). Where a long run simulation experiment is being conducted the most practical solution is to discard output from a 'warm-up' period of two or three years. However where it is desired to study responses to a given year's climate pattern, this must be done under equilibrium conditions. That is, by running the model over and over until the starting conditions become the same as the output.

Finally, if knowledge of optimal factor levels is the objective for experimentation, a variety of optimising designs are available for use on a simulation model (see e.g. Harrison, 1978). Choice of optimum seeking method is covered by Harrison (1978) but is likely to depend to a large degree on availability of computer packages for optimisation. However, in comparison to programming techniques such as linear programming (see Thierauf & Grosse, 1970), deriving optima can be time-consuming and cumbersome where a large number of factors are involved. A simulation model is more suited to use for a general study of the optimal region.

### **3.6 REVIEW OF SOME GRAZING SYSTEM SIMULATION STUDIES**

Over the last decade there has been quite a number of grazing system models published. This must be due in part to initial curiosity prompted by the promise of an emerging technique for studying grazing systems. Before contemplating an addition to the

list of published models, there is clearly a need to assess progress made by previous studies, particularly in respect to the similarities and differences between the structure of different models and the degree of generality of structure achieved.

Some early grassland simulation models have been reviewed by Seligman (1976). The following represents a general review of the major features of more recently published simulation models relevant to this study.

### 3.6.1 Deferred Grazing Model (Smith & Williams, 1973)

The motivation for construction of this relatively complex grazing model was very specific. Namely to enable generalisation from a field experiment in Western Australia, to the effects of different lengths of deferment of grazing and different stocking rates, on pasture production and liveweight gain of sheep grazing subterranean clover pasture in the first 105 days post-seed germination. In the version of the model reported, the driving variables (sunshine hours, rainfall and pan evaporation) and starting conditions (density of viable seeds and plant weight and height and emergence) were taken from the field experiment. Pasture growth was treated in some detail but the sheep component was greatly simplified to predict just liveweight gain of dry sheep, based on a simple energy balance.

The structure of the pasture growth component of the model was quite general. Specificity was obtained by choosing parameters which fitted the field observations. All herbage grown was considered to remain green. This was probably a fair assumption within the bounds placed on the model. Maximum growth rate was taken from the literature on subclover. Actual growth rate was determined first by

two asymptotic functions, relating growth rate to level of radiation (sunshine hours) and leaf area index (LAI). Soil moisture and productivity effects were included as dimensionless (0-1) multipliers. The soil moisture multiplier and the ratio  $ET/PET^4$  were related separately to level of available soil moisture from 0 to 30 cm depth (based on field observations). PET was estimated from pan evaporation with adjustments depending on LAI. The soil productivity multiplier was used to scale simulated pasture production to observed levels at the field experiment site.

Total herbage intake was entered as a function of pasture height and cover (kg DM/ha), the function being multiplied by maximum intake per sheep, and stocking rate. Construction of the intake component was empirical and somewhat patchy. For example, daily increase in pasture height in the absence of grazing was assumed to be constant and independent of pasture growth rate, being derived from the average increase in height per day recorded in the field experiment. Decrease in pasture height due to consumption was assumed as the ratio of consumption/growth, multiplied by 0.16, again chosen to fit the field data. Finally, maximum intake per sheep was estimated as that which gave maximum liveweight gain in the field experiment (1.14 kg DM/day).

As expected predictions of the model were close to field observations. However, the scope of the model for studying different grazing systems is obviously limited. Of note was the general (adaptable) structure of the pasture growth component, a feature of which was the conscious omission of temperature effects on growth in a sward situation.

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<sup>4</sup>Evapotranspiration/Potential Evapotranspiration

### 3.6.2 LEYFARM (Arnold et al., 1977; Galbraith et al., 1980-81)

This model has been developed over a number of years, and comprises a pasture (Galbraith et al., 1980-81) and sheep (wethers only) submodel (Arnold et al., 1977). The total model, like that of Smith & Williams (1973) was based on an annual pasture grazing system involving subclover. However this model was more comprehensive than the former.

The major objective for the model was to develop a realistic predictor of grazing system behaviour which could be used to assess the effects of various management practices at locations within Western Australia. This purpose has already been achieved to a certain extent (Galbraith et al., 1980-81).

An earlier version of the pasture submodel was described by Seligman (1976) as being "unabashedly empirical". This statement was prompted by the fact that the components were based on statistical relationships (i.e. correlated responses) of grafted linear, or quadratic form, which fitted available experimental data. Subsequently quite an effort has gone into calibrating and validating the model against detailed data collected in the field (Biddiscombe et al., 1980-81). This has produced a version which behaves realistically (Galbraith et al., 1980-81).

Subclover seed set and germination were specified in detail. Potential growth rate was determined as an asymptotic function of green cover (in kg DM/ha). Grazing effects on growth were assumed to operate through a reduction in green cover, by consumption. Radiation, temperature, soil moisture and maturity effects on growth were entered as multipliers. Radiation effects were modelled complexly, based somewhat arbitrarily on a number of assumptions. At low green covers, potential growth rate, was unaffected by the level

of radiation owing to 'little competition between leaves for light'. As green cover increased, an increasing level of radiation was assumed to be required to achieve potential growth (see Fig. 3.3). The function was unreasonable at the extreme near zero radiation. At low green covers growth was unaffected, while at high green covers excessive respiration was implied (i.e. half of the potential growth rate).

Temperature effects on growth were included only below 1000 kg Green DM/ha (GDM/ha). Below 300 kg GDM/ha a quadratic function (optimum 20 °C) was assumed. Between 300 and 1000 kg GDM/ha temperature and radiation interacted to affect growth. Finally potential growth rate post-flowering was assumed to decline with time, in line with field observations.

Senescence rate was assumed to be 0 below 500 kg GDM/ha. Above this it increased exponentially with a factor to 'speed up' senescence rate post-flowering. Decay rate was related to temperature and dead cover, under wet conditions.

The animal sub-model was more general than that of Smith & Williams (1973), but still only described wethers under continuous grazing. Voluntary intake was represented as a function of liveweight, being dependent on age. The effects of accessibility and digestibility on selection and intake of green and dead grass and clover were included.

Wethers were represented by an energy balance specified in units of digestible organic matter. Maintenance requirements were increased at low pasture covers. Wool growth was specified from potential daily growth rate for wool, tempered by digestible organic matter intake, and percentage nitrogen in the diet.

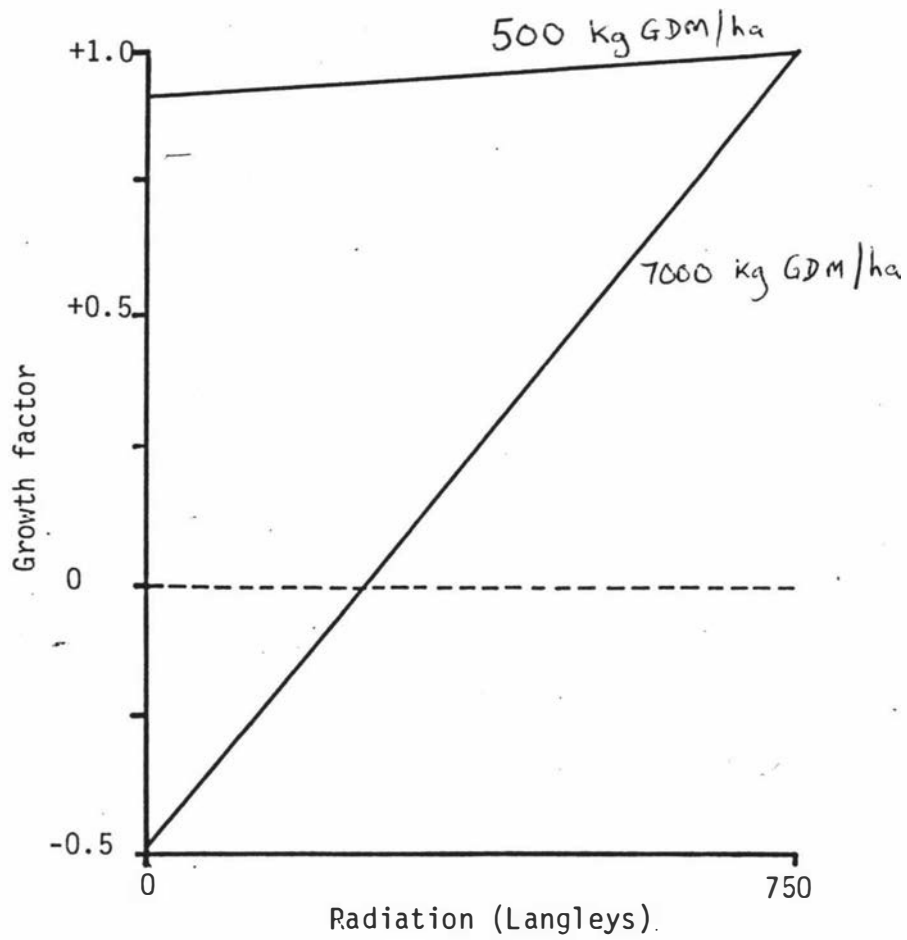


Figure 3.3 Effect of interaction between green pasture cover and radiation on the pasture growth multiplier in Galbraith *et al.* (1980-81).

Once again this model was tuned to a specific pasture type and a simple animal production system. It did not appear to lend itself readily to adaptation to other pastoral systems. However the pasture intake functions were adaptable.

### 3.6.3 CANPAS III (Fick 1978, 1980)

CANPAS was constructed as a skeleton model (e.g. Dent, 1975) of perennial pasture production (ryegrass, white clover) on farms in Canterbury, New Zealand. Pasture represented just one of the modules<sup>5</sup> of a total model intended for assembling as required, to simulate any specified mixed cropping farm in Canterbury.

The model predicts growth, senescence and decay. It is structured around an exponential pattern of pasture regrowth following cutting, and contains a number of arbitrary functions and ad hoc assumptions (added during development), which have been derived to account for the major observed climate and seasonal differences in pasture production as measured in a number of New Zealand pasture cutting trials. Predictions of pasture accumulation under a range of cutting regimes at Winchmore Research Station were reasonable. However, the model was not tested under grazing or lax cutting regimes. The structure of the model was not sufficiently general, conceptually, to enable simple adaptation to suit other environments, and grazing regimes.

Briefly, potential growth rate increased with increasing LAI until a critical LAI was reached, beyond this potential growth rate remained constant. Relative growth rate during the exponential growth phase was specified according to day length. However this function was overridden by a temperature function where the latter was more

<sup>5</sup>Other modules were to include wheat, lucerne and fat lamb production.

limiting. Both functions were derived empirically from New Zealand data. Critical LAI was described as a function of day of the year.

Soil productivity (fertility) was assumed to act on critical LAI, reducing it in less fertile soils. Fertility was assumed to be directly related to soil water-holding capacity below a water-holding capacity of 115 mm. The biological justification for these two assumptions was not made clear.

Finally, a drought injury parameter was included to delay the return to potential growth rate following a drought, and a ceiling restriction was set on total pasture yield (determined as a function of day of the year) such that growth was not permitted if it meant that the ceiling would be violated. One would have expected the model to predict its own 'reasonable' ceiling yields based on the balance between growth rate and decay rate.

Senescence was assumed to occur because of shading, drought and maturity. Senescence increased from 40 to 80 kg DM/ha/day (New Zealand measured rates), as green yield increased from 1 to 3 times green yield at critical LAI. Whenever the ratio of ET/PET fell below 0.1, 10% of green cover was assumed to senesce per day, and when green pasture digestibility fell to its minimum allowable level, senescence occurred at a daily rate of 5% of green cover above 500 kg GDM/ha. Decay rates were based on the model of Hunt (1977).

Prediction of herbage digestibility was quite complex (see Fick, 1978), but essentially the digestibility of two classes of green material (new regrowth and residual from previous regrowths) declined daily until a minimum level was reached. The daily rate of decline was a function of day of the year.

### 3.6.4 Net Growth Models (Wright & Baars, 1976; Baars, 1980)

Wright & Baars' model of perennial ryegrass, white clover pasture in New Zealand formed the pasture component of a beef grazing model reported on by Wright et al. (1976) and developed to investigate the role of modelling in agricultural research. The guideline for the pasture model was that it should respond in a realistic fashion to commonly available climate variables, and grazing management decisions.

The basic structure was simple. Twelve quadratic functions (one for the mid-point of each month) described net growth rate as a function of pasture cover, assuming average temperatures and non-limiting soil moisture. Each monthly function passed through zero pasture growth rate at zero pasture cover and at ceiling yield. Daily functions were obtained by linear interpolation.

Air temperature and soil moisture modified basic growth rate. The soil moisture multiplier (0-1) was set equal to the ratio of ET/PET, which in turn was a function of available soil moisture and PET (e.g. Denmead & Shaw, 1962). Soil moisture availability was defined in two horizons, a surface rewetting, and a lower horizon. Three ad hoc temperature factors were used to adjust basic growth rate. Growth rates were positively correlated with minimum air temperature from mid July to mid December, negatively correlated with maximum air temperature from mid-December to mid-April and positively correlated with maximum temperature from mid-April to mid-July.<sup>6</sup>

Baars' (1980) model was developed from the previously described model. The objective for further development was to produce a more widely applicable model<sup>7</sup> for use by Farm Advisers in simulating

<sup>6</sup>Mean monthly minimum or maximum temperature was taken as 1.

<sup>7</sup>The functions for the original model were for Waikato pastures.

pasture growth rates in regions, and under managements, not covered by existing field data.

The 12 quadratic functions relating growth rate to pasture cover were replaced by 12 exponential growth functions. Exponential coefficients were calculated from mean monthly radiation data at the site of interest. Maximum growth rates and ceiling yields were specified as a function of time of year. Changes were also made to the temperature functions.

The biggest problem facing the use of net growth pasture models, as part of a sheep grazing system model, is that pasture is not partitioned into green and dead DM. This is likely to result in over-estimation of pasture available for grazing, particularly in late summer-autumn, since sheep almost totally neglect dead pasture.

### 3.6.5 Breeding Ewe Model (White, 1975, 1976; White et al., 1983)

This model was constructed to study grazing systems involving the breeding ewe in Australia. It describes a self-replacing flock of Merino ewes grazing annual pastures in North Victoria. A specific application of the model has been in evaluating the economic and biological consequences of changes in stocking rate and lambing date and it contains a number of decision rules and economic assumptions related to the above use.

The model increments in time-steps of one week. Only continuous grazing is allowed, with all sheep grazing one paddock. Allowance was made for ewes in different physiological states within the mob, by maintaining a number of cohorts from conception to weaning. Each cohort contained either single or twin-bearing ewes mated over a period of two weeks.

Major emphasis was placed on the animal component of the model. In comparison, the pasture component was less developed. Potential pasture growth was specified relative to week of the year. This was reduced by an assumption, when mean air temperature was less than 10 °C, and when green cover was less than a critical level. This level was related to potential growth rate.

Losses from green pasture were assumed through trampling, which was related to stocking rate and senescence, estimated as a function of total pasture cover, and soil moisture uptake. Decay was predicted relative to rainfall in the preceding fortnight.

Digestibility of green herbage declined both with time from germination of annual species and with increasing green cover

Digestibility of dead herbage declined from 55 to 35% through summer, the rate of decline being hastened following rain.

Voluntary intake was calculated as a function of expected (normal) liveweight of a sheep of a given age. During lactation, voluntary intake was adjusted for potential milk production on the assumption that a ewe producing 3.6 kg milk/day would have an intake twice that of a dry ewe. The proportion of voluntary intake consumed depended on herbage digestibility (increasing up to 85%) and availability (increasing up to 1500 kg DM/ha). Intake of green herbage was calculated first, then potential intake of dead DM was set as the amount of voluntary intake not satisfied by green DM intake.

Suckling lambs were assumed to eat only green herbage. Potential herbage intake was calculated by subtracting milk intake (kg organic matter/day) from potential intake of the lamb. Calculated herbage

intake was, where necessary, reduced to conform to potential intake determined by lamb age and level of milk consumption.

The nutritional value of ingested feed was based on the metabolisable energy (ME) it contained. The general approach to the partition of ME intake between maintenance and production was similar to the scheme developed by ARC (1965).

Fasting energy requirements were calculated as a function of age and metabolic liveweight. These were multiplied by an exercise factor to account for grazing activity and climatic conditions (highest in winter). Maintenance ME was calculated from fasting requirements by allowing for the efficiency of energy utilisation for maintenance (KM). Surplus ME was retained in the body with an efficiency (KF), dependent on ME concentration of the diet. Energy loss from the body equalled ME deficit multiplied by KM. Change in liveweight depended on the energy value of the gain, which was related to liveweight.

If a ewe was pregnant, obligatory ME requirements were specified depending on litter size and day of pregnancy. Requirements were independent of lamb birth weights, which were calculated in retrospect from ewe liveweight at lambing and change in ewe liveweight over the 6 weeks preceding lambing.

Potential milk production was calculated for single and twin-bearing ewes, as a function of week of lactation, scaled by lamb birth weight. Actual milk yield was assumed to be reduced in relation to anticipated energy deficit. ME used for pregnancy and lactation was added to maintenance prior to calculating energy retention by the ewe.

Potential weekly wool growth rate was specified from potential annual fleece weight for a dry sheep (an input) by allowing for seasonal variation in wool growth. Actual weekly wool growth rate was then related to ME intake (less that used for pregnancy or lactation) and potential ME intake of a dry ewe.

Ewe fecundity was determined first from ovulation rate, which was related to month of the year, ewe liveweight at mating, and ewe liveweight change three weeks prior to mating. Then possibilities of fertilisation failure (higher in spring than autumn) and embryo mortality (dependent on fecundity status - single or twin, mating liveweight and ewe liveweight change over 21 days post-coitus), were assumed. Finally, lamb survival to weaning was based on lamb birth status (single or twin), birth weight and mean weekly climatic conditions at lambing.

Despite many of the parameters having been derived from data on the Australian Merino (e.g. potential lactation curves, lamb birth weight, and reproductive parameters), the basic structure of this model appeared quite general and adaptable.

### 3.6.6 Sheep Model (Vera et al., 1977)

This model was constructed to further develop range models existing at the time of construction. It represented energy intake and utilisation by the grazing ewe.

Like White's model this model used the ME nutritional approach. A major difference between the two models was the method of calculating energy deficits in pregnant and lactating ewes. Vera et al. assumed separate partial efficiencies for mobilised energy in satisfying the requirements of maintenance, pregnancy and lactation. So for a

pregnant ewe in negative energy balance the efficiency of dietary energy use for pregnancy was 0.2, and mobilised energy 0.25. For lactation the respective efficiencies were 0.7 and 0.85, and for maintenance they were KM and 1.0. White, by adding ME requirements for pregnancy and lactation to maintenance, assumed the same percentage increase in efficiency of energy use from mobilised energy for pregnancy and lactation as for maintenance. For example, if KM was 0.7 partial efficiencies for dietary and mobilised energy would be 0.2 and 0.285 for pregnancy, and 0.7 and 1.0 for lactation.

Other differences included: (1) specific calculations of energy used in walking and grazing, (2) allowance for predicted lamb birth weight in describing requirements during pregnancy, and (3) potential milk yield for ewes in negative energy balance was specified by placing an upper limit to body energy mobilisation, with potential yields being reduced where ewe liveweight declined below -17% of 'normal' liveweight.

### 3.6.7 Sheep Model (Graham et al., 1976)

This model was constructed as a first attempt at a general model which can simulate the processes of digestion and metabolism in sheep for any situation.

This is probably the most comprehensive published sheep model. It treats both nitrogen and energy utilisation in sheep of any age or physiological state, on a daily basis. It also has an environmental component influencing heat loss from the shorn sheep. Amino acids (nitrogen) made available from the diet are partitioned between the various body functions depending on requirements, in much the same way as ME is partitioned. Potential production of wool, conceptus and

milk, are tempered by the availability of both nitrogen and energy. The composition of body gain or loss (protein or fat) is dependent on the nitrogen and energy balance after the productive obligations are met.

Relationships describing nitrogen use were derived empirically and the authors caution against using the model beyond the bounds of the original observations. However predictions of lifetime body composition are quite reasonable. One of the problems in applying such a model in a grazing system model, is the lack of information for quantifying levels of crude protein in pastures. The final decision on adapting such a model must however rest on whether the extra complexity is justified by the objectives for the model.

#### 3.6.8 Grazing Model (Christian et al., 1978)

This model is probably the most comprehensive grazing model designed for application in practical farm decision making. It has been constructed to enable examination of a wide range of grazing management decisions for a number of mobs of sheep and has an optimisation routine.

Parameters for determining relative net pasture growth rate were user specified. Green herbage was assumed to pass through a range of digestibility classes. The rate of maturation was a function of season. Material was lost from each digestibility class by decay. Potential intake was progressively satisfied from successive classes of herbage, in descending order of digestibility. The contribution from each class depended on its digestibility, availability, and the proportion of potential intake not previously satisfied.

The sheep component was similar in structure to White (1975) and Vera et al. (1977).

### 3.6.9 Grazing Model (Edelsten & Newton, 1977)

This model was built as part of an overall research programme to specify an optimum lamb production system for lowland farmers in Great Britain.

The model simulated a flock of ewes and lambs from the time of lambing until lambs were sold. Emphasis was placed on evaluating economic returns resulting from manipulation of grazing rotations, concentrate feeding, silage conservation, lambing dates and stocking rates. Many features of the system were treated simply. For example net pasture growth was entered as a table from cutting data and digestibility was related to time of year.

The most interesting feature of this model was that each animal in the flock was modelled individually. The internal dynamics of the model were deterministic, but each animal was assigned a factor from a normal distribution of factors of specified standard deviation and mean equal to one. This factor was used to adjust the predicted (mean) intake and potential milk production for that individual. Initial weights, birth dates and birth status of the lambs were set at the beginning of the simulation.

While individual animal specification appeared to be justified in simulating the very intensive systems represented by this model, the additional execution time required makes it impractical for most situations.

### 3.6.10 Intake Model (Sibbald et al., 1979)

Sibbald et al. have produced a conceptual model of herbage intake as a basis for predicting herbage and diet quality at a range of stocking rates and grazing management strategies. Herbage was represented as quantities in discrete digestibility classes, ranging between 34 and 80%. Each class covered 2 digestibility units. New growth entered weekly at 80% digestibility. The proportion of each class deteriorating to the next class was calculated relative to digestibility, from one of three functions derived empirically for different times of the year. Deterioration from the lowest digestibility class was lost from the system.

Diet selection was modelled by the allocation of 100 'bites'. Under random selection the number of bites allocated to each class would be proportional to the amount of herbage each contained. A conceptual selection index was calculated relative to grazing pressure (predicted DM intake/DM present) to determine selection bias for each digestibility class (i.e. the multiple of randomly allocated bites allocated to a class). Selection was then restricted by a maximum percentage of herbage that could be removed from each class, and a second maximum percentage removal where a class contained less than 5% of total herbage.

The model appeared to give reasonable predictions of diet digestibility when compared to field data, but was not widely tested.

## 3.7 CONCLUSIONS

From the foregoing it can be seen that there are a number of published models which have general relevance to this study. Each differs in terms of the objectives for their development, and in degree of generality. Most structures contained some empirical and

ad hoc relationships, if only to make them fit observed data from the system of interest, so that they could be used for experimentation.

Ad hoc relationships appeared to be most prevalent in the pasture and intake components of models, where no generally accepted structure emerged. The animal components were in the main based on the ME nutritional approach, and showed a great deal of similarity in the way energy was partitioned.

Another common feature of the models was that one component (e.g. pasture, animal or management) was treated in much greater detail than the others. Obviously the stated objectives for the model had some influence on this, although it is suspected that disciplinary orientation of the modeller(s) may also have had an influence.

None of the models reviewed were completely suitable for use in studying NIHC grazing systems because they were tailored towards specific pasture types, topography or classes of stock not applicable to New Zealand's NIHC. In addition no model was general enough in structure to be easily adapted simply by altering the value of a number of parameters. Some preliminary results of a modelling effort that has been going on in NIHC have been published by Field et al. (1981). However details of their model were not published, except to state that it was driven by pasture cutting data which were adjusted by a seasonal multiplier to fit observed growth rates under set stocking. The objectives of the model were to aid in management decision making (i.e. appropriate stocking rates) in farmlot trials. However the preliminary nature of the work was emphasised.

The unsuitability of any single model, coupled with the difficulties in adapting another person's model (see Section 2.4.1.2), determined that it would be necessary to construct a new model to

study NIHC grazing systems. Despite being an ambitious aim it was desired to make this model as conceptually general (biologically meaningful) in structure as possible, to enable it to be readily adapted, say to other sheep grazing systems in New Zealand. The published models did however, provide a good base from which to start, particularly the animal components of these models.

## Chapter 4

### INTRODUCTION TO MODELLING STUDY

#### 4.1 INTRODUCTION

To deal with the stated aim of investigating opportunities for increasing production on NIHC sheep farms, using a systems approach, it was first necessary to conduct a thorough search of the relevant literature, and to assemble information describing the system into a model, as a statement of current understanding about the system.

The need to construct a new model, rather than adapt an existing model was discussed in Section 3.7. However, existing models, and in particular the model of White (1975), provided a base to start from.

In this Chapter a brief overview of the system under study is presented, an introduction to the structure and boundaries of the model are given and sources of data used in model construction are discussed. Following, in Chapters 5 and 6, the initial version of the model is described. Subsequent modifications to components of the model, based on component evaluation, are discussed in Chapter 7 and in Chapters 8 and 9 results of experimentation on the model are presented and overall conclusions are discussed.

#### 4.2 BRIEF DESCRIPTION OF NIHC GRAZING SYSTEMS

Physical features of NIHC pastoral land, and its production statistics, are reviewed by Hight (1979). The aim in constructing the grazing model was to represent only those farms developed in terms of pasture, subdivision and stock water reticulation. Neither the technology involved in developing pastures, nor the economics of pasture development and subdivision were at issue.

On most hill country farms there is a lack of ploughable land. Hence, systems are constrained by an inability to grow forage crops, or conserve surplus pasture. Animal production systems comprise mainly breeding ewes and cows and their replacements, with varying degrees of finishing of male lambs and beef weaners. The degree of finishing tends to depend on land contour and fertility, and summer rainfall. Animals not finished are generally sold as stores in either early summer or autumn, in the case of lambs, or at autumn weaner sales in the case of calves. Surplus ewe lambs are usually either sold as ewe lambs in late summer or as two-tooths one year later.

The challenge to grazing research is to devise systems that achieve most efficient utilisation (economically) of pasture grown, and to identify and where possible alleviate, technological constraints to system improvement.

### 4.3 DETAILS OF MODEL ORGANISATION

#### 4.3.1 System Boundaries

The conservation and feeding of hay or silage, or the growing of forage crops, is not practical on many NIHC farms. Since this reduced flexibility is a major problem confronted by hill country farmers, perennial pasture was the only feed source considered in the model.

Despite the presence of cattle on many NIHC farms, sheep were the only animal species represented. Cattle, were omitted purely to limit the size of the study. However in recent years there has been a trend toward sheep only systems in NIHC (NZMWBES, 1984b). One reason for this has been the long-term comparative economic advantage of sheep over cattle (NZMWB, 1984b). As well, there has been a growing realisation that sheep alone, are capable of controlling spring

pasture if appropriately managed, negating one of the traditional roles for cattle.

While recognising that economic circumstances could readily change, and that factors such as weed control and complementarity between species (e.g. for feed and labour requirements) will ensure the place of cattle in many systems, it was considered relevant to study sheep grazing systems in light of their technical and economic possibilities.

Even within sheep grazing systems it was not possible to investigate all opportunities for increasing production in the time available. Incorporation of hoggets and hogget lambing into the systems were not studied, although data concerning these aspects were assembled in the model.

#### 4.3.2 Model Type

Simulation was the method chosen for this study.<sup>1</sup> The appeal of simulation lay in the lack of restriction on model structure, and on the form of relationships in the model. This allowed complex relationships in the grazing system to be expressed relatively easily. It also allowed flexibility to develop and evaluate specific components of the model in isolation, by altering input and output to suit the situation. A drawback of simulation (noted in Section 3.5), is the lack of optimising ability possessed by techniques such as linear programming. This means that alternative systems cannot be compared under conditions where all other control decisions are at their optimum levels, and comparisons may be affected by these decisions.

<sup>1</sup>The computer program was written in Fortran 77 for running on a PRIME 750 computer.

### 4.3.3 Time Unit

Components of the model were standardised to a time period of 1 day. One day is an often quoted unit of time in the pasture literature, and in the sheep literature levels of rationing and intake are also often expressed on a daily basis. Longer time units of one or two weeks, while saving on computing time, were ultimately considered unsuitable because grazing decisions in intensive hill country systems, such as length of rotation, or time between shifts, are usually made in multiples of days rather than weeks.

## 4.4 SOURCES OF DATA FOR MODEL CONSTRUCTION

NIHC is serviced by a relatively small number of research scientists. The two major research stations, Whatawhata and Ballantrae, at present employ in the vicinity of 14 and 6 scientists, respectively, and a number of regional satellite stations each employ one or two scientists. Past research commitments to the application of current knowledge to specific hill country problems, resulted in a situation where at the commencement of the study, little information of a suitable nature for model construction existed for the hill country environment. This initial problem was circumvented by the assumption that much of the basic information relating to perennial pastures and animals in other environments would apply to the hill country environment, with appropriate adaptations.

In general, greater difficulty was experienced in obtaining suitable data for the pasture component than the animal. The only published information on hill country pasture growth related to descriptions of the annual pattern of net production assessed by the trim technique (Radcliffe, 1974), on varying aspects at a number of

sites (Gillingham, 1973; Suckling, 1975) and under varying fertiliser treatments (Suckling, 1975; Lambert et al., 1983). As such, the data lacked the detail required for model construction on both the dynamics of pasture production under grazing, and the environmental determinants of growth. It did however show that, unlike the reasonably homogenous environments described by other grazing models, pasture production in the hill country environment varies markedly between sites of different slope and aspect within a farm. This is because of differences in microclimate, soil fertility and species composition between aspects and slopes and makes it difficult to establish the concept of a representative pasture.

On the other hand the relationships used in a sheep component were relatively well researched. An extensive recent review of animal responses to dietary energy (ARC, 1980) and many of its sources, provided data for the sheep component.

The review accompanying the description of model components was not exhaustive. No attempt was made to discuss all of the literature on the various components. Rather, major works yielding estimates of the important functions and parameters, as determined by structure of the model chosen, were reviewed. The functions derived varied in complexity from simple linear functions, to more complex logistic functional forms. A complex function was used where there was substantial evidence to support its use or where, conceptually, it appeared to be the best choice. In other instances linear functions were adopted as a first approximation.

#### 4.5 DESCRIPTION OF THE MODEL

A description of the relationships used in the model is given in Chapters 5 and 6. Because the same basic relationships could conceivably be structured differently in a simulation model built by another person, no program listing has been included. However all of the biological relationships contained in the model are presented in Chapters 5 and 6.<sup>2</sup> These are given either in equation form or as a graph for simple linear or grafted linear functions.

<sup>2</sup>Note also some alterations to basic components which are given in Chapter 7.

## Chapter 5

### THE PASTURE-SOIL COMPONENT

#### 5.1 INTRODUCTION

The approach adopted in many previous pasture models of limiting the model to a specific area or a few species based on empirical data was not suitable for this model because of data limitations and difficulties in establishing what constituted a representative hill country pasture (see Section 4.4). This prompted the move towards construction of a more general model which could explain variation in pasture production between sites and aspects on hill country, based on differences in the environmental determinants of production. The pasture was treated as an ecological entity, thus avoiding the question of the effects of species composition on the pattern of production. Species composition was assumed to be determined by soil fertility.

A pasture may be viewed as a dynamic system consisting of two states, live (green) and dead, with tissue flows occurring between these states and both into and out of the system. Live tissue enters the system as a result of photosynthetic activity by the sward. If not consumed by a grazing animal, it will eventually senesce, flowing into the dead pool. Tissue in the dead pool is lost from the system via decomposition, or removal by soil flora.

In this Chapter factors included in the model which affect tissue flow rates are discussed. They are shown diagrammatically in Fig. 5.1. A relevant review of tissue dynamics within a sward, sighted after construction of this part of the model, is given by Hodgson et al. (1981).

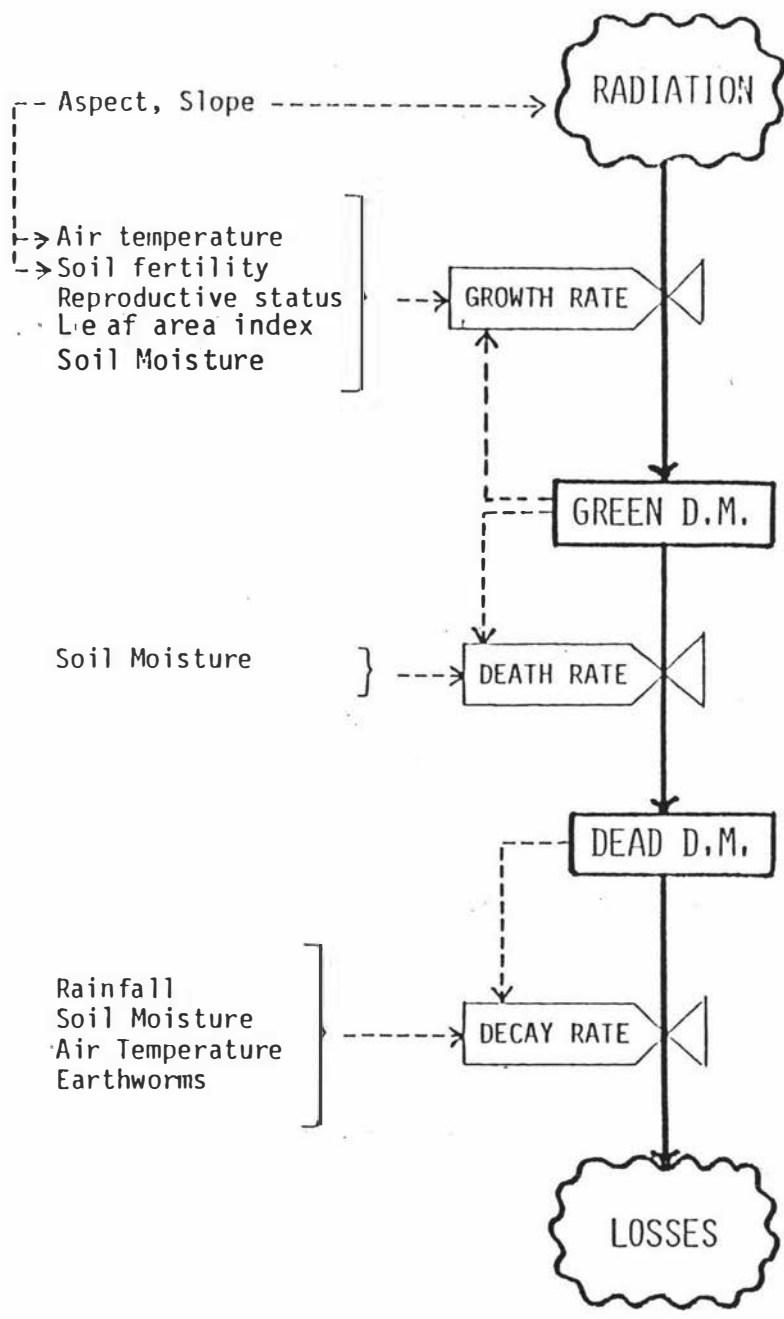


Figure 5.1 Flow diagram of pasture production.

## 5.2 THE GENERAL PASTURE MODEL

### 5.2.1 Estimation of Growth Rate

Despite it being possible to predict pasture growth by correlation to any major growth limiting factor e.g. soil water availability over summer (Scotter *et al.*, 1979), or temperature (Baars & Waller, 1979; Field, 1979), the starting point for photosynthesis is energy supplied by solar radiation. In the absence of limitations by other factors the level of photosynthesis conducted by a plant is governed by the amount of solar energy received (Alberda, 1962; Sheehy & Peacock, 1975). For these reasons radiation was chosen as the variable to 'drive' the pasture component of the model.

The efficiency of radiation use for photosynthesis is influenced by a number of factors. Hesketh (1963), Cooper & Tainton (1968) and Sheehy & Peacock (1975) all demonstrated that leaves of different pasture species differ in the efficiency with which they conduct photosynthesis. As well, differences occur between leaves formed during reproductive and vegetative stages of pasture growth (Woledge & Leafe 1976). Upper limits to the efficiency of radiation use in the model were specified depending on soil fertility and reproductive status of the sward. Attainment of the upper limit depended on the light intercepting ability of the sward, as assessed by its leaf area index, air temperature, and soil moisture levels.

#### 5.2.1.1 Potential Growth in a Closed Canopy

It was assumed that in a closed canopy (i.e. above critical LAI), since a sward intercepts in excess of 95% of incoming radiation (Brougham 1956), net photosynthesis<sup>1</sup> should be proportional to energy

<sup>1</sup>That is net photosynthesis determined as the increase in plant dry weight per unit area, resulting from gross photosynthesis less photosynthate used up in respiration associated with growth.

supplied by solar radiation. Despite Sheehy & Peacock (1975), Woledge & Leafe (1976) and Sheehy (1977) all observing gross carbon influx to approach an asymptote in pastures at high radiation intensities, saturating light intensities would seldom be experienced by pastures in New Zealand, except for short periods on some summer days. Net photosynthesis was therefore assumed to be directly proportional to daily radiation receipt.

A relationship was derived between daily radiation and net photosynthesis ( $\text{g DM/m}^2/\text{day}$ ) by assuming net photosynthesis to be reasonably approximated by crop growth rate for pasture, estimated by the regression of plant dry weight over time, under frequent assessment in favourable conditions (W.G. Duncan pers. comm.).

Maximum crop growth rates (CGR) for pasture are reviewed by Cooper (1970). From New Zealand work reviewed maximum CGR appears to be about 18 to 19  $\text{g DM/m}^2/\text{day}$ , measured by Brougham in pure ryegrass swards in spring. Average radiation levels were 510 Langleys/day.<sup>1</sup> Assuming energy is stored in pasture at 18 J/g DM, this represents an efficiency of energy utilisation of 1.56%, or expressed as the relationship between net photosynthesis and daily radiation,  $0.037 \text{ g DM/m}^2/\text{Langley}/\text{day}$ .

Pasture growth rate was calculated from net photosynthesis less the fraction of total sward weight used by daily maintenance respiration (MR) (see Sheehy et al., 1979). A constant of 1.5% of sward weight was assumed by Sheehy et al. (1979) for MR in their detailed physiological model of ryegrass growth. However here, MR was assumed to be related to temperature (A.P. Chu pers. comm.) and was

$$1 \text{ Langley} = 1 \text{ cal. cm}^{-2} = 4.186 \times 10^4 \text{ J.m}^{-2}$$

increased linearly from 0 at 4 °C with a slope of 0.09375 percentage units per degree C.

On most hill country soils, soil fertility restrictions will limit maximum CGR well below that described by Brougham for a highly fertile soil. Assessment of the upper limit to efficiency of radiation use on a soil is difficult, owing in part to the number of nutrients that affect growth. However, phosphate status has been recognised to provide a good index of soil fertility status (e.g. Smith, 1979). The annual yield response to increasing application rate of phosphate on a given soil is asymptotic (Lambert, pers. comm.), with yield at zero applied phosphate reflecting the residual fertility of the soil. The effect of soil fertility on the efficiency of net photosynthesis (PSlope) could therefore reasonably be expected to follow a similar trend. No attempt was made to quantify such a relationship, except to establish guidelines to upper and lower limits.

The upper limit of PSlope on a highly fertile soil was assumed to be  $0.04 \text{ g DM/m}^2/\text{Langley/day}$ , based on Broughams' results (Cooper, 1970). The lower limit, at zero fertiliser, will vary depending on soil type. However assuming maximum growth to be 30 to 50% higher than the measured average (Brougham & Glenday, 1969), and average radiation at maximum growth to be 500 Langleys/day, an approximate value of  $0.02 \text{ g DM/m}^2/\text{Langley/day}$  can be calculated for southern North Island hill country from Lambert & Roberts, (1978).

Grasses display a greater efficiency of radiation use during the reproductive phase of growth than during the vegetative phase (Anslow & Green, 1967; Hunt & Field, 1978). This increased efficiency has been attributed to both increased leaf efficiency (Leafe et al., 1974) and a change in nutrient partitioning

between root and aerial growth in favour of the latter (Ryle, 1970).

In the field, reproductive growth for ryegrass dominant pastures appears to be in the order of 23 (Noble, 1972) to 41 percent (Anslow & Green, 1967) greater than vegetative growth under similar environmental conditions, with adequate soil water. Theoretical relative efficiencies of ryegrass growth throughout the year, at Palmerston North, are described by Hunt & Field (1978). Initiation of reproductive growth occurs around mid-July. Emergence of inflorescences begins from the start of November (Wilson, 1959) and the reproductive cycle is completed by mid to late December. In browntop (Agrostis tenuis) dominant pastures, reproductive growth commences about one month later than for ryegrass, it is of shorter duration and there is a more marked difference between peak reproductive, and vegetative growth rates (Lambert unpub. data).

The relative pattern of efficiency in Hunt & Field (1978) was taken as the basis of the index used to determine seasonal efficiency of net photosynthesis for ryegrass dominant pastures. Efficiency in the vegetative and early reproductive stages of growth from Hunt & Field, was constrained to a lower limit of 76% (Curve 1, Fig. 5.2) of peak efficiency, in line with data of Noble (1972). This is higher than for ryegrass alone and allows for the presence of other pasture species that do not exhibit the same seasonal efficiency pattern as ryegrass. The assumed pattern of seasonal efficiency for browntop dominant pastures is shown on curve 2, Fig. 5.2.

Composition of the pasture, that is ryegrass or browntop dominant, was assumed to be correlated to soil fertility. At the lowest soil fertility parameter setting, browntop relative seasonal

efficiencies were assumed, and at the highest the ryegrass curve was followed. Linear interpolation was conducted between these extremes.

To the authors' knowledge, no New Zealand hill country meteorological stations are equipped with Eppley pyranometers or equivalent recorders for measuring radiation. Most do, however, have Campbell-Stokes sunshine hour recorders. Angstrom (1924) developed an equation to describe the relationship between daily sunshine hours and radiation (Q), enabling sunshine hour data to be used to drive the model.

$$\text{The equation: } Q/Q_0 = a + b \times (n/N) \quad (5.1)$$

has constants a and b which are determined by least squares procedures from a series of simultaneously measured radiation and sunshine records (n) to give an empirical fit for different geographical regions. De Lisle (1966) published values for a and b, for five New Zealand regions averaged over the years 1954 to 1965. Values for  $Q_0$ , radiation per unit time and area outside the atmosphere, and N, maximum possible sunshine hours, can be obtained for any latitude from Smithsonian tables in List (1951), p. 418 and sunrise, sunset tables, respectively.

The weakness of Equation 5.1, is that it does not account for the fact that in reality a small increase in n at noon has the same effect on Q as a larger increase in n near sunrise or sunset (Revfeim 1981). Revfeim proposed a model which used hourly sunshine records. It had an accuracy of prediction of,  $r = 0.99$ , compared to  $r = 0.94$ , for Equation 5.1. However hourly sunshine records are not available without re-analysis of sun cards so Angstrom's equation was used to convert sunshine hours into solar radiation, in Langleys.

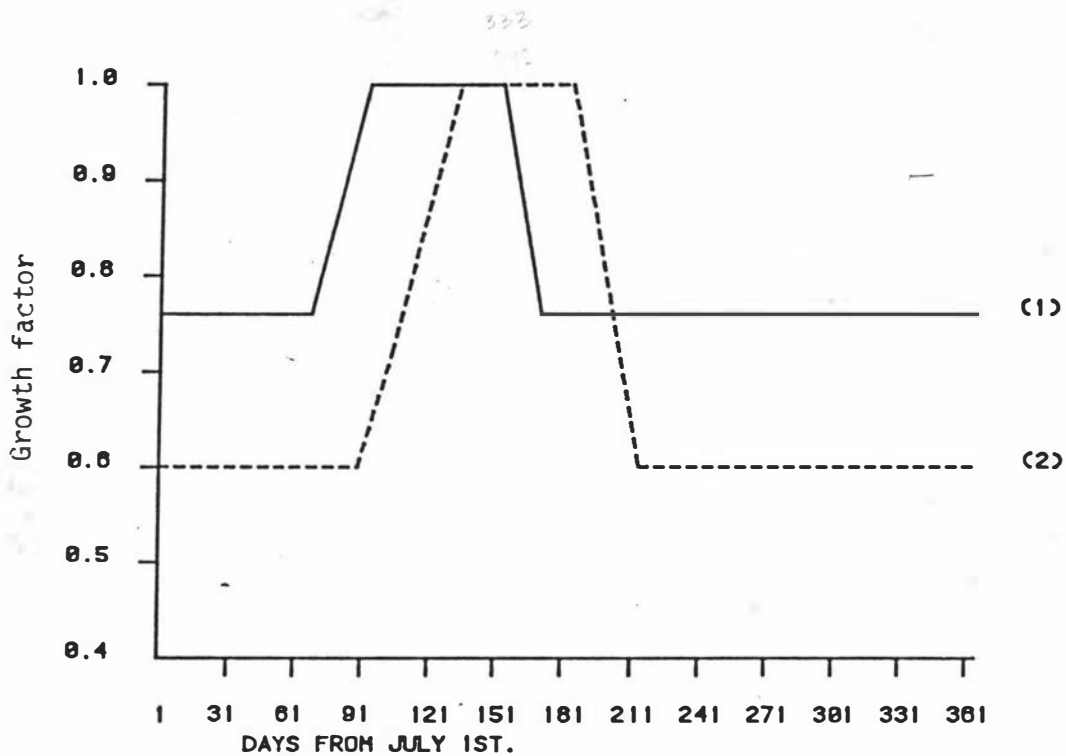


Figure 5.2 Relative seasonal efficiencies of pasture growth. Curve 1 represents ryegrass and curve 2, browntop dominant pastures.

#### 5.2.1.2 Growth in a Non-closed Canopy

The proportion of total radiation intercepted by a sward is commonly related to its leaf area index (LAI). Assuming similar photosynthetic efficiencies between leaves of different ages, a close relationship should exist between LAI and growth rate, so that growth rate should increase with increasing LAI until full light interception ( $L_{crit}$ ) is achieved. Brougham (1956) established such a relationship. Above  $L_{crit}$ , LAI appears to have little effect on the rate of net photosynthesis, according to studies reviewed by Brown & Blaser (1968).

Critical LAI is largely dependant on sward structure and in particular the positioning of the leaves. Erect swards that maintain their leaves at an acute angle exhibit a higher  $L_{crit}$  than prostrate, horizontal leaved swards. Sward structure changes to become more erect during the reproductive phase of growth. This results in a higher  $L_{crit}$  during late spring regrowths (e.g. Anslow, 1965, Leafe et al., 1974, Tainton, 1974) than during vegetative growth in autumn and winter.

Utilising the data of Leafe et al., (1974), relative light interception was derived for the reproductive and vegetative growth phases, depending on LAI (Fig. 5.3). Critical LAI for reproductive and vegetative growth was 6 and 3.75, respectively. Interpolation between the two curves was governed by the seasonal efficiency index in Fig. 5.2.

Despite LAI having been successfully related to total pasture cover (kg DM/ha) (Brougham, 1956; Brougham & Glenday, 1966), a relationship solely with green pasture cover was sought to avoid bias associated with build-up of dead matter following repeated lax

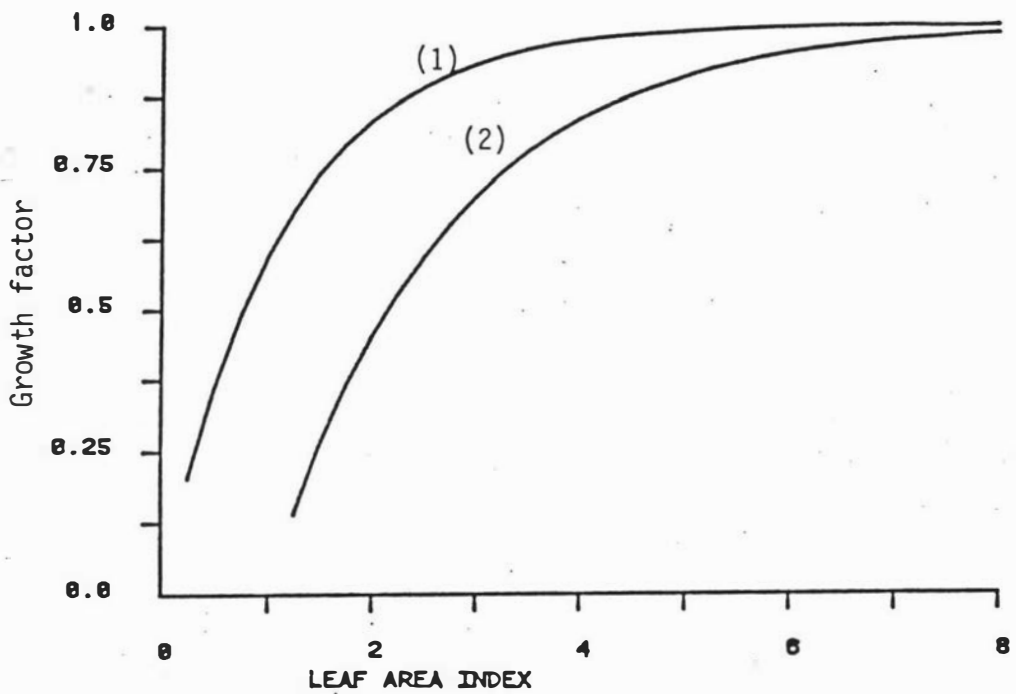


Figure 5.3 Relative effects of LAI on pasture growth.  
 Curve 1 = vegetative and Curve 2 = reproductive swards.  
 Curve 1 =  $1 - \text{EXP}(-0.9 \cdot \text{LAI})$   
 Curve 2,  $\text{TV} = \text{LAI} - 1$   
 $\text{IF}(\text{TV} \cdot \text{LT. } 0.01) \text{TV} = 0.01$   
 Curve 2 =  $1 - \text{EXP}(-0.6 \cdot \text{TV})$

grazing. Individual regrowths in studies conducted by Hunt (1970), Tainton (1974) and Sheehy & Peacock (1975), were analysed. A unit increase in LAI corresponded to between 625 and 313 kg GDM/ha. A median value of 370 was chosen for the model. From this relationship  $L_{crit}$  was reached at approximately 2200 kg GDM/ha and 1400 kg GDM/ha during the reproductive and vegetative stages of growth, respectively.

Rate of pasture regrowth following grazing was expressed solely in terms of the light intercepting ability of the sward. In reality level of root reserves (Harris, 1978) and photosynthetic efficiency of residual leaves may also influence rate of regrowth. However lack of suitable data on which to base quantitative descriptions of these effects prompted their initial omission from the model.

#### 5.2.1.3 Temperature Effects on Growth

That temperature can limit growth has been well established by Mitchell (1956a) and Mitchell & Lucanus (1960, 1962) in controlled environment studies. Temperature influences leaf extension rate, leaf appearance rate and rate of tillering. Tiller growth is close to optimum for temperate species of grasses, over quite a range of temperatures, 10 to 20 °C, but declines rapidly at temperature extremes, there being some differences between species. Browntop and ryegrass have similar temperature optima, 15-18 °C although relative growth of ryegrass is greater at low temperatures. Optimum temperature for white clover is much higher, 22-25 °C. From the above studies on tiller growth responses to temperature, one function was derived to describe relative effects of temperature on sward growth (Fig. 5.4). It most closely described browntop behaviour.

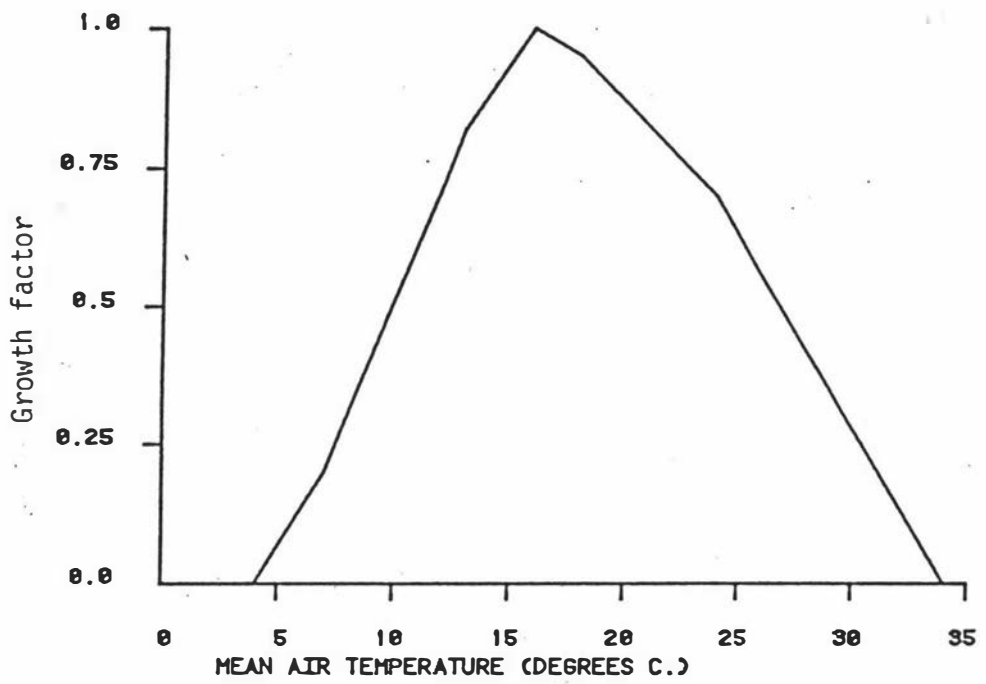


Figure 5.4 Relative effect of temperature on pasture growth.

Two problems were anticipated in applying the temperature function derived from controlled environment data. Firstly, mean air temperature measured at standard meteorological height, 1.2 m above the ground, may not adequately reflect temperature at the plant meristem. Secondly, the response of leaf growth on a tiller in an isolated plant may be different to that in a sward. In addition, density of plant cover may change the temperature met by the plants (Mitchell, 1956b), and buffer diurnal variations. Galbraith et al. (1981-81) included this as a feature of their subclover model. They considered there to be no effect of temperature where pasture cover was above 1000 kg DM/ha.

Initial 'runs' with the model suggested that the temperature function behaved reasonably for all but the winter months, when it appeared to over-restrict growth. This aligned with evidence from a study of field data by Baars & Waller (1979), who found maximum air temperature at 1.2m., to be the most highly correlated temperature variable to winter growth. It also supports Mitchell & Lucanus's (1960) finding that, at low temperatures, growth is affected more by temperature changes during the light than during darkness. So, mean air temperature was substituted by maximum air temperature in Fig. 5.4, for the period April 15 to September 1.

#### 5.2.1.4 Soil Moisture Effects on Growth

Soil moisture limitations to growth occur below some critical level of available water held in the soil. The generally held view (Borg, 1980) is that growth is restricted in direct proportion to the ratio of daily (ET/PET), since stomatal closure to reduce transpiration also restricts uptake of CO<sub>2</sub> for assimilation by

photosynthesis. The ratio ET/PET is used to restrict growth in this model.

Below a critical soil moisture content,  $\theta_c$  (Fig. 5.5), ET is limited by available soil moisture (ASM). A variety of approaches used in modelling the relationships between ET and ASM are reviewed by Johns & Smith (1975) and experimental data on the topic are reviewed by Borg (1980). Most relationships are characterised by a falling rate of ET/PET below  $\theta_c$ , (see Fig. 5.5) although Scotter et al. (1979) consider that below  $\theta_c$ , ET is purely a function of soil moisture deficit and is restricted only if PET is greater than ET permitted by the soil. Apart from Scotter et al., the major differences in modelling approaches appear to lie in the value of  $\theta_c$  at which soil moisture begins to limit ET/PET. According to Borg (1980) experimentally recorded differences may be partially explained by the experiments of Denmead & Shaw (1962). They found that as PET increased,  $\theta_c$  increased. Wright & Baars (1976) based their function on the data of Denmead & Shaw (1962), adapting it for New Zealand pastures. It was therefore decided to use their relationships in this model (Fig. 5.6). Scotter et al.'s model, while having the advantage of relative simplicity, relies on empirically derived parameters for different soil types, which are not currently available.

Level of plant-available water (= ASM), depends on the effective rooting depth of the pasture and soil water-holding capacity between field capacity (-0.3 bars) and wilting point (-15 bars pressure). Pasture roots penetrate as far as 120-130 cm in deep, free-draining soils (Evans, 1978). Rickard and Fitzgerald (1970) reported shallower root depths of 30 to 35 cm on soils covering gravel and sand. Gradwell (1974) assumed an effective rooting depth of 75 cm

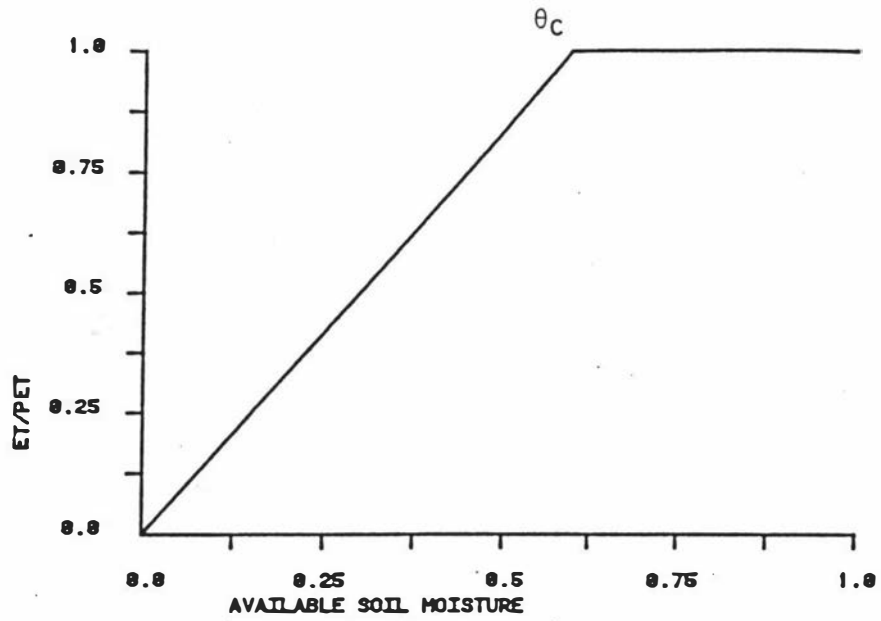


Figure 5.5 Generalised relationship between available soil moisture and ET relative to PET.

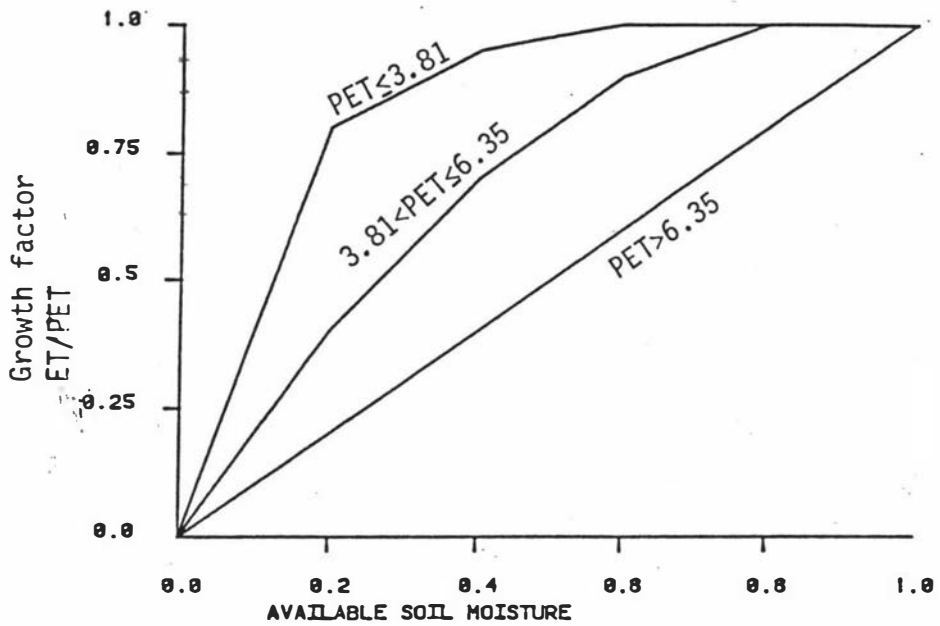


Figure 5.6 Relative effect of available soil moisture on pasture growth and ET/PET.

in his calculations. In NIHC soils, relatively shallow rooting depths occur (Bowler, pers. comm.). A level of 50 cm was therefore assumed, above which, the level of ASM is around 76 mm in a Judgeford silt loam (Gradwell, 1974).

Daily change in the soil moisture content of the root zone,  $\Delta S$ , can be represented as in Equation 5.2

$$\Delta S = R - ET - D - R_o, \quad (5.2)$$

where R = rainfall, ET = evapotranspiration, D = drainage below root zone, and  $R_o$  = runoff (all measured in mm/day).

Rainfall was assumed to add directly to soil water reserves without loss, unless it was less than 1 mm/day, in which case it was assumed to be held in the foliage. To account for the effect of rain when the soil profile was relatively dry, a surface layer of soil was defined which was preferentially filled to field capacity (e.g. Wright & Baars, 1976; Scotter et al., 1979). Following rain, ET proceeded at the rate determined by ASM in the surface horizon, until ASM in the top horizon, equalled ASM in the lower horizon. Water was then used from the entire profile. Depth of the recharge horizon was assumed to be 10 cm (21 mm soil water), a depth containing at least 50 percent of the roots (Bowler pers. comm.).

Runoff of rainfall from hill country is likely to be influenced by four major factors; rainfall intensity, antecedent soil water content, slope, and vegetation cover. Ive et al. (1976) developed a model for run-off from flat land. This model was studied to investigate the possibility of adapting it to hill country. However, it was decided not to include run-off below field capacity owing to the absence of suitable data relating to the effect of slope, and the likely event of run-off from one area becoming run-on for another.

Once the soil reached field capacity, additional rainfall was assumed to be lost by drainage below the effective root zone.

Potential evapotranspiration was determined using the formulae proposed by Priestly & Taylor (1972) as in Scotter et al. (1979).

$$PET = A * R_n * V / (V + G) \quad (5.3)$$

where V was the rate of change of saturation vapour pressure with temperature, G was the psychrometric constant, R<sub>n</sub> was net radiation expressed in equivalent mm/day evaporation (assuming a latent heat of vaporisation of 2.46 MJ/kg) and 'A' was a dimensionless parameter, taken as 1.3 (Scotter et al., 1979). R<sub>n</sub> was estimated as:

$$R_n = 0.62 * R_s - 0.6 \quad (5.4)$$

where R<sub>s</sub> equalled daily radiation in equivalent mm/day evaporation.

V/(V+G) was related to mean air temperature (MAT) as:

$$= 0.429 + 0.0129 * MAT \quad \text{for } MAT > 10 \text{ } ^\circ\text{C} \quad (5.5)$$

$$= 0.406 + 0.015 * MAT \quad \text{for } MAT < 10 \text{ } ^\circ\text{C}. \quad (5.6)$$

### 5.2.2 Estimation of Senescence and Decay Rates

Studies reporting experimental effects on net growth rates, without reference to senescence and decay, dominate New Zealand's agronomic literature. This is understandable when one considers the difficulties involved in measuring the latter. Yet senescence and decay are as important as growth rate in determining feed availability for grazing sheep.

Studies on senescence and decomposition in pasture have been reported by Hunt (1970), Morris (1970), Wilman & Mares Martins (1977), and Cayley et al. (1980). Senescence rate was assumed to be a constant proportion of total live herbage (W.G. Duncan pers. comm.).

The data of Hunt (1970), were analysed to provide estimates of senescence rate expressed in this way. Remarkably similar values occurred for both spring reproductive, and autumn vegetative growth, 0.79 and 0.88%/day, respectively. A constant value of 0.8%/day was assumed, based on an assessment of the above data by W.G. Duncan (pers. comm.).

As pasture comes under stress from drought, the senescence rate of individual leaves and tillers increases (Ong, 1978). The data of Cayley et al. (1980) clearly support this fact. Death rates during periods with low precipitation/evaporation ratios were six to seven times higher than during periods of ample water supply.

In the absence of suitable data a linear increase in senescence rate was assumed from 0.8%/day, when soil water levels in the top horizon (SMHA) reached 20% of ASM in SMHA to 2.4%/day at zero available soil moisture in SMHA. A three-fold increase in senescence rate corresponds with unpublished data of D.F. Chapman (pers. comm.).

Decomposition of dead pasture was taken to include leaching losses and removal below the surface by earthworms, as well as microbial decay. It was not possible to derive a simple relationship between decay rate and dead DM/ha because the build-up of decomposer populations is influenced by such factors as the dampness of dead herbage (Cayley et al., 1980) and temperature. A model for predicting microbial decay and leaching losses from litter has been published by Hunt (1977). This model was modified slightly, to predict the decomposer and leaching fractions of decomposition losses in this model. In brief, dead material was divided into two pools: soluble, (i.e. readily decomposable material) and insoluble, (i.e. not readily decomposable). The amount entering the respective pools was correlated

to the nitrogen content. Nitrogen content of newly senesced pasture was treated as constant and assumed to be 1% (e.g. Robson & Deacon, 1978). Substitution of 1% N into Hunt's (1977) equation, predicted the soluble fraction to be around 40% of newly senesced DM.

Leaching losses occurred solely from the soluble pool. Potential leaching loss rate increased linearly with rainfall from 0 to 50%/day, at 10 mm rain. Actual loss rate by leaching was then dependent on temperature (Fig. 5.7).

Microbial decay operated on both pools and was dependent on temperature and moisture. Soil moisture limitations to the decomposer population were assumed to be related to the level of ASM in SMHA (Fig. 5.8). Moisture was assumed non-limiting on days when rain fell, regardless of soil moisture level. The temperature multiplier is depicted in Fig. 5.9. Potential decay rates at optimum moisture and temperature were 90 and 3%/day of the soluble and insoluble pools, respectively.

Initially earth worms were not included, and the model allowed insufficient dead DM losses in the late autumn/winter period. Data of Sharpley et al. (1979) showed the significance of earthworms in removing dead material during this period. Cast production commences following autumn rains and reaches a maximum by late May, declining to near zero by the end of October. Besides season and soil moisture, the amount of dead DM/ha appears to be the major determinant of the amount of dead DM removed by worms. Rate of removal of dead DM from the insoluble pool was calculated in relation to season, using the data of Sharpley et al. (1979) (Fig. 5.10).

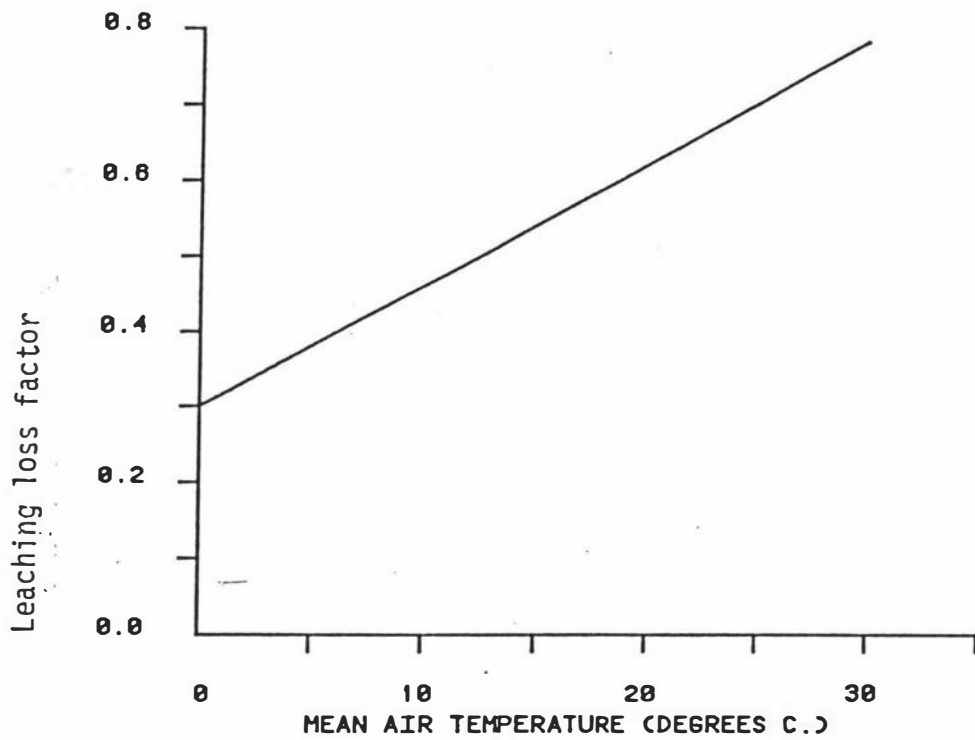


Figure 5.7 Temperature multiplier for dead pasture losses by leaching.

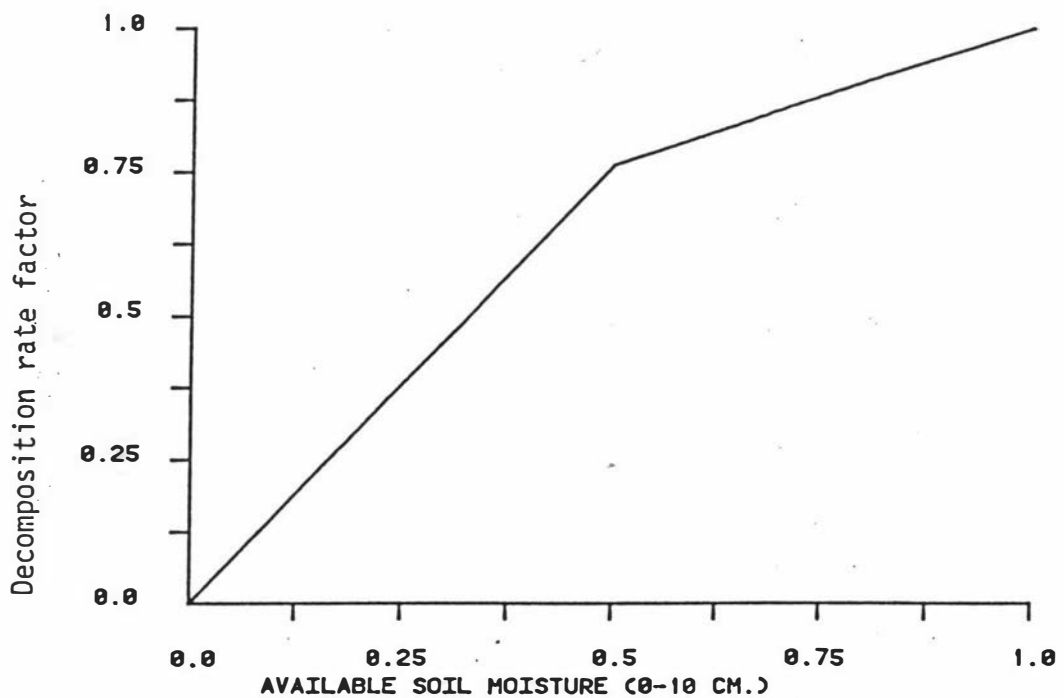


Figure 5.8 Soil moisture multiplier for dead pasture losses by decomposition.

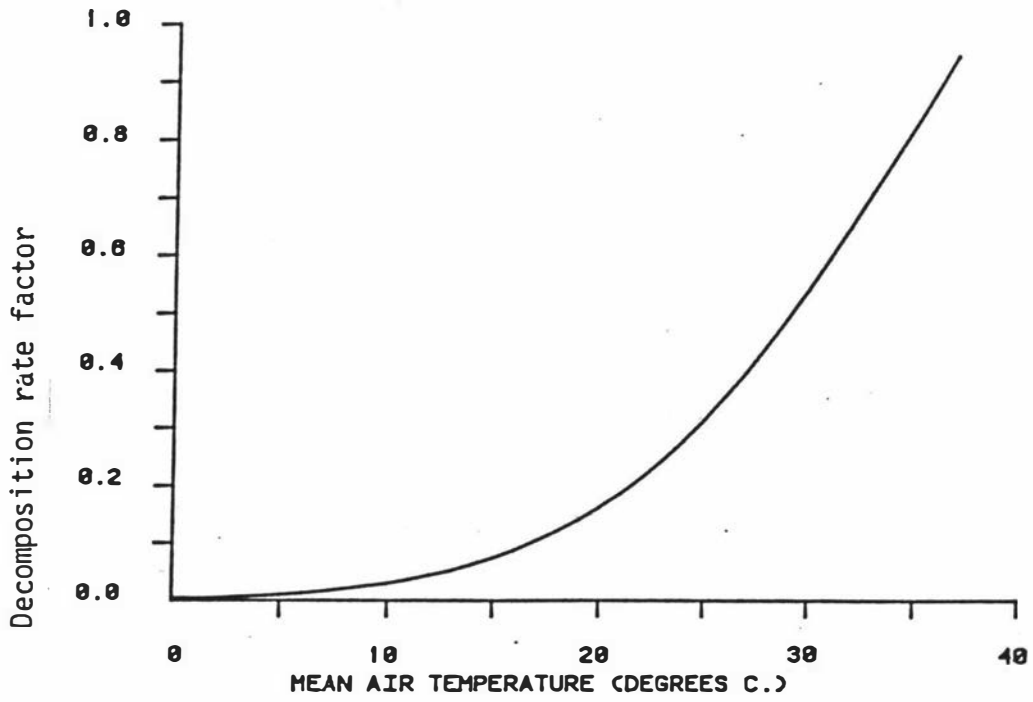


Figure 5.9 Temperature multiplier for dead pasture losses by decomposition.  
 (= EXP(-5.66 + 0.24 \* T - 0.239E-2 \* T \*\* 2))

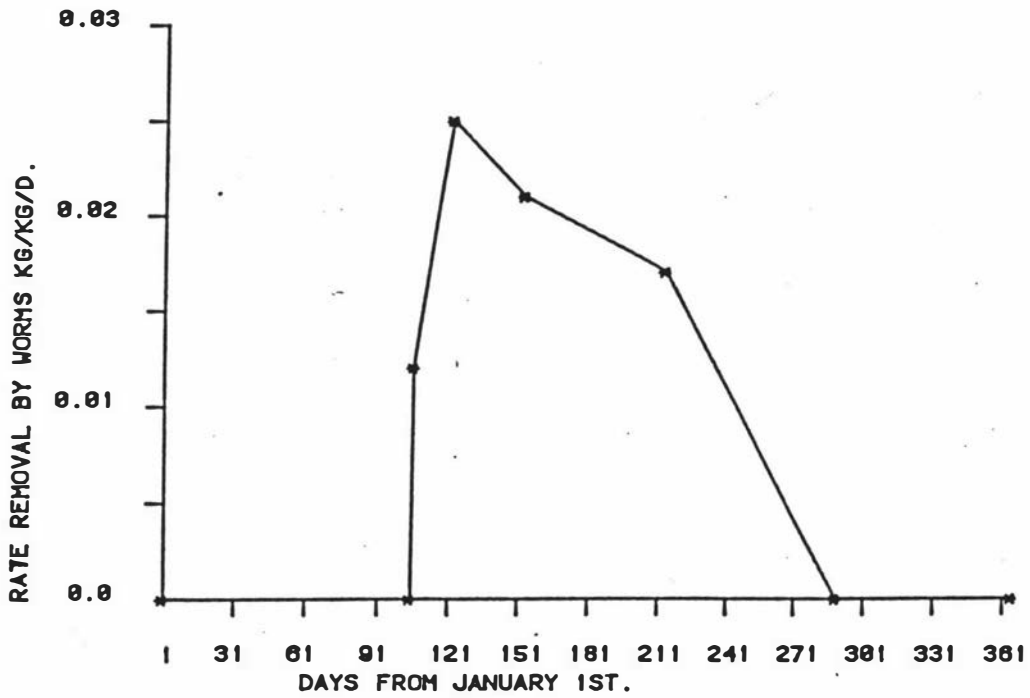


Figure 5.10 Effect of day of year on the rate of dead pasture removal by earthworms.

### 5.3 ADAPTATION OF THE GENERAL MODEL TO HILL COUNTRY

Pasture production on hill country is characterised by variability owing to the influences of terrain on both microclimate, and soil characteristics. Obtaining meteorological data for each major slope and aspect land class is obviously not practical. The best practical solution considered was to derive a set of factors relating climate on the various slopes and aspects, to climate experienced at a standard site.

Shading occurs to varying degrees on different aspects depending on the azimuth of the sun, time of day, and gradient and vertical height of the hills. For most of the year northerly facing aspects receive more radiation (McAneney & Noble, 1976) and higher temperatures (Gillingham, 1973) than their southerly facing counterparts. Whereas steep slopes receive the same amount of radiation as an equivalent piece of land on a horizontal plain, but spread over a larger area. Annual rainfall is, on average, similar between aspects (Lambert, 1973). However specific rainfall events can deliver different amounts of rain to different aspects, depending on the wind direction prevailing at the time. In addition land slope is likely to cause redistribution of rainfall, with run-off from steep areas contributing additional water to flatter sites.

Data from a number of sites throughout New Zealand were inspected with a view to deriving a set of factors for north and south aspects which could be applied to standard meteorological temperature and radiation recordings. Grass temperatures for north and south aspects at Whatawhata (Gillingham, 1973) and Te Awa (Suckling, 1975), and 3 cm air temperatures at Coopers Creek (Radcliffe & Lefever, 1981) were available. Ratios for the mean monthly south:north aspect

temperatures of the three sites are presented in Fig. 5.11. Any thought of obtaining a standard set of factors was obviously over-ambitious. The pattern was similar for all sites but with increasing latitude, differences increased between North and South slopes. Some variation in temperature ratio may however be due to differences in topography, and/or position of recording up the slope, if these occurred. Tests with the model, simulating pasture growth on north and south aspects, at Ballantrae, suggested that the Gillingham (1973) derived temperature factors were the most satisfactory. Factors for north and south aspects (see Appendix A) were determined by dividing mean monthly grass temperature by mean Stevenson screen temperature at the nearby Whatawhata meteorological station. Mid-month factors were obtained by interpolation.

Altitude also affects temperature, but in a fairly precise manner. For this reason a correction was built in for difference in altitude between the meteorological station and the site to be simulated. Linear regression of monthly mean temperature against altitude at four local meteorological stations for 1972 data yielded an average regression coefficient of  $-0.0064$  °C/m increase in altitude. Variation in regression coefficients between months was not great. The stations ranged in altitude from 30 to 340 m above sea level.

A model reported by McAneney & Noble (1976) performs the calculation of incident radiation ( $R_i$ ), relative to  $R_i$  on a horizontal surface, for any slope, of given aspect at latitude  $37^\circ$  South. However, only the amount of direct radiation received depends on solar geometry, the diffuse component is similar for all slopes. In essence McAneney & Noble's model estimates only the differences in direct radiation (McAneney pers. comm.), hence it

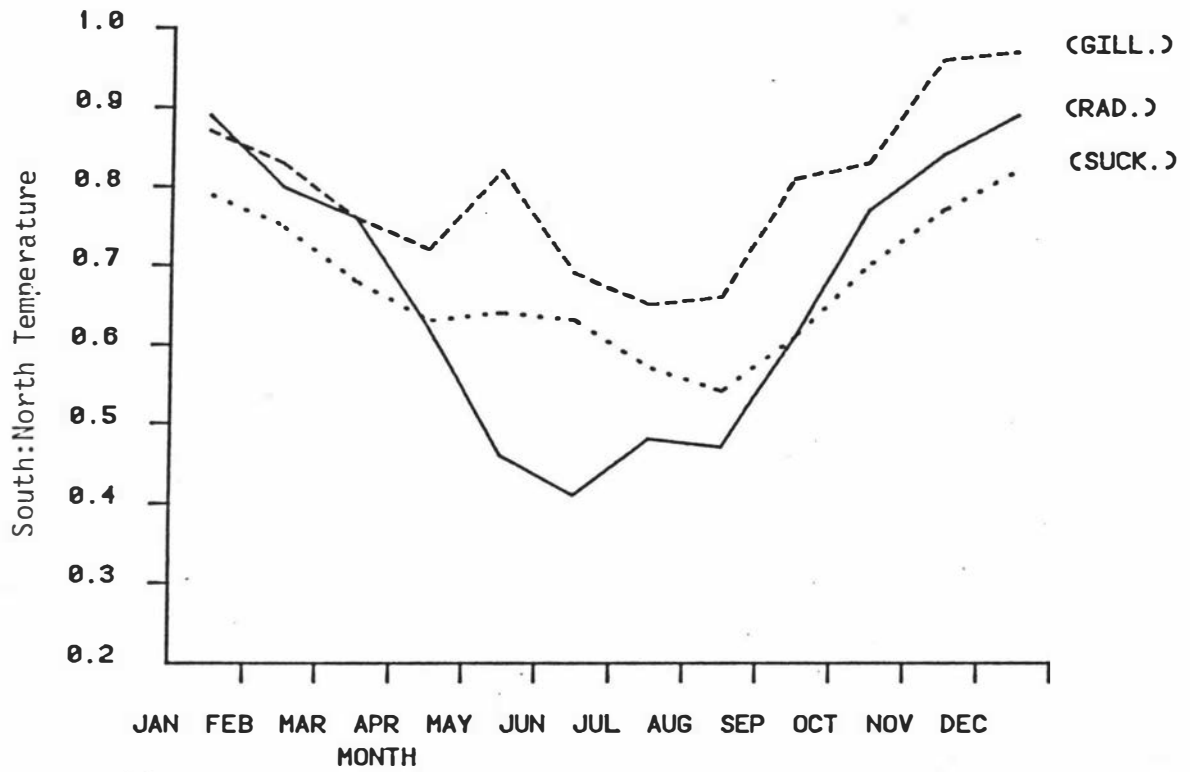


Figure 5.11 The ratio of south:north aspect temperatures at 3 sites in New Zealand.

under-estimates  $R_i$  on south aspects, particularly in winter when most  $R_i$  on south aspects is diffuse. Aspect and slope factors for direct radiation were therefore derived from McAneney and Noble (1976), (Appendix A) and the diffuse component of  $R_i$  was assumed equally distributed between aspects and slopes (Liu & Jordan, 1960). The size of the diffuse component was predicted as a function of cloudiness (Liu & Jordan, 1960), where degree of cloudiness was assessed as the ratio of total daily radiation, to radiation received at the top of the atmosphere by Liu & Jordan's function:

$$P_{\text{diffuse}} = 1/(1 + \text{EXP}^{-3.08 - 6.295 * KT}) \quad (5.7)$$

where  $0 < KT < 0.75$ , and  $KT$  is the ratio of total daily radiation received on a horizontal surface, to extraterrestrial daily insolation on a horizontal surface.  $P_{\text{diffuse}}$ , is the ratio of diffuse to total radiation on a horizontal surface.

It can be appreciated that a detailed description of topography and aspect is still required for both the meteorological station and the simulation site in order to choose accurate translation factors for temperature and radiation. However it was considered desirable to provide the facility in the model for use of the above, or other user supplied factors, for occasions where differences between aspects are central to the study. The simpler approach is to assume that the meteorological data, corrected for altitude, applies on average to the simulation site.

Of equal or greater importance to pasture production as climatic differences between slopes and aspects, are soil fertility and water holding differences between slopes (Lambert pers. comm.). Soils on steep slopes tend to be shallower, possess a lower level of fertility, and lower water-holding capacities, than soils on easier gradients.

In addition, fertility is transferred from steep slopes by the grazing animal. Transfer occurs via dung and urine to sites where stock congregate (Gillingham, 1978), i.e. flat warm areas (Suckling, 1975) and to tracks from where they graze steeper slopes (G.W. Sheath, pers. comm.).

Lambert et al.'s (1983) data showed an average ratio of annual pasture production between the slope classes 1-12, 13-25, and >25 degrees of 1:0.71:0.52 . These ratios were taken as the factors used to weight the soil fertility parameter (PSlope) for each slope class.

#### 5.4 SUMMARY

In Chapter 4 some of the limitations regarding availability of data relating to factors effecting pasture production in NIHC were mentioned. This determined that a general pasture model was required which could respond realistically to environmental factors producing site and season differences in production.

In the present chapter a proposed outline for a general perennial pasture model was described. Factors affecting the major parameters were discussed, and the literature was reviewed in an effort to obtain estimates for values of the major parameters. Finally, adaptations necessary to standard meteorological data to describe variation in hill country pasture production were discussed. It remained to test these initial assumptions, the subject of Chapter 7, and to discuss implications for further research, the subject of Chapter 9.

## Chapter 6

### THE ANIMAL COMPONENT

#### 6.1 INTRODUCTION

The sheep component of the model was based on relatively well researched relationships describing production in relation to energy consumed.

Having ingested and digested a given amount of pasture, the sheep has available energy to sustain the various body functions and to channel towards production. The quantity of energy supplied, and the 'rules' for partitioning this energy between productive processes, determine the level of production, and the change in body reserves.

Nitrogen nutrition was not modelled primarily because the additional realism to be gained was considered to be greatly outweighed by the additional complexity of the model. In addition little data exists on factors effecting levels of nitrogen in hill country pasture. The major implication of excluding a nitrogen balance was that body composition of the sheep, fat and protein, was not explicitly modelled. However, in the young growing sheep, where this would be of most interest, it appears that there is little effect of nutrition on body composition other than that which can be explained by the relationship with empty body weight (Searle & Graham, 1970).

In this Chapter, factors that influence pasture intake and partitioning of energy for sheep in differing physiological states are discussed. Conversion of energy into animal products is covered, factors affecting reproductive efficiency are outlined, and finally the structure of the complete model is discussed. A flow diagram of

the intake and energy utilisation components of the model is given in Fig. 6.1.

## 6.2 PASTURE INTAKE

### 6.2.1 Introduction

Regulation of voluntary intake in the sheep appears to be determined by a complex system of feedback mechanisms aimed at maintaining energy balance (Baile & Forbes, 1974; Forbes, 1977). This results in alterations to potential intake in response to the differing energy requirements of each physiological state (e.g. shorn, pregnant, lactating, dry). Voluntary intake is also limited by physical capacity of the rumen (Forbes, 1977) when digestibility of the diet falls below a given level (Conrad et al., 1964), and hence is closely related to diet digestibility over the range, 30 to 75% digestibility (Blaxter et al., 1961).

### 6.2.2 Herbage and Diet Digestibility

Digestibility of the diet was determined from correlations between sward characteristics and average sward digestibility, and between average sward digestibility and digestibility of the diet, using currently available New Zealand data. Insufficient data were available to substantiate the more elaborate conceptual approaches to diet selection taken in some models (see Section 3.6).

Rattray (1978) showed the digestibility of a ryegrass dominant pasture follows a seasonal trend, even in a leafy sward maintained by close grazing. He also showed that the average digestibility of a sward could be related to the percentages of green and dead DM in the sward. In addition, from Hamilton et al. (1973) it appeared that average digestibility declines as green cover increases. Browse et

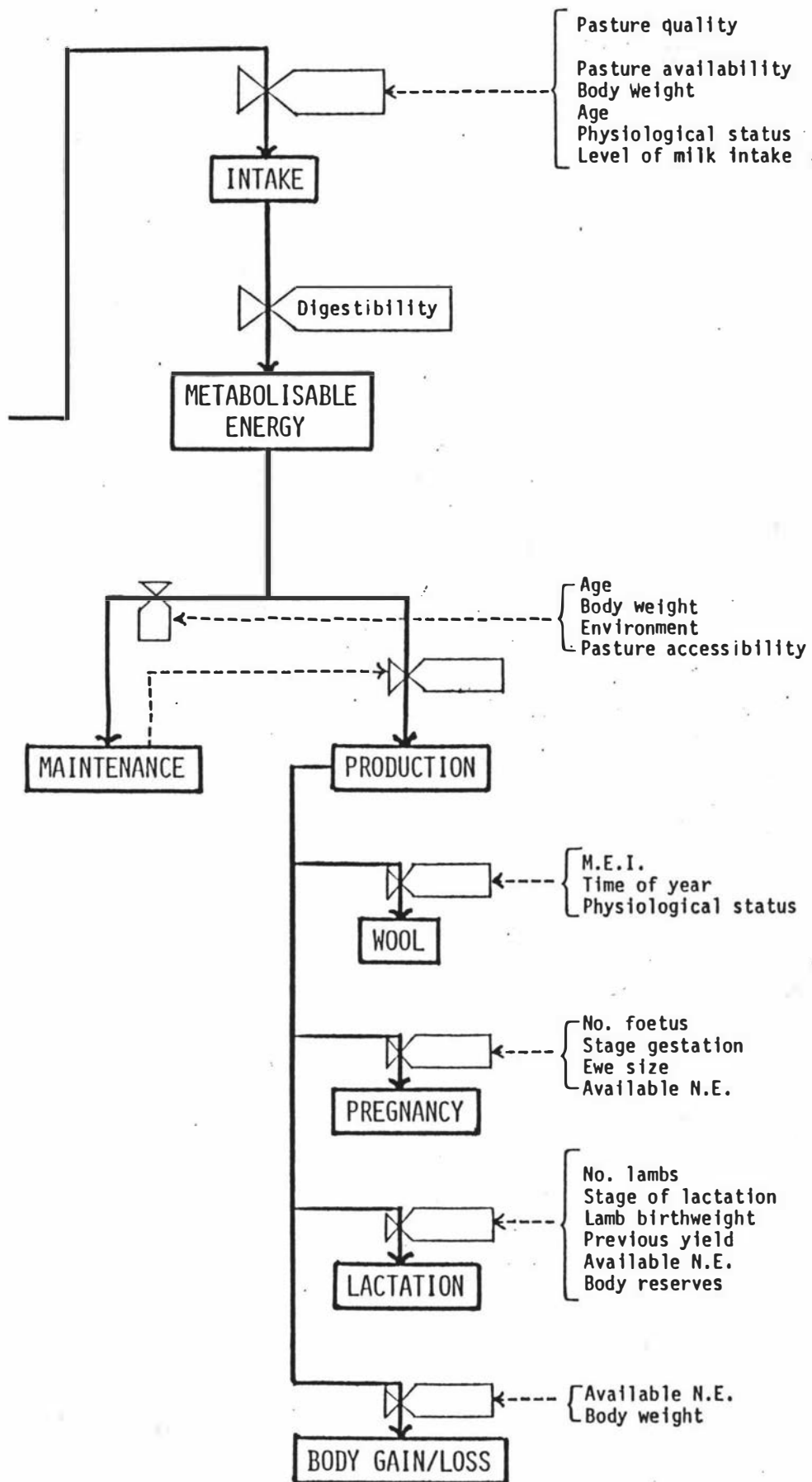


Figure 5.1. Flow diagram of energy utilisation by the sheep.

al.'s (1981) data suggested that this could be related to increasing amounts of reproductive stem in the sward, particularly over summer (see Fig. 6.2). Data of Browse et al. (1981) and Guy et al. (1981) were therefore analysed to see if percentage green stem in a grazed sward could be related to green cover (Fig. 6.2). Excluding data points relating to two treatments in Guy et al. (1981), which had been previously hard grazed from a high cover and hence contained a high proportion of stem relative to total green cover, a good linear relationship was derived ( $r = 0.93$ ). From Figs. 6.2 and 6.3, Fig. 6.4 was constructed to represent the decrease in digestibility of green herbage with increasing green cover. Fig. 6.4 applied only when a sward contained reproductive stem. That is until it was controlled in late summer by grazing below 1050 kg GDM/ha, (see Section 7.4.1.2). Digestibility of green herbage was therefore calculated from peak seasonal digestibility derived for browntop swards (Lancashire & Ulyatt, 1974; Ulyatt, 1978; see Fig. 6.5), and decreased as in Fig. 6.4 with increasing green cover.

Average sward digestibility (ASD), was calculated by assuming the digestibility of dead DM to be 33% (Rattray, 1978).

Digestibility of the diet selected (DDS) was related to ASD as in Equation 6.1, derived from data reviewed by Hughes et al. (1980).

$$\text{DDS} = 0.7 * \text{ASD} + 30 \quad (6.1)$$

Sheep select a diet which is of higher digestibility than the average of the sward, no doubt due in part to the almost virtual exclusion of dead DM from the diet (Clark et al., 1982). However since DDS will depend on grazing pressure as well as ASD, and since no data existed to allow the former effect to be included, DDS was arbitrarily constrained so that it did not exceed the digestibility of

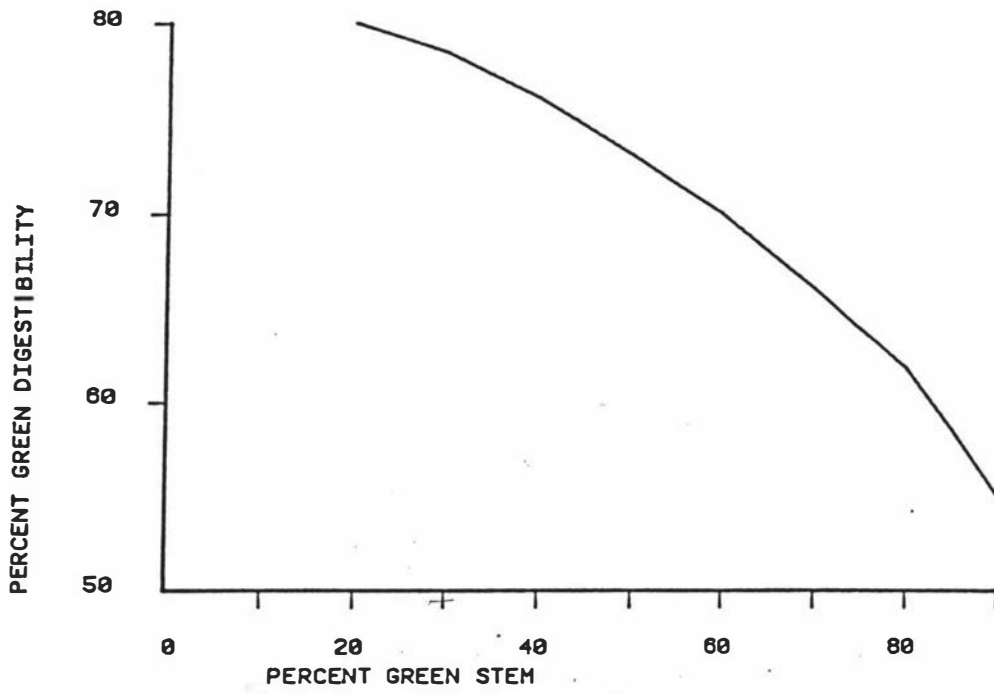


Figure 6.2 Effects of green stem on green herbage digestibility (adapted from Browse *et al.* 1981).

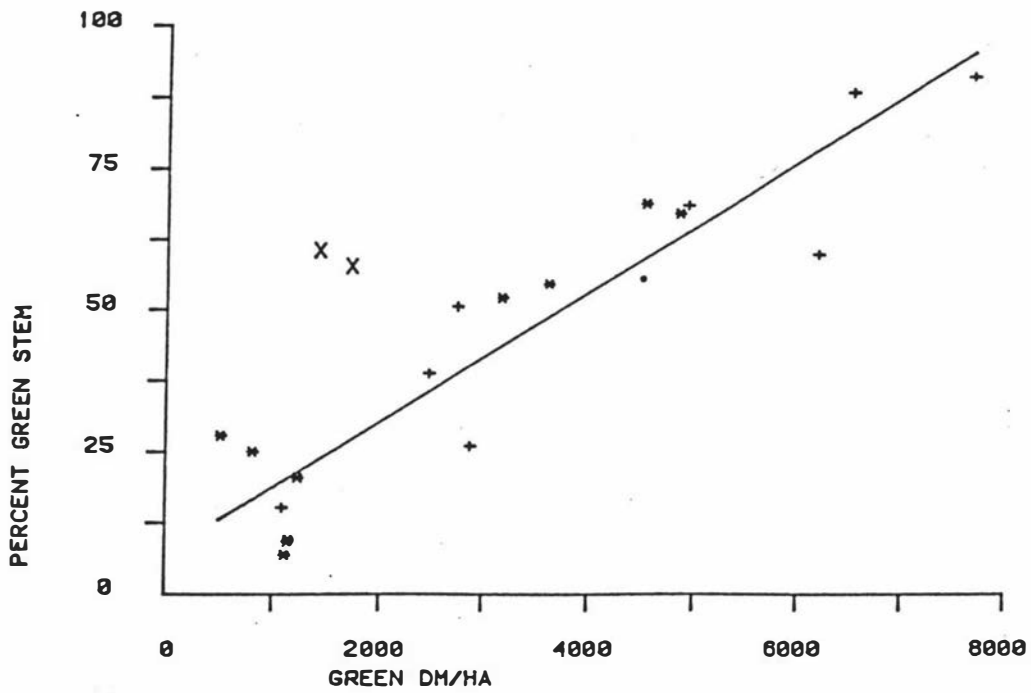


Figure 6.3 Relationship between green cover and percentage green stem. Points marked X were discarded - see text.

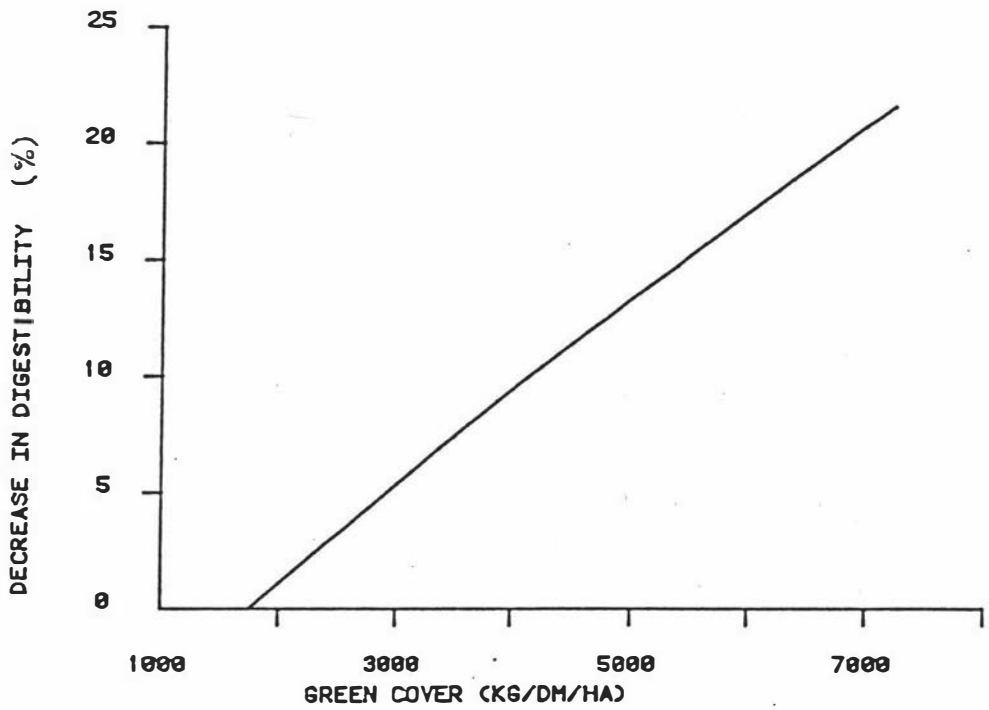


Figure 6.4 Assumed reduction in green herbage digestibility with increasing green cover.  
 ( $= 1 - (1.08 * \text{EXP}(-0.44\text{E-}4 * \text{GDM/ha}))$ ):

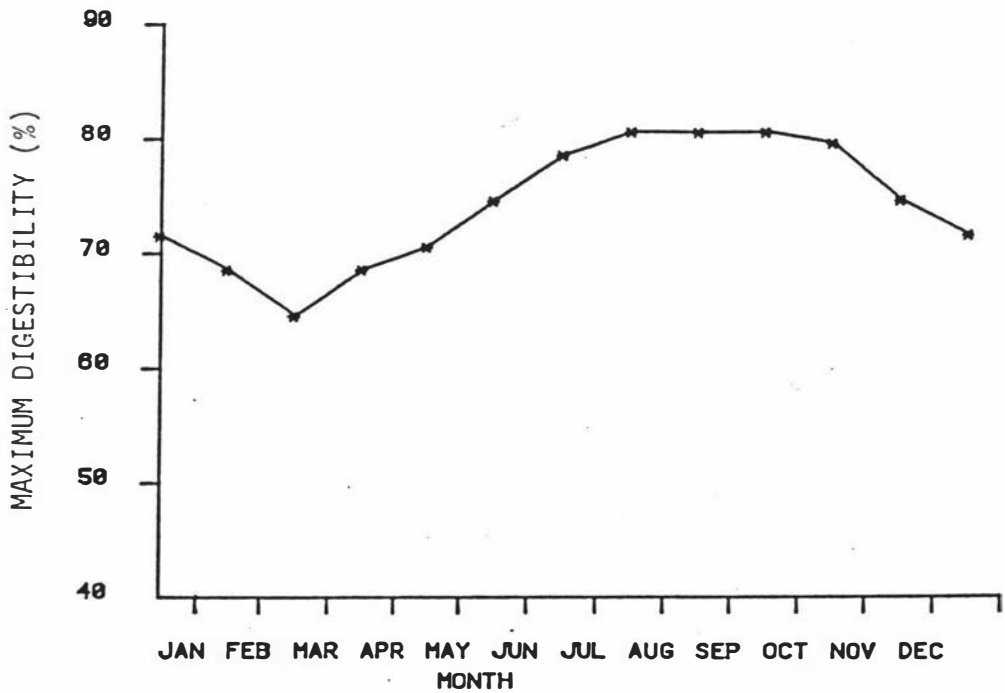


Figure 6.5 Assumed maximum green herbage digestibility in each month.

the green herbage. Actual proportions of green and dead consumed are discussed in section 6.2.4.

### 6.2.3 Determination of Voluntary Intake

Davey (1973) showed voluntary intake to increase after a change in physiological state which caused an increase in energy demand, even when digestibility was limiting. This suggested that digestibility constraints to voluntary intake operate relative to voluntary intake for a particular physiological state, and was the basis for this assumption in the model.

The voluntary intake of non lactating, non pregnant sheep was estimated as a percentage of liveweight, relative to digestibility of the diet, and age, from Ulyatt et al. (1980), (see Fig. 6.6). The 'young' relationship was used for growing lambs until they reached 30 kg fleece-free liveweight. Between 30 and 50 Kg, values were obtained by interpolation between the young and mature relationships, provided that the sheep was less than 16 months of age. Otherwise the 'mature' relationship was used. However two adjustments were made to the mature sheep relationship shown in Fig. 6.6. First, voluntary intake in mature sheep below 50 kg fleece-free liveweight<sup>1</sup> was made independent of liveweight (e.g. Blaxter et al., 1982) and was assumed to equal that of a 50 kg sheep. Second, to account for Arnold & Birrell's (1977) evidence that intake eventually declines as sheep become obese, when fleece-free liveweight was greater than 50 kg, a multiplier was used to reduce voluntary intake calculated from Fig. 6.6.

<sup>1</sup> 150 kg was assumed to be normal mature weight for a NZ Romney.

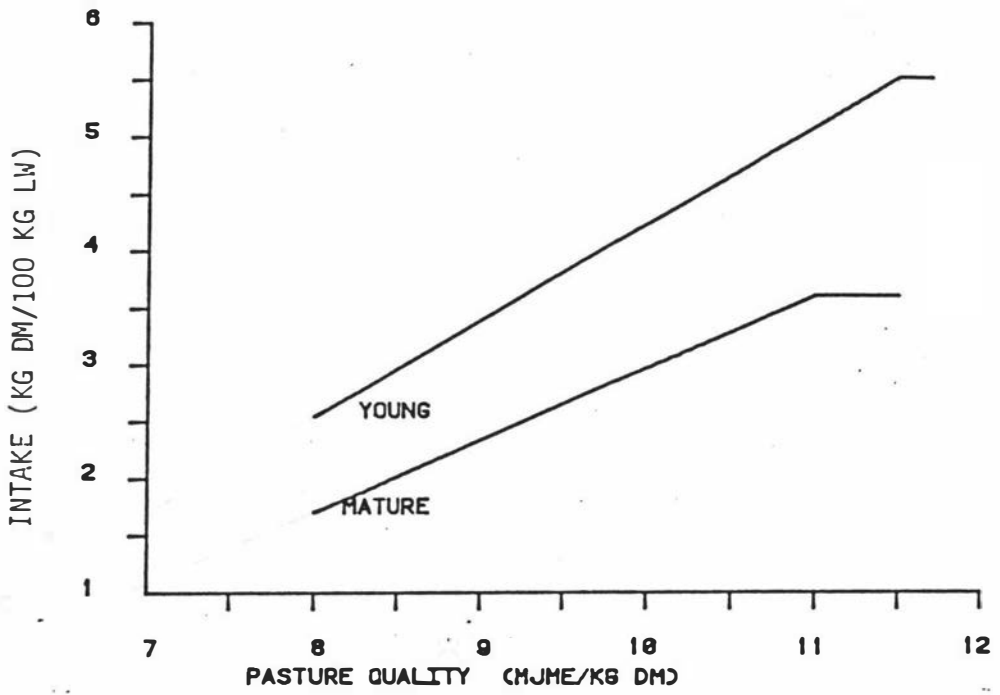


Figure 6.6 Voluntary intake in dry sheep. Young <16 months of age - see text.

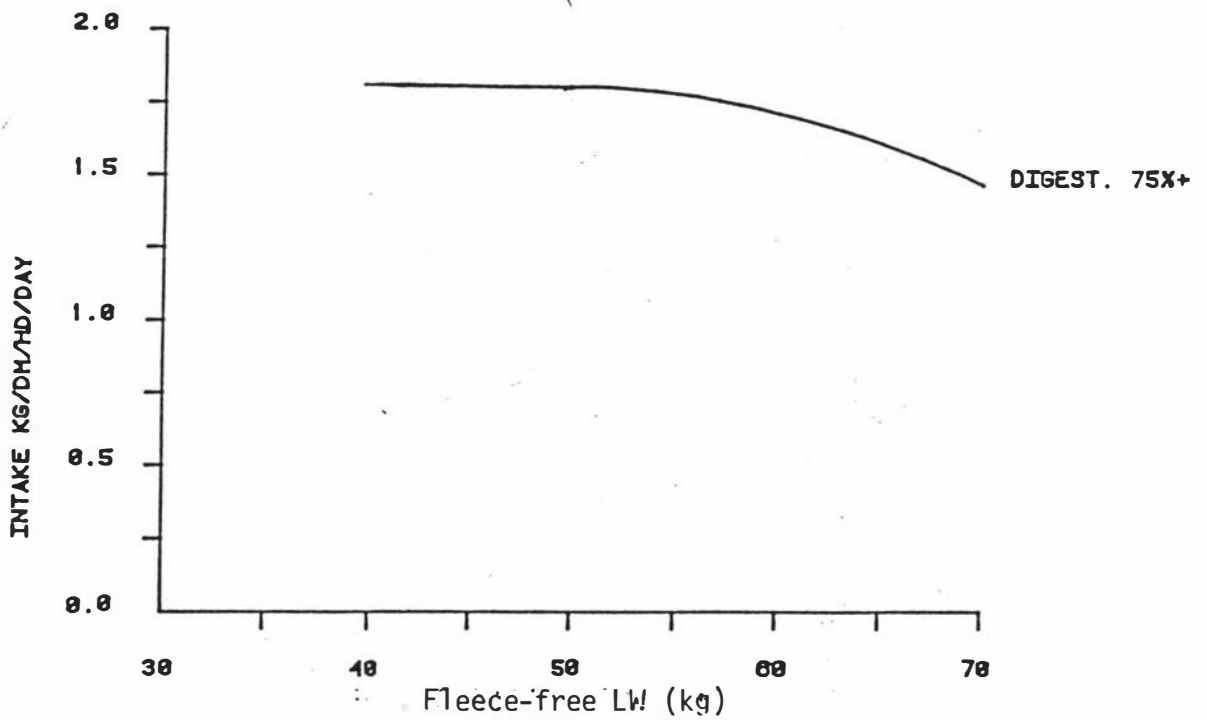


Figure 6.7 Effect of liveweight on mature ewe intake. Pasture digestibility  $\geq 75\%$

A multiplier based on Arnold & Birrell's (1977) results proved too severe so Equation 6.2 was synthesised to ensure that voluntary intake (VI) did not increase above that of a 50 kg ewe, and declined slowly at higher weights (Fig. 6.7).

$$VI = VI * (1 - 0.021 * (WT - 50)) \quad (6.2)$$

where WT is fleece-free liveweight.

The literature showed no clear effect of pregnancy in changing voluntary intake (Vera et al., 1977) so it was not included as a modifier of voluntary intake. Voluntary intake for lactating and shorn ewes was assessed relative to voluntary intake in non-lactating and woolly ewes of the same liveweight.

Voluntary intake increases to a maximum 3 to 5 weeks post-lambing (Hadji pieris & Holmes, 1966, Maxwell et al., 1979) and declines to non-lactating levels 12 to 14 weeks post-lambing. Twin-rearing ewes reach a higher peak voluntary intake, and maintain a higher voluntary intake throughout lactation, than ewes rearing singles (Hadji pieris & Holmes, 1966). In Maxwell et al.'s data this trend was less clear owing to large weekly fluctuations in the pasture intake of ewes rearing singles. The function representing the voluntary intake factor (LF) for ewes rearing single and twin lambs (Fig. 6.8, Equation 6.3) was taken from Christian et al. (1978) and is based on the data of Hadji pieris & Holmes (1966) and Arnold & Dudzinski (1967).

$$LF = 1 + 0.017 * T^{1.4} * EXP(-0.05 * T * F) \quad (6.3)$$

where T is day of lactation, and F = 1 for ewes rearing singles and 1.5 for ewes rearing twins.

Post-shearing, energy requirements (Coop & Drew, 1963; Wheeler et al., 1963; Elvidge & Coop, 1974), and appetite stimulation (Wodzicka-Tomaszewska, 1963, 1964; Davey, 1973) depend on

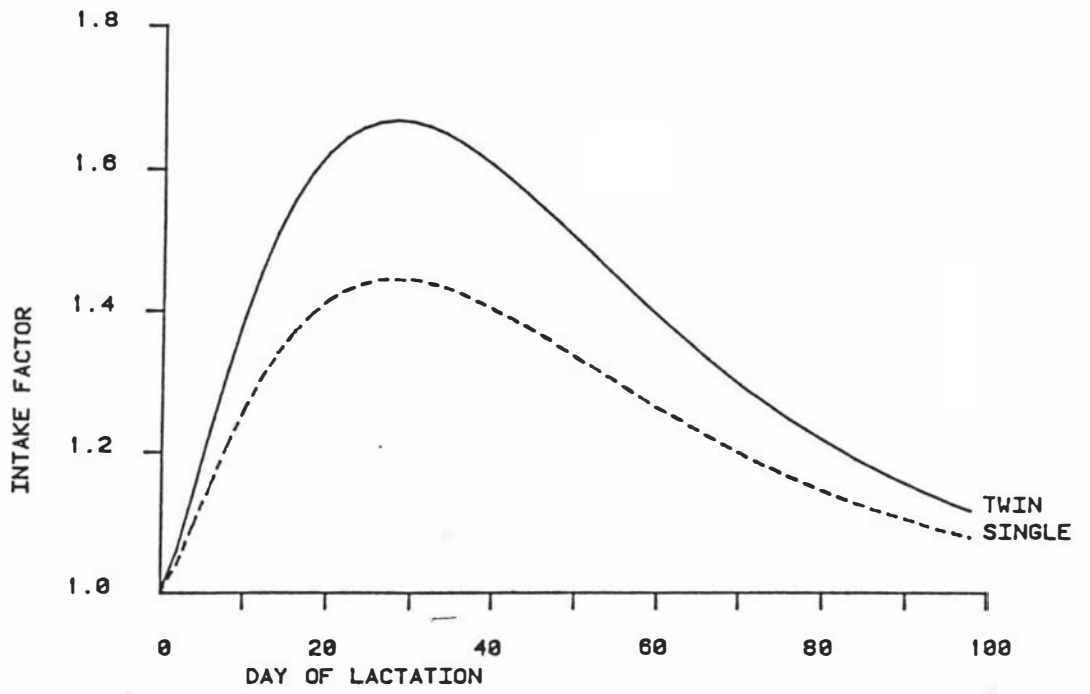


Figure 6.8 Intake factor for lactating ewes.

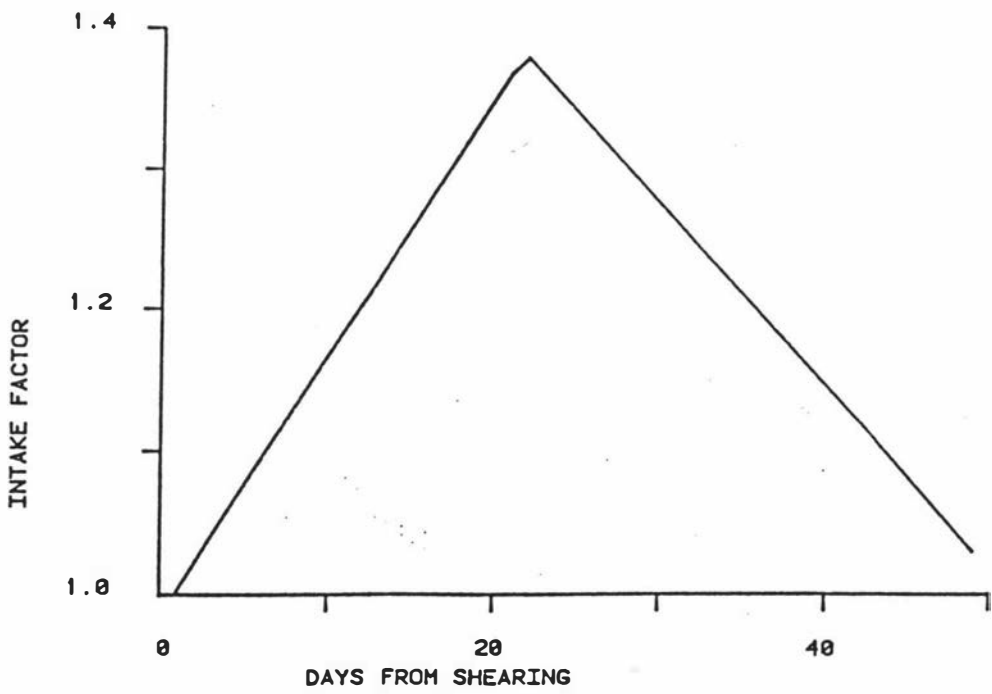


Figure 6.9 Basic intake factor for sheep post shearing.

environmental factors which dictate heat loss from the body. Despite peak heat production occurring immediately post-shearing (Davey, 1973), there is a lag of 3 to 4 weeks before maximum voluntary intake is achieved. By 7 weeks post-shearing voluntary intake returns to pre-shearing levels (Wodzicka-Tomaszewska 1963, 1964). The basic pattern of increase in voluntary intake used in the model (Fig. 6.9) was derived from Wodzicka-Tomaszewska's (1964) data. This was adjusted daily by a multiplier (CF) determined from mean air temperature (MAT) (Equation 6.4), to account for climatic influences on voluntary intake. Constraints were imposed on Equation 6.4 so that where  $MAT < 10$ ,  $MAT = 10$  and where  $MAT > 18$ ,  $MAT = 18$ . Above 18 °C it was assumed that no increase in intake would occur.

$$CF = -1.498 + 0.512 * MAT - 0.238E-1 * MAT**2 \quad (6.4)$$

Where sheep were shorn during lactation the greater of the two intake factors was used. This situation does not appear to have been studied.

#### 6.2.4 Effects of Pasture Availability on Intake

Hughes et al. (1980) recently reviewed information related to effects of sward physical characteristics on intake. Effects are many and varied and much of the information is qualitative in nature. However under closely defined grazing procedures it is possible to condense these into two major quantifiable indices, allowance (kg DM/head/day) and cover (kg DM/Ha). At high grazing pressures both are important (e.g. Rattray et al., 1980), but at low grazing pressures, commonly associated with set stocking, only cover is important.

Because green herbage makes up almost the total diet in sheep, intake of green DM was determined first, relative to green cover and allowance. The percentage of green DM in the diet (PGD) was determined from the percentage of green DM in the sward (PGP) (Equation 6.5, Clark et al., 1982). The small quantity of dead DM in the diet was assumed never to be limited by availability.

$$\text{PGD} = \text{EXP}(-\text{EXP}(-7 * \text{PGP})) \quad (6.5)$$

The conceptual configurations of Freer (1973) and White (1975), relating intake of dead DM to the availability of green and dead DM, were considered to contribute little extra realism under NIHC conditions.

Under high grazing pressures, intake as a fraction of voluntary intake, was related to allowance, as a multiple of voluntary intake, to facilitate the derivation of one set of functions relating intake to allowance for all physiological states.

Voluntary intake is achieved at an allowance of around four times voluntary intake with 90% of voluntary intake being achieved at an allowance of about twice voluntary intake (Hodgson, 1975). This means that for any given actual allowance sheep with a higher voluntary intake will utilise more. Higher utilisations owing to higher intake drive lines up with Arnold & Dudzinski's (1967) observations.

Data for the functions describing intake in relation to allowance and pasture cover were derived from Rattray et al. (1980). Rattray et al. related ovulation rate in ewes, firstly to allowance for different pre-grazing covers and secondly, to post-grazing residual green cover. Apparent intakes were calculated where cover was non limiting, i.e. 2500 kg GDM/ha. Assuming maximum intake to be 1.7 kg DM/ewe in autumn, Equation 6.6 was derived to fit the data,

where the asymptote (A) equalled one. At lower covers the same basic function was assumed to hold, but parameter A was related to pre-grazing green cover as in Equation 6.7. At very low allowances, below  $0.25 * VI$ , Equation 6.6 predicted greater than 100% utilisation. Rattray *et al.*'s relationships did include very low allowances, so below an allowance of  $0.8 * VI$ , percentage pasture utilisation was assumed to equal that at  $0.8 * VI$ , provided residual cover did not go below 200 kg GDM/ha.

when  $ALLOW > 0.8 * VI$

$$M = A * \text{EXP}(-1.016 * \text{EXP}(-1.0308 * ALLOW)) \quad (6.6)$$

$$A = 1 - 1.42 * \text{EXP}(-0.00198 * \text{GDM/ha}) \quad (6.7)$$

where M is intake as a fraction of voluntary intake, and ALLOW is allowance as a multiple of voluntary intake. Some intake factors predicted from these functions are shown in Fig. 6.10.

Under set stocking, daily changes in cover are small and intake as a fraction of voluntary intake can be successfully related to pasture cover (e.g. White, 1975). In the absence of New Zealand data the function derived by White (1975) was used to describe intake under set stocking,

$$M = 1 - \text{EXP}(-0.2E-5 * \text{GDM/ha}^{**2}) \quad (6.8)$$

### 6.2.5 Intake by Suckling Lambs

Lambs were assumed to consume all the milk supplied by their mothers. Twin lambs were assumed to share the milk equally.

Herbage intake by lambs is zero for the first two to three weeks of life (Joyce & Rattray, 1970). Rate of transition from non-ruminant to ruminant depends both on age and milk intake (Hodge, 1966; Joyce & Rattray, 1970; Penning & Gibb, 1979). Low levels of milk intake are

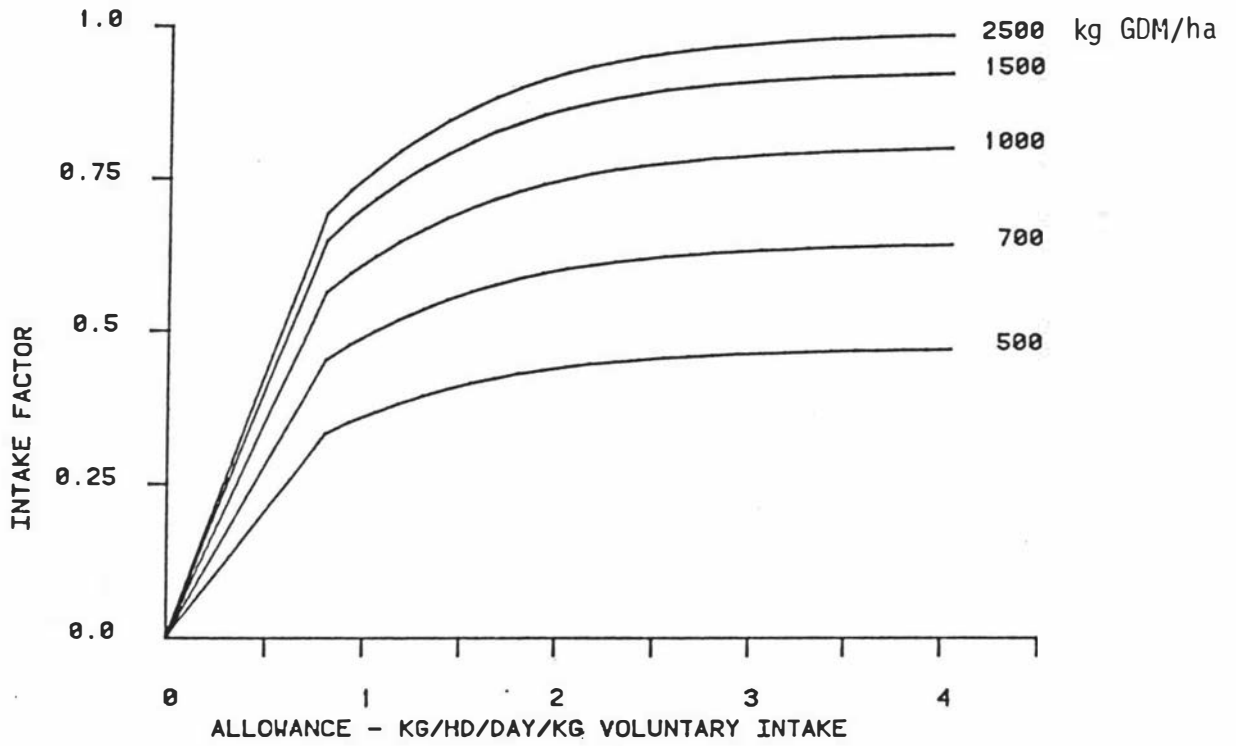


Figure 6.10 Assumed relationship between green pasture allowance and green pasture intake, as a multiple of VI.

compensated by increased herbage intake, when measured on a per kg liveweight (LWT) basis (Penning & Gibb, 1979). However since lambs on a high milk diet tend to be heavier, total herbage intake in these lambs may be greater.

Herbage intake for lambs at pasture is higher than for indoor fed lambs (Penning & Gibb, 1979). Therefore data of Hodge (1966) were used to construct a series of linear relationships between potential herbage intake and milk intake (both in g DM/kg LWT), at five-day intervals throughout the suckling period. Potential herbage intake was assumed at 5% of liveweight by seven weeks of age. This was higher than in Hodge (1966), but closer to that assumed in the model for weaned lambs, 5.5%. Coefficients and intercepts used in the model are given in Table 6.1. Interpolation was conducted between period means.

TABLE 6.1: Potential herbage intake of suckling lambs, related to milk intake (HDMI = Herbage dry matter intake, MDMI = milk dry matter intake)

Age (days)	Regression Coefficient (g HDMI/g MDMI)	Intercept (g HDMI/kg LWT)
16	-0.145	5.5
21	-0.426	16.5
26	-1.22	39.0
31	-1.62	44.0
36	-1.78	47.0
41	-1.79	49.0
46	-1.8	50.0
51	-1.8	50.0

In the absence of suitable data the effect of herbage quality on potential herbage intake (PHDMI), was included as a multiplier,

decreasing linearly with decreased pasture quality (e.g. Wardrop & Coombe, 1961).

$$\text{PHDMI} = \text{PHDMI} * (-0.7595 + 0.153 * Q) \quad (6.9)$$

where Q is MJME/Kg DM.

In reality, quality of the suckling lambs' diet would seldom be below 75% digestibility.

### 6.3 ENERGY UTILISATION BY THE SHEEP

#### 6.3.1 Introduction

Utilisation of feed by the animal was described using metabolisable energy (ME) as the unit of nutritive value (e.g. Blaxter, 1962). Gross energy in pasture is about 18.4 MJ/kg DM and varies little throughout the year. Digestible Energy (DE) content depends on digestibility. Losses between DE and ME are closely approximated by 19% of DE.

The priorities for partitioning dietary ME between maintenance and the productive processes were specified in a similar manner to that in White (1975) and Vera et al. (1977). Partitioning of dietary ME during underfeeding has received relatively little attention in the lactating and pregnant animal. Most studies have concentrated on estimating additional energy requirements for pregnancy and lactation based on the energy retained by these processes following adequate feeding.

Determinants of energy demand by the different productive processes and the relationships between energy retained and physical yield of product assumed in the model are discussed in this section. A flow diagram of the animal component was given in Fig. 6.1.

### 6.3.2 Maintenance

Theoretically maintenance comprises energy used to support basic body functions (i.e. Fasting Heat Production, FHP) plus the heat increment provoked by consuming feed below maintenance. Differences in FHP have been related to differences in metabolic body weight, for mature animals of different species (Klieber, 1961). However it has been found during attempts to measure FHP within a species that measurements are affected by nutrition prior to estimation (Webster, 1978), and that they are higher per unit metabolic body weight in growing than in mature animals. Many estimates of FHP therefore simply represent energy requirements at zero intake, extrapolated from regression through data at low levels of feeding (e.g. Graham & Searle, 1972). The function used by White (1975) relating FHP per unit metabolic body weight, to age, for stall fed sheep was taken as a starting point for estimating FHP as described above. The function was subsequently altered to conform to a slightly lower metabolic rate for the young lamb, in line with data from Walker & Jagusch (1969).

$$\text{FHP} = A * \text{WT}^{0.75} \quad (6.10)$$

$$\text{where } A = 0.233 + 0.025 / (0.125 * 32^{AGE}) \quad (6.11)$$

WT is fleece-free liveweight and AGE is age expressed in units of 1 year.

In the grazing sheep, maintenance requirements are considerably greater (plus 40%, Coop & Hill (1962)), than those of sheep confined to a pen. Further, maintenance requirement at grazing depends on pasture accessibility (Coop & Drew, 1963). The additional energy requirement associated with grazing hill country was assumed as 65%, compared to around 40% for flat land (Coop & Hill, 1962). Pasture accessibility effects on maintenance (EPA) were related to green cover

and are given in Fig. 6.11. These were adapted from Arnold et al. (1977).

The heat increment of feeding, below maintenance (1-KM), was related to ME concentration of the feed, (Q MJME/kg DM) MAFF (1975),

$$KM = 0.55 + 0.016 * Q \quad (6.12)$$

Maintenance energy requirements, (MEM) in MJ ME, were therefore described by Equation 6.13.

$$MEM = (FHP * 1.65 * EPA)/KM \quad (6.13)$$

### 6.3.3 Pregnancy

Energy retention in the products of conception has been the subject of a number of comprehensive studies. Geisler & Jones (1979) assembled much of this information into a model which has proved a useful review of the work. They derived a standard foetal growth curve by scaling foetal weight at term to 1 kg. Their function was used in this model (Fig. 6.12 and Equation 6.14). Actual foetal growth was obtained by multiplying the standard function by anticipated birth weight.

$$WF = -0.347E-4 + 5.026 * \text{EXP}(-\text{EXP}(-0.0143 * (T - 180.3))) \quad (6.14)$$

where T is day of pregnancy (must be greater than 30).

Lamb birth weight has been shown to be related to size of the ewe at mating (Donald & Russell, 1970). However Rattray & Trigg (1979) showed that nutritionally induced ewe liveweight differences at approximately day 100 of pregnancy influenced birth weight. This may have been due to nutritional effects on placental development (Davis et al., 1981). Potential lamb birth weight was determined relative to conceptus-free, fleece-free, ewe liveweight on day 95 of pregnancy. The relationships in Fig. 6.13 were assumed, using data from Lewis

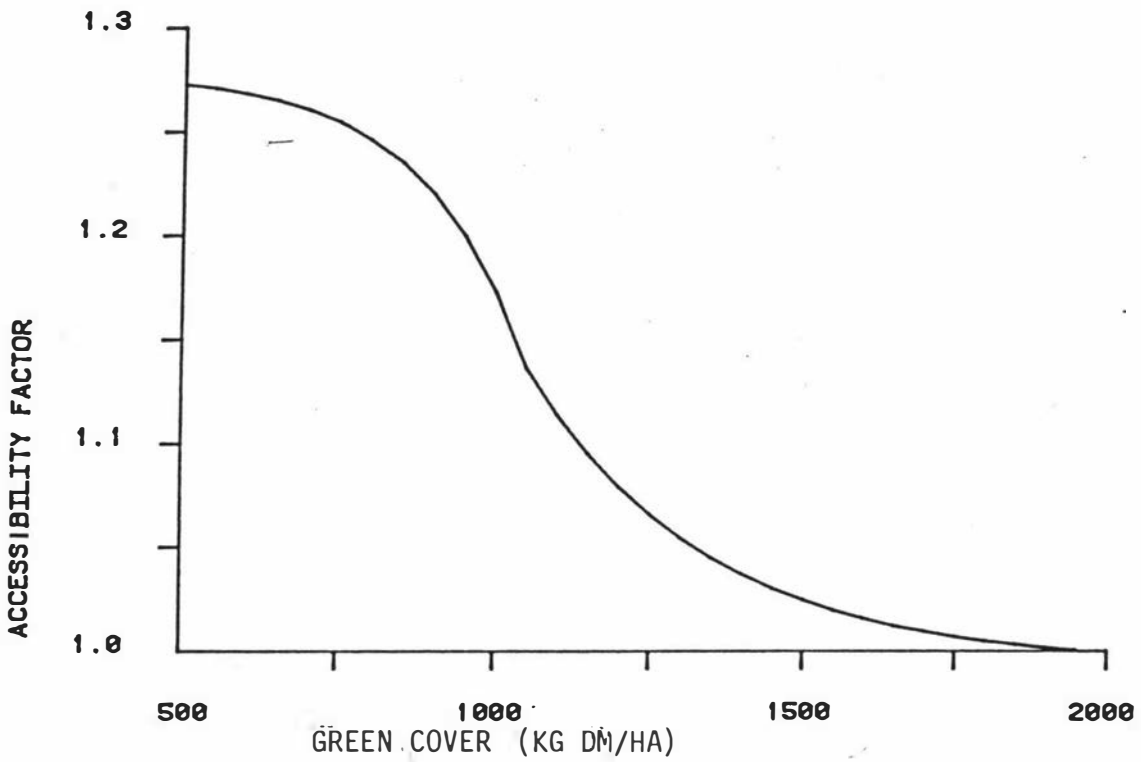


Figure 6.11 Effects of pasture cover (accessibility) on maintenance requirements.

$$\text{If } \text{GDM} \leq 1050, \text{ AF} = (10.35 - 1.15 * \text{EXP}(0.006 * (\text{GDM}-1050))) / 8.1$$

$$\text{ELSE} \quad \text{AF} = (8.05 + 1.15 * \text{EXP}(-0.0034 * (\text{GDM}-1050))) / 8.1$$

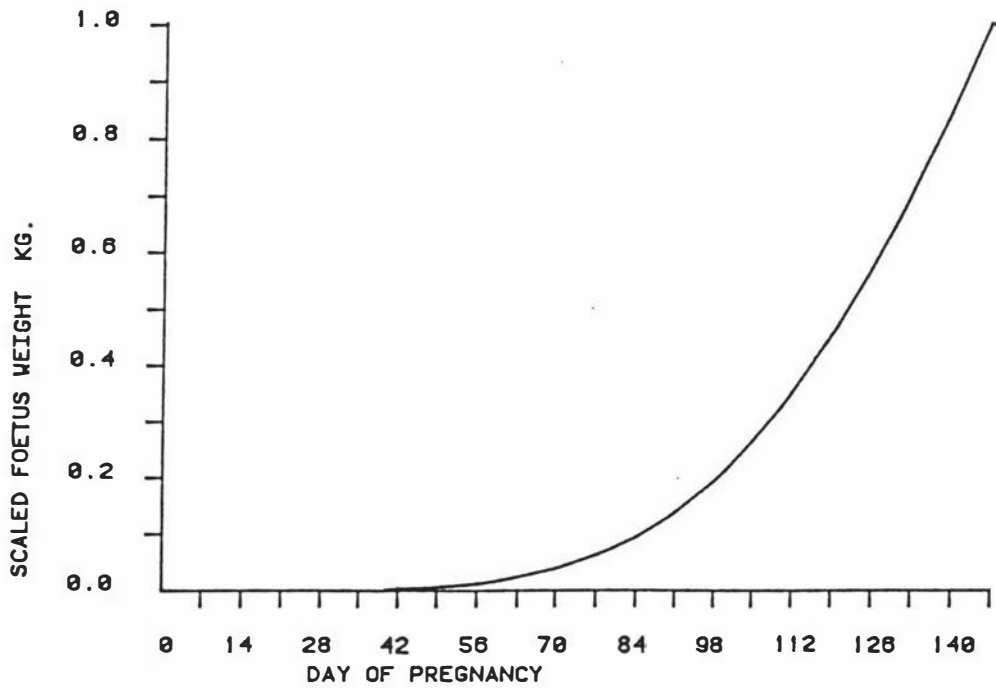


Figure 6.12 Scaled foetal weight through gestation.

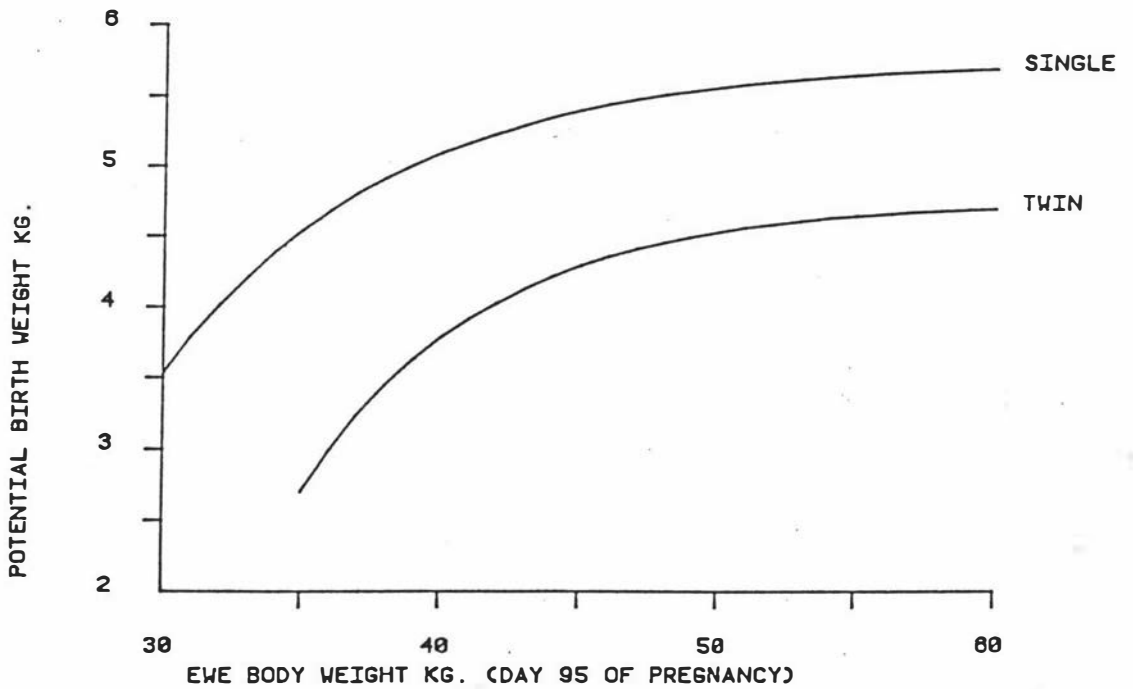


Figure 6.13 Potential lamb birth weights as a function of ewe fleece-free conceptus-free liveweight on day 95 of pregnancy.

(1959), McCall (1977) and Rattray & Trigg (1979). Up until Day 95, potential birth weight was estimated daily.

Nutritional effects on foetal growth after day 95, (e.g. Rattray et al., 1974b; Russel et al., 1977; Rattray & Trigg, 1979), were assumed to hold the foetus back in time on the potential growth curve, (e.g. Geisler & Neal, 1979). A nutritionally deprived foetus was assumed to have the same future growth potential as a younger foetus at the same weight. However, foetal growth rate was not permitted to fall below 84% of potential daily growth, a level shown to be maintained even at very low feeding levels (Rattray & Trigg, 1979).

Foetal energy content (in MJ) was related to stage of development (T, in days) by Equation 6.15, after day 75 of pregnancy. Before day 75, energy content was assumed to be 1 MJ/kg.

$$FE = -9.99 + 0.195 * T - 6.64E-4 * T^{**2} \quad (6.15)$$

Weight and energy content of the placenta, fluids and uterus (Figs. 6.14 and 6.15) were determined as in Geisler & Jones (1979) except that uterus weight was related to actual ewe conceptus-free fleece-free liveweight, rather than liveweight at mating. Mammary weight, was related to total foetal weight from the data of Rattray et al. (1974b) as:  $0.2 * \text{total weight of foetus}$ . Mammary tissue was differentiated from maternal tissue on Day 100. Assumed energy content of mammary tissue is shown in Fig. 6.16 (Rattray et al. 1974b).

Estimates of the efficiency of ME use for conceptus growth range from 10 to 21% (Robinson et al., 1980). These are gross efficiencies, determined from the amount of ME stored in the conceptus and apparent ME used for pregnancy. Furthermore they are averages over all or quite a large part of pregnancy.

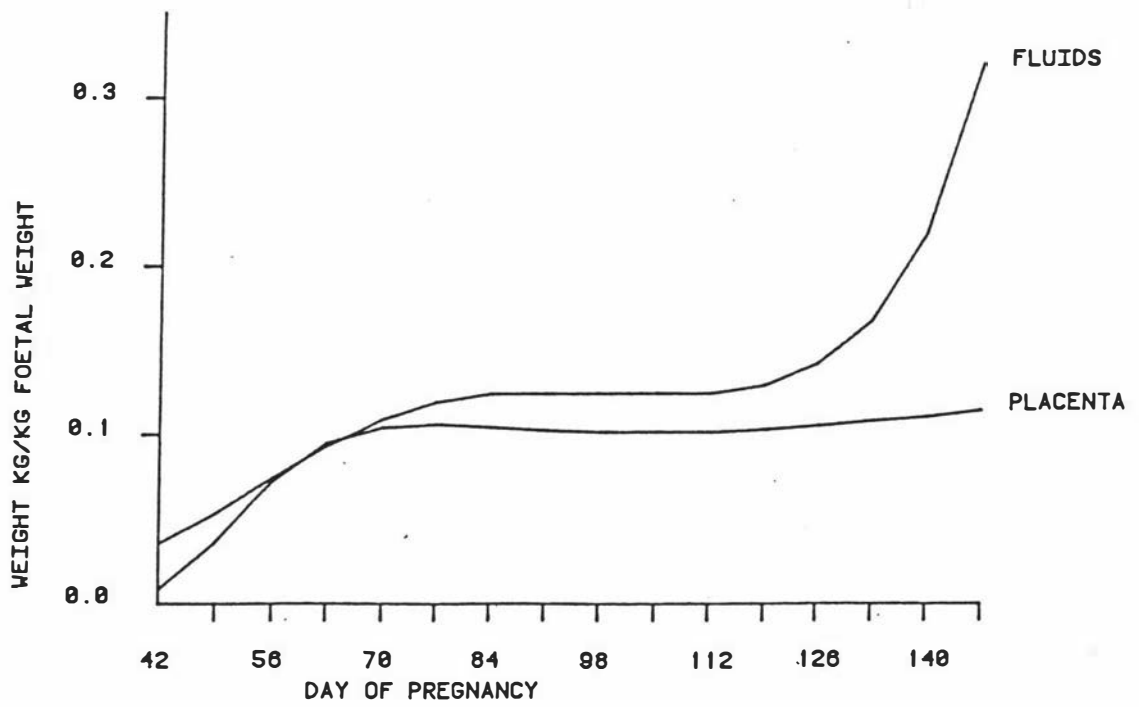


Figure 6.14 Weight of placenta and fluids, relative to foetal weight, through gestation.

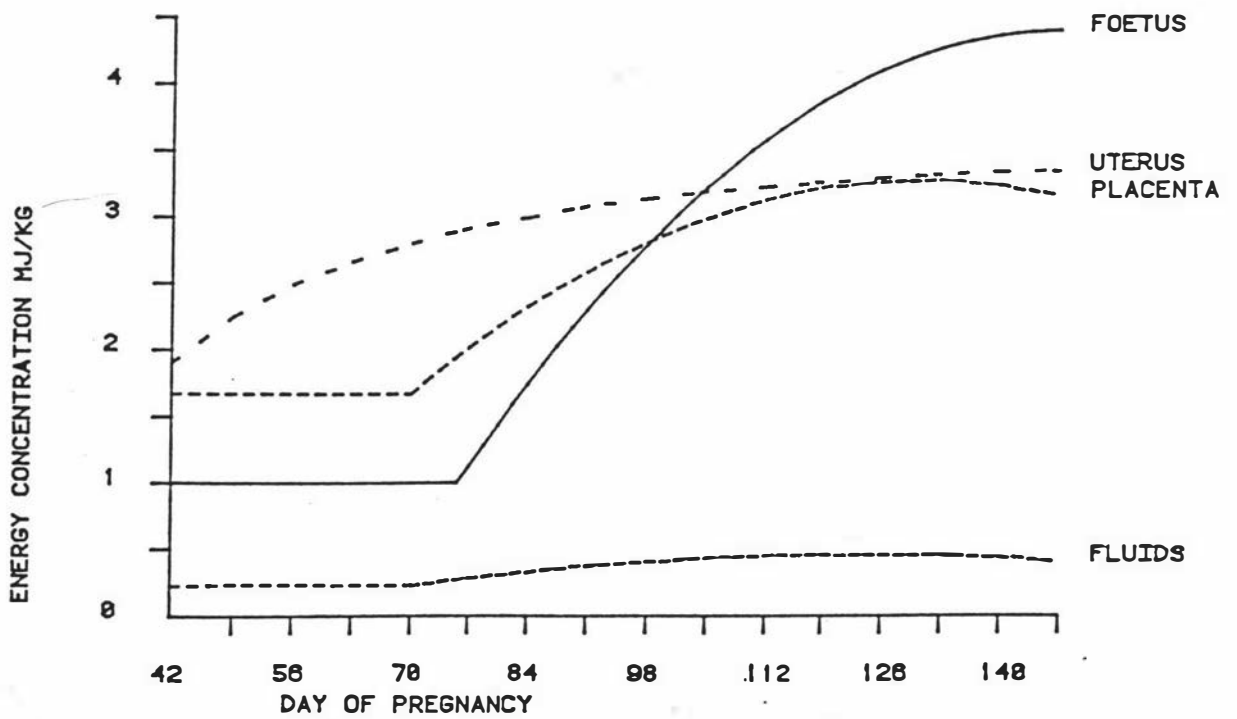


Figure 6.15 Energy concentration in the various components of pregnancy through gestation.

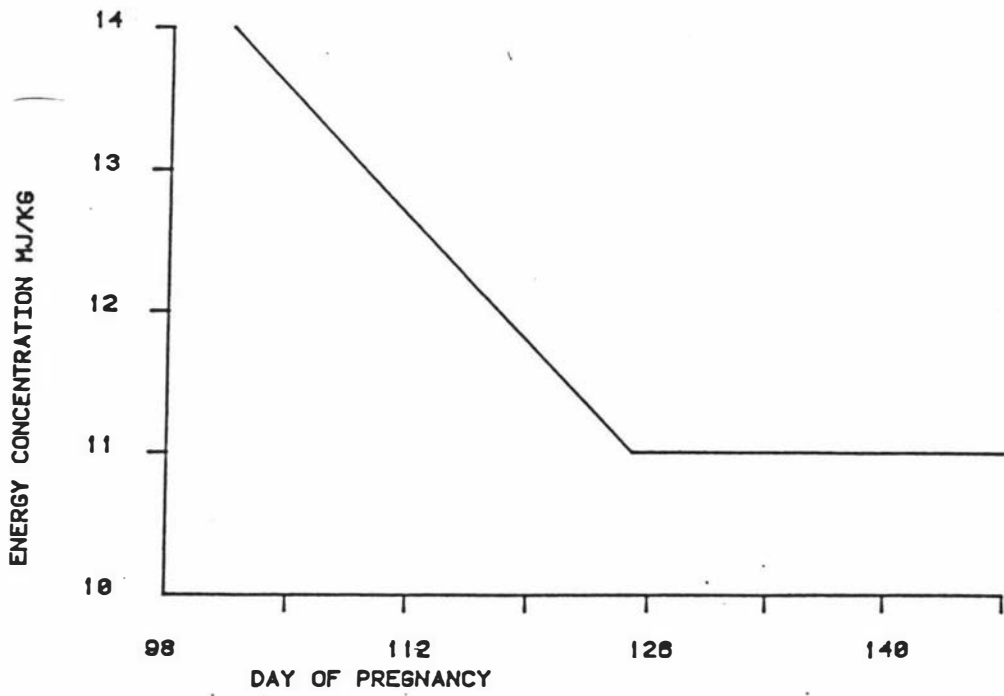


Figure 6.16 Energy concentration in the mammary gland through gestation.

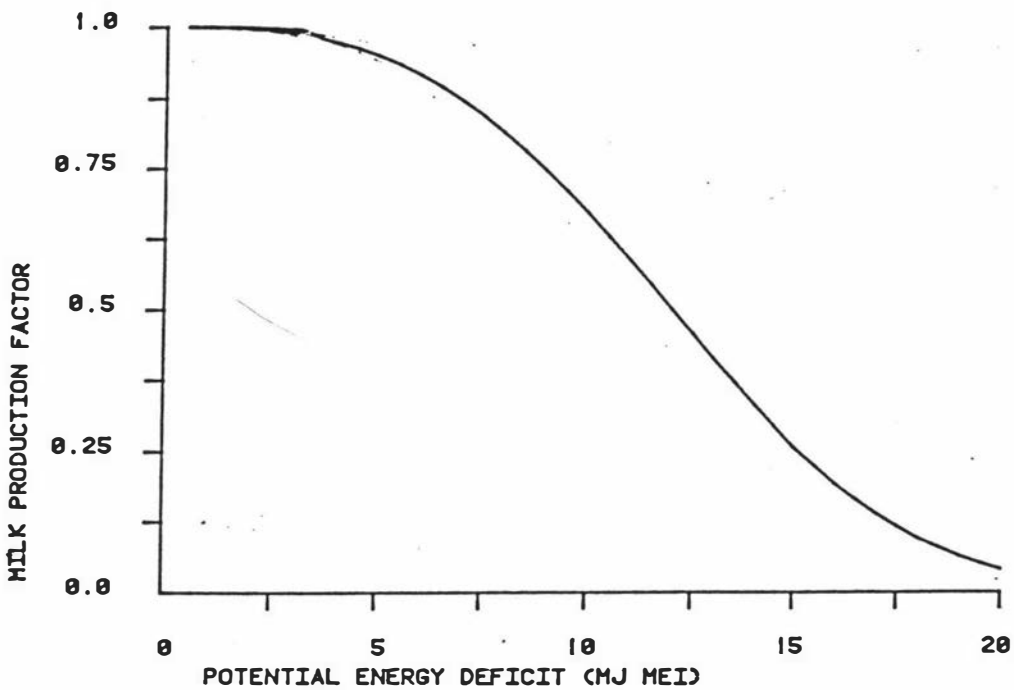


Figure 6.17 Generalised functional form describing reduction in potential milk yield with increasing energy deficit (adapted from White, 1975).

It was decided to partition energy used for pregnancy between conceptus maintenance and conceptus gain (Rattray et al., 1974a), since this structure best explained the decreased gross efficiency of ME use with improved feeding, noted by Graham (1964).

Maintenance of mammary tissue was determined as part of maternal maintenance. Conceptus maintenance requirements were assumed to be 0.525 MJME/kg conceptus metabolic weight, the efficiency of ME use for maintenance (KCM) having been taken as 80% (see Rattray et al., 1974a). The efficiency of ME use for conceptus and mammary gain, using the above assumptions regarding maintenance, was calculated as 25% from Rattray et al. (1974a).

#### 6.3.4 Lactation

Given good nutrition, ewe milk production increases post-lambing. Production peaks around the third week of lactation and thereafter declines steadily (Corbett, 1968). The pattern is similar to that in cows (Corbett, 1968) and has been described by White (1976) using the functional form derived for cows by Wood (1967).

$$Y = A * WL^{**B} * EXP(-C * WL) \quad (6.16)$$

where WL is week of lactation, parameter 'A' provides the scale for the level of milk production, and the parameters 'B' and 'C' determine the pattern of ascent and descent, relative to 'A'.

Nutrition of the ewe in late pregnancy has been implied as a factor influencing potential milk production (Treacher 1970), as has intake capacity (birth weight) of the young lamb (Peart, 1967). The latter mechanism is supported by the fact that ewes rearing twins produce 30% more milk than those rearing singles (Barnicoat et al., 1949). White (1975) derived equations relating 'A' to lamb birth

weight (BWT, kg) for ewes rearing twins and singles. They appeared to conform with New Zealand data, and so were adopted.

$$A(\text{singles}) = 0.35 * \text{BWT} \quad (6.17)$$

$$A(\text{twins}) = 0.5 * (\text{BWT} + 1) \quad (6.18)$$

Values for the parameters 'B' and 'C' were established from New Zealand data on romney ewes (Jagusch et al., 1972; Geenty & Jagusch, 1974; Geenty, 1979) by fitting a linear transformation of Equation 6.16 (i.e.  $\ln Y(\text{WL}) = \ln(A) + B * \ln(\text{WL}) - C * \text{WL}$ )

where  $\ln$  is the natural logarithm.

Representative estimates for 'B' and 'C' (Table 6.2) were 0.5 and 0.19 for ewes rearing twins. Limited data on ewes rearing singles suggested a similar pattern of lactation to ewes rearing twins so the above values were adopted for ewes rearing singles.

TABLE 6.2: Parameter values for lactation curve obtained by fitting New Zealand data

Reference/Parameters	A	B	C
Geenty(1979) Twins	2.89	0.422	0.217
Geenty (1979) Twins	2.92	0.349	0.191
Jagusch <u>et al.</u> (1972) Twins	2.77	0.545	0.199

If insufficient feed is consumed for a ewe to remain in positive energy balance while producing at potential milk yield, some buffering of milk production appears to occur through liveweight loss, before milk production is decreased (e.g. Trotter et al., 1975). To

account for these effects the general functional form assumed by White (1976) was adopted (Equation 6.19, Fig. 6.17).

This describes the reduction in milk yield (MILKFC) resulting from different levels of energy deficit (EMB), and allows for a level of mobilisation without deleterious effect on milk production, and reduction in milk production before maximum mobilisation is reached. A family of curves was postulated with the value of parameter 'D' depending on ewe buffering ability (i.e. liveweight) and week of lactation. The relationship between D and liveweight and week of lactation was derived by calibration to Peart's data (see Section 7.6.3).

$$\text{MILKFC} = \text{EXP}(-D * \text{EMB}^{**3}) \quad (6.19)$$

Where short duration restrictions to intake (2 weeks) occur in early lactation, milk production returns to potential levels when ad libitum feeding is resumed, but this does not occur following prolonged restriction (4 weeks) (Peart, 1970). To account for the latter effect, milk yield after week four of lactation, was restricted from rising above the average daily yield of the previous week where actual milk yield was less than 80% of potential over the first 4 weeks of lactation. In addition, milk yield in late lactation (>5 weeks) was restricted from rising above the average daily yield of the previous week as a matter of course.

The energy content of ewes' milk varies between 24.1 and 26.3 MJ/kg DM of milk, depending on composition (Jagusch & Mitchell, 1971). Values of 26 MJ/kg DM and 18.5% DM were chosen as representative of Jagusch and Mitchell's data. Various estimates of the partial efficiency of milk production (KL) range from 59% (Maxwell et al., 1979) to 75% (Orskov & Robinson, 1972) for ewes. A value of 65% was

chosen as a best estimate from work on dairy cows (Holmes et al., 1981).

The efficiency of ME use for maintenance and gain in suckling lambs were both assumed to be 0.77 (Jagusch & Mitchell 1971). As lambs commenced grazing, KM and KF were assumed to take values intermediate between milk and grass values, in proportion to the amount of ME they received from each source.

### 6.3.5 Body Tissue Change

Surplus ME, after meeting the day's requirements for maintenance and production, was stored as body tissue. The efficiency (KF) with which ME was retained as tissue energy depended on the quality of the diet (Q, MJME/kg DM) (MAFF, 1975).

$$KF = 0.0435 * Q \quad (6.20)$$

KF was assumed to be unaffected by physiological state except during lactation, when KF was assumed to equal KL (ARC, 1980).

For a positive energy balance, energy retained was calculated as :

$$ER = (MEI - MEM - MEP - MEL) * KF \quad (6.21)$$

where MEM, MEP and MEL were ME used in maintenance, pregnancy and lactation respectively, and MEI was ME intake.

Where energy balance is negative, the information is not as clearly defined. Theoretically, in the dry sheep, loss of energy from tissue increases as:  $KM * MEI$ , per unit deficit of MEI below maintenance (MEM)

.Expressed in a general equation:

$$ER = MEI * KM - FHP \quad (6.22)$$

where FHP, above, includes the grazing components of maintenance in Equation 6.13.

Graham et al. (1976) considered that KM was too high for calculating negative energy balances and that KF was valid at least down to an MEI of half MEM. Despite this it was decided to retain Equation 6.22.

The partial efficiency of catabolised energy use for lactation (KML) has been assessed as 0.84 in cows (ARC, 1980). The same efficiency was assumed to hold in ewes. During pregnancy, Robinson et al.'s (1980) data suggested that energy supplied from body tissue was used with about twice the efficiency of dietary ME in twin bearing ewes. Accordingly, the energy deficit resulting from shortage of ME to meet pregnancy requirements was assumed to be 0.5 times the deficit in MEP.

Energy retention in pregnant and lactating ewes in negative energy balance was therefore described as:

where  $MEI > MEM$

$$ER = (MEI - MEM) * 0.5 - MEP * 0.5 \quad (6.23)$$

$$\text{or } ER = (MEI - MEM - MEL) * KL/KML \quad (6.24)$$

where  $MEI < MEM$

$$ER = (MEI * KM - FHP) - MEP * 0.5 \quad (6.25)$$

$$\text{or } ER = (MEI * KM - FHP) - MEL * KL/KML \quad (6.26)$$

Change in empty body weight (EBWC, kg) was determined from energy retention (ER) and the energy value of gain (EVG, MJ/kg<sup>-1</sup>).

$$EBWC = ER/EVG \quad (6.27)$$

The energy value of gain (and loss) was related to empty body weight (EBW, kg) by Equation 6.28, derived by White (1975) from the data of Searle & Graham (1970).

$$\text{EVG} = 0.52 * \text{EBW} + 3.5 \quad (6.28)$$

where EBW is empty (30 hour, fasted) body weight.

An upper limit to EVG must occur at 39 MJ/Kg, the energy content of fat, but in practice EVG has not been measured this high.

Equation 6.28 was bounded at 35 MJ/kg.

Energy value of gain in young lambs can be extremely variable, and depends on level of nutrition. Under-nourished lambs mobilise fat to produce protein (Jagusch & Mitchell, 1971). Energy value of gain was therefore considered constant at 8 MJ/kg, until Equation 6.28 took over. A value of 8 MJ/kg is in the range of Jagusch & Mitchell's data.

Liveweight change (LWC, kg) was estimated by assuming the weight of gut contents to be 6% of fasted body weight (Hughes, 1976). Wool growth (WG, kg) and growth of the products of pregnancy (CG, kg) were added and change in liveweight was therefore estimated as:

$$\text{LWC} = \text{EBWC} * 1.06 + \text{WG} + \text{CG} \quad (6.29)$$

### 6.3.6 Climate Effects

Additional energy requirements of sheep after shearing were related to environmental heat demand (EHD, MJ) from an equation adapted from Blaxter (1977).

$$\text{EHD} = ((\text{TR} - \text{MAT} + \text{E} * \text{IE}) / (\text{IT} + \text{IE})) * \text{SA} \quad (6.30)$$

where SA is surface area ( $\text{m}^2$ ), TR is rectal temperature (39 °C), MAT is mean air temperature, E is the minimal loss of heat by vaporising moisture (1.3 MJ/ $\text{m}^2/\text{d}$ ), IE is external insulation (see below) and IT is tissue insulation (1.33 °C. $\text{m}^2.\text{d}/\text{MJ}$  for adult sheep)

$$\text{SA} = 0.09 * \text{LWT}^{0.66} \quad (6.31)$$

$$IE = (R/(R+F)) * 1/(0.115+0.099 * V)^R * \ln((R+F)/R) * (Z-0.09 * V)/4.18. \quad (6.32)$$

where R is the radius of a sheep (150 mm), F is the length of fleece in mm, V is air velocity in miles per hour, and Z is the thermal insulation of 1 mm of fleece ( $0.59 \text{ } ^\circ\text{C}\cdot\text{m}^2\cdot\text{d}/\text{Mcal}$ ).

Fleece length (in mm) was related to fleece weight (FLWT, kg) (Graham et al., 1976), as:

$$F = (\text{FLWT}/(0.08 + 0.005 * \text{LWT})) * 10 \quad (6.33)$$

Where heat production on any day was not sufficient to meet the environmental heat demand, maintenance was increased at the expense of energy retained in body tissues until sufficient heat was produced to meet demands.

### 6.3.7 Wool Growth

Wool growth in temperate sheep breeds is subjected to an annual rhythm. Under normal levels of feeding the ratio of wool grown in the summer can be three times that grown in the winter (Coop, 1953; Bigham et al., 1978).

It is generally accepted that wool growth rate is linearly related to intake for a particular diet (e.g. Sumner, 1979). Linear relationships between wool growth rate and liveweight gain in recent New Zealand studies (Sumner & Rattray, 1980; Sumner & Smeaton, 1981) adds weight to this observation. The slope of the relationships are affected by the seasonal rhythm of wool growth (Sumner, 1979) and lactation (Hawker, 1981a). Also, a lag occurs before wool growth rate reaches equilibrium following an alteration to intake (Nagorcka, 1977).

Relationships between clean wool growth rate and ME intake were derived from data summarised by Hawker (1981a) relating to New Zealand trials at pasture. Digestible organic matter, the unit used by Hawker for intake, was converted to MJME using a factor of 15.5 MJME/kg DOM (Jagusch & Coop, 1971). Grams of clean dry wool grown per MJME intake are given in in Table 6.3 for different times of the year. There was quite a range in responses.

TABLE 6.3: Wool growth rate responses calculated from Hawker (1981a)

Dates	Class of Sheep	Response (g clean wool/MJMEI)
1 Sept-31 Oct	Hogget	0.60-0.78
1 Nov - 9 Dec	Hogget	0.69-0.94
Feb - May	Lamb	0.45-0.96
Autumn	Ewe	0.63-0.88
Mid winter	Ewe	0.39-0.55
Sept-Dec	Ewes lactating (single)	0.35-0.38
Sept-Dec	Ewes lactating (twin)	0.30-0.36

Responses in the model were interpolated from responses chosen from Table 6.3 as being representative of four times of the year. For non lactating sheep, these were:

end of March	0.65
end of December	0.90
end of September	0.60
end of June	0.40.

For lactating ewes, end of September values were changed to 0.26 and 0.22 for ewes rearing singles and twins respectively, and values of 0.35 and 0.30 were assumed to be reached by the end of November and remain until day 84 of lactation, or weaning, whichever came first.

Wool growth rates at zero intake were assumed to be 0.5 g/day in June, 1.0 g/day in September and March and 1.5 g/day in December.

The lag function incorporated in the model was that derived by Nagorka (1977). The lag was defined as the time taken for wool growth rate to change by 2/3 of the difference between its current value and the new equilibrium value to which it asymptotes. The numerical form of the equation, with the time increment (t) as 1 day, was as follows:

$$WGR = 0.96 * WGR(t-1) + (EFF * MEI(t))/24 \quad (6.34)$$

where WGR is wool growth rate in MJ wool, EFF is efficiency of wool growth (MJ/MJ MEI), and MEI is metabolisable energy intake.

Energy content of wool was taken as 24 KJ/g (Graham et al., 1976) and clean dry wool was assumed to be 70% of greasy weight (Sumner, pers. comm.). Energy partitioned to wool was assumed to be syphoned off first.

#### 6.4 REPRODUCTION

In this section the prediction of lambing pattern and the number of lambs born and weaned by ewes and ewe hoggets is discussed. The data reviewed were New Zealand data and relate primarily to the NZ Romney.

In mature Romney ewes the breeding season begins around the beginning of February (Quinlivan & Martin, 1971a) and extends until the end of August (Hight et al., 1976). However the majority of ewes do not commence cycling until early April and oestrous activity tails off after mid-June. The percentage of non pregnant ewes expected to show oestrus over each 17 day cycle was predicted relative to date of ram entry, from the data of Quinlivan & Martin (1971a) (Fig. 6.18).

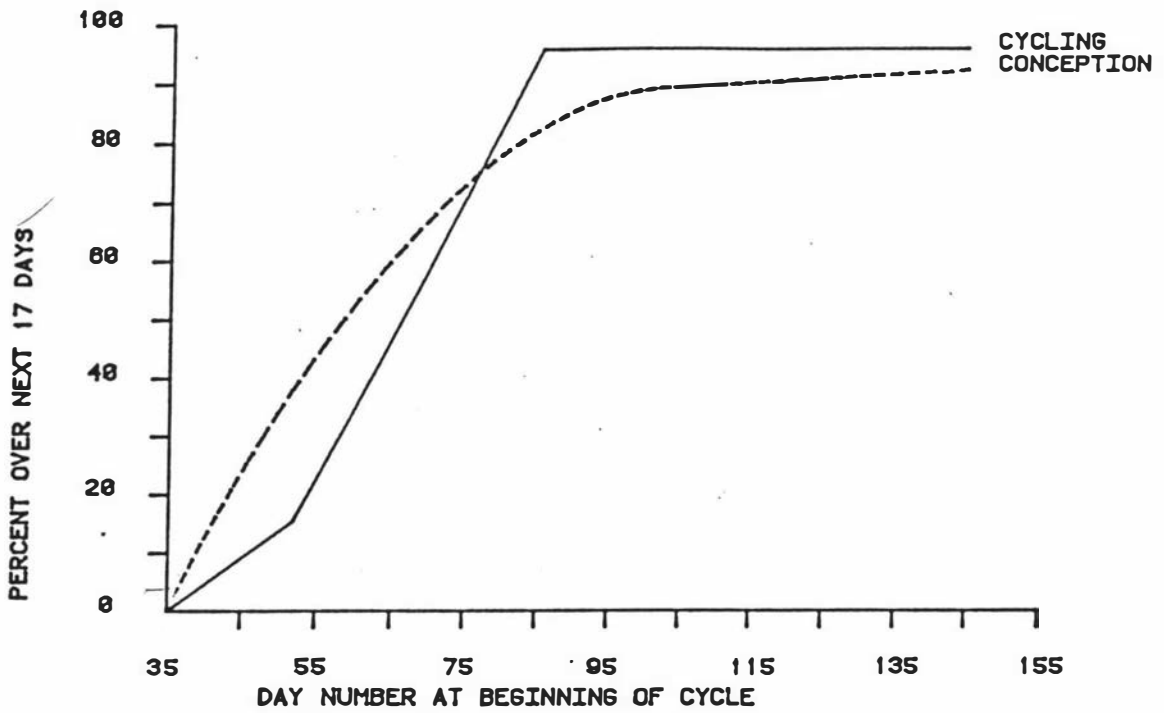


Figure 6.18 Effect of day of year on the percentage of non-pregnant ewes expected to cycle and the percentage of cycling ewes expected to conceive over succeeding 17 day periods. Equation for conception curve:

$$\text{IF}(\text{DAY}.\text{LT}.103)\text{Z} = (\text{DAY}-103)**2$$

$$\text{ELSE Z} = 0$$

$$\text{Concep} = 82.036+0.071169*\text{DAY}-0.01826*\text{Z}.$$

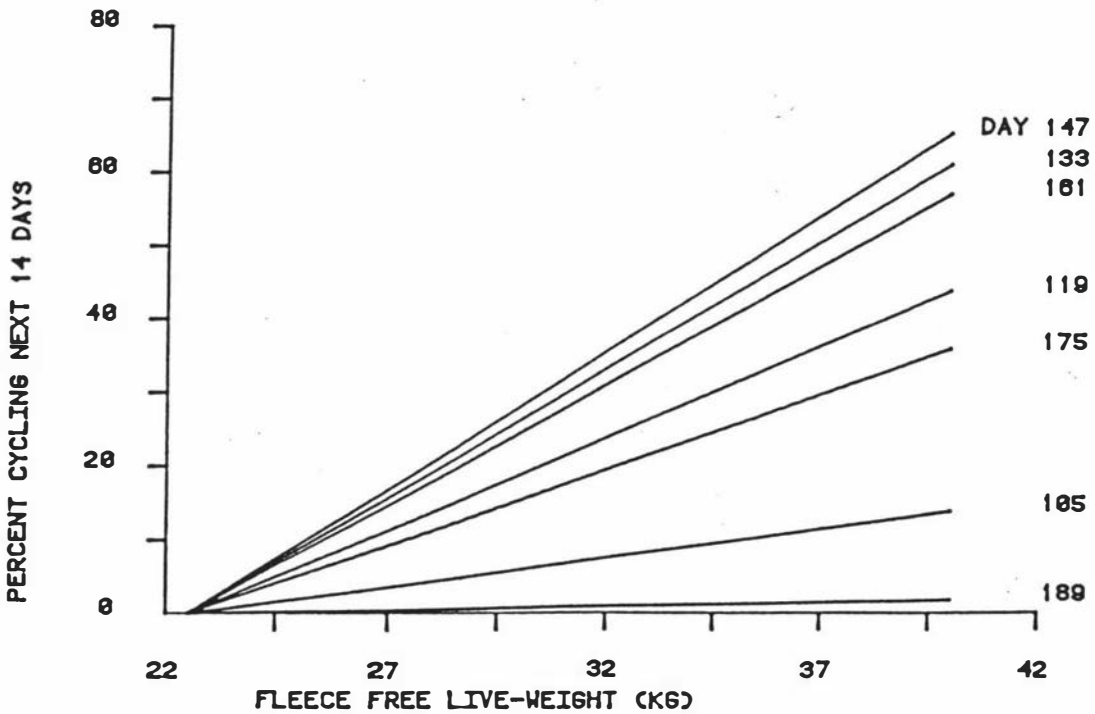


Figure 6.19 Effect of the day of year and hogget fleece-free LWT on the percentage of hoggets expected to cycle over succeeding 14 day periods.

Specification of the decline in oestrous activity beyond mid-June was considered of no practical importance.

Failure to cycle was assumed to be the most likely reason for increased barrenness of ewes weighing less than 40 kg (Coop, 1962; Hight & Jury, 1973). The percentage of non-cycling barren (NCB) ewes, on any day, was related to average flock liveweight. Using Hight & Jury's data and assuming that flock liveweight was normally distributed, with a coefficient of variation of 15%, the relationship derived was:

$$\text{NCB} = 252.16 - 10.21 * \text{LWT} + 0.104 * \text{LWT}^2 \quad (6.35)$$

when  $\text{LWT} < 50$  kg.

The average liveweight for non-cycling ewes ( $\text{LWT}_{\text{NCB}}$ , kg) becomes:

$$\text{LWT}_{\text{NCB}} = 0.3 + 1.39 * \text{LWT} - 0.014 * \text{LWT}^2. \quad (6.36)$$

The breeding season in the ewe hogget is much shorter than for the ewe. Where hoggets are well grown, i.e. 32 to 34 kg, it commences in mid-April and finishes in mid-July (Moore et al., 1978). However, both commencement date and duration of breeding season depend on liveweight (Hight et al., 1973; Moore et al., 1978). Very few hoggets below about 27 kg exhibit oestrus.

Relationships between average hogget liveweight and percentage of hoggets exhibiting oestrus over 14 day periods were derived from Hight et al., (1973) and Moore et al., (1978) (Fig. 6.19).

Conception rate also increases as the breeding season advances in mature ewes (Quinlivan & Martin, 1971a). The function derived from Quinlivan and Martin for successive 17-day periods is shown in Fig. 6.18. In hoggets, conception rate is much lower than in ewes (Lewis, 1959; Allison et al., 1975). It does not appear to be related

to liveweight and is similar for successive oestrus cycles (Lewis, 1959). Conception rate was therefore taken to be 55% (Lewis, 1959).

It is well known that liveweight at mating and liveweight change pre-mating, influence ovulation rate of ewes (Coop, 1966). Rattray et al. (1981) proposed a model describing the probability of a multiple ovulation, relative to liveweight at mating, and change in liveweight in the six weeks prior to mating, for different breeds of ewe. The equation for Romney ewes was used in the model to describe the probability of a multiple ovulation:

$$\ln(P/(1-P)) = -20.714 + 0.2256*LW1 + 0.4876*LW2 - 0.005936*LW1*LW2 \quad (6.37)$$

where P is the probability of multiple ovulation, LW1 is pre-flushing liveweight and LW2 is mating liveweight.

Multiple ovulations were all assumed to be twin ovulations and the equation was applied daily to each group of ewes conceiving. The appropriate number of ewes were then designated as either twin or single ovulators.

All ewe hoggets were assumed to have single ovulations, since few (less than 4%), have twin lambs (McCall & Hight, 1981).

The percentage of ewes lambing 0, 1 or 2 lambs, as a result of one or two ovulations, shown in Table 6.4, was taken from Kelly & Knight (1979). No effects of early pregnancy feeding, on embryonic mortality (e.g. Edey, 1976), have been recorded under New Zealand conditions. Embryonic mortality in ewe hoggets was included in the conception rate parameter.

TABLE 6.4: Lambing performance of ewes related to ovulation rate from Kelly & Knight (1979)

Number of eggs shed/ewe	Percentage of ewes with			lambs
	0	1	2	
1	3.6	96.4		
2	2.7	27.7	69.6	

Mortality of lambs near birth under hill country conditions has been recorded by Hight & Jury (1969). Other things being equal, percentage mortality within twin and single-born lambs was related to lamb birth weight. The former died in greater numbers from starvation/exposure at low birth weights, and the latter from dystocia problems at high birth weights. Relationships between average birthweight (BWT, kg), and mortality were derived using the data of Hight & Jury (1969) by assuming birth weight to be normally distributed about the mean with a coefficient of variation of 18.5% (McCall, 1977). Percentage survival of single and twin-born lambs calculated in this way is:

$$= -40.11 + 55.59 * BWT - 6.14 * BWT**2 \quad (\text{singles}) \quad (6.38)$$

$$= -2.115 + 33.83 * BWT - 3.3 * BWT**2 \quad (\text{twins}), \quad (6.39)$$

No account was taken of climatic effects on lamb mortality owing to lack of data.

The distribution of twin deaths between ewes losing one, or both of a set of twins was taken from New Zealand survey data (Quinlivan & Martin, 1971b). Thirty-eight point six percent of twin deaths were both lambs from a set of twins. For each 100 twin

deaths the number of twin-bearing ewes rearing 0 or 1 lamb, was therefore calculated as 19.3 and 61.4, respectively.

Death rate of ewes was assumed 0.6% of ewes mated, between the end of June and the beginning of lambing, and 4% of ewes mated, over lambing. These are New Zealand average figures from Quinlivan and Martin's (1971b) survey.

## 6.5 STRUCTURE OF THE COMPLETE GRAZING MODEL

Having established relationships that describe an individual animal, the next problem was to describe the mean behaviour of a mob,

since individuals within a mob vary in liveweight and may be dry, pregnant or lactating at one point in time.

It was decided to describe mean characteristics of a mob by following the fortunes of an average individual within the mob. For lambing ewes, or ewe hoggets, it was necessary to describe three average (marker) animals representing ewes carrying 0, 1 or 2 fetuses and rearing 0, 1 or 2 lambs. Marker ewes, lambing on the median lambing day, were chosen at the end of mating and were followed until weaning. Mean ewe and lamb liveweight and fleece weight were determined from the performance of the markers and the number of animals they represented.

Liveweights for the three marker ewes were determined after mating by assuming the liveweight of dry ewes to be the weighted average of the liveweight of non-cycling barren ewes (Equation 6.36) and average flock liveweight (i.e. for ewes suffering embryonic loss). Liveweight of twin-bearing ewes was assumed to be 3.5 kg heavier than single bearing ewes (Hight & Jury, 1973). Average liveweight of

twin and single-bearing ewes was calculated from flock average liveweight, corrected for removal of dries. For hoggets, average liveweight of those bearing lambs was taken to be 3 kg higher than dry hoggets (Allison et al., 1975).

Pattern of lambing, and median lambing day, were determined by keeping track of the number of ewes conceiving singles and twins on each day of mating. Since the average pasture intake for a mob during lactation will depend on lambing pattern and may not be represented by intakes of the markers, numbers of ewes lambing on each day, updated by lamb mortality, were maintained until weaning to derive average voluntary intake for the flock. Intakes of marker ewes within the flock were determined independently.

Mortality in lambs born prior to median lambing day was related to predicted birth weight from foetal weight on the day in question, relative to potential foetal weight, and extrapolated to birth weight at term. Following median lambing day, mortality was assumed to be related to birth weight of the marker lambs.

The complete model was structured so as to represent as closely as possible conditions on an actual farm. Practical grazing decision options were constrained by the impositions of paddock subdivision and mob segregation. Provisions were made for three mobs of sheep, two of which could bear lambs, and up to 40 equally sized paddocks.

Each set of decisions was carried out for a user defined period. Grazing decisions required to be specified for each mob included, whether the mob was to be set-stocked or rotationally grazed, the number of paddocks to be grazed over the period between shifts, and the number of days between shifts. Choice of paddock at each shift was decided by the model, being the paddock with the highest pasture

cover when rotational grazing, or every alternate highest paddock, when set stocking. The latter procedure ensured that other mobs, if present, were not left with only paddocks which had a low cover. In addition a specified number of paddocks were able to be retired from grazing at a specified average cover or date, and were returned to grazing on a similar basis. Paddocks retired were those with the highest cover.

No two mobs were permitted to graze any paddock simultaneously. A mob was however permitted to follow another mob in a leader/follower system, the shifting decisions for the leading mob being based on those for the following mob.

Other decisions were deliberately left general. For instance the decision regarding selling of surplus lambs (timing and numbers) was left to be explicitly stated by the user. The important point was that inclusion of other decision rules, when and if required, could be accommodated.

## 6.6 SUMMARY

In this Chapter the structure and assumptions of the intake and sheep components of the model were described. The point was made that the relationships describing energy utilisation in the sheep have been relatively well researched. However the same could not be said for the mechanisms governing pasture quality and intake.

A review of the relevant literature, and a description of the assumptions made in the model, made up the bulk of the Chapter. The review was conducted first for intake and then for each of the physiological states of the sheep. In the concluding section a brief description was given of the structure of the complete model.

The extent to which the overall model reflects any disciplinary imbalance (in terms of level of detail in construction, or emphasis) was due to the state of knowledge represented in the literature, rather than a conscious bias on the part of the modeller. Conclusions about this state of knowledge are given in Chapter 9.

The validity of the assumptions made in both Chapters 5 and 6 is the topic for Chapter 7.

## Chapter 7

### MODEL DEVELOPMENT AND EVALUATION

#### 7.1 INTRODUCTION

In Chapters 5 and 6 the relationships initially assumed in the model were described. Model development up until the stage reported in the present chapter involved mainly checks that model logic was as intended.

In this chapter the processes of: (1) component evaluation, (2) development of model structure, and (3) assessment of model validity, are described. Some difficulties confronted in validating a model were discussed in Section 3.4. The approach to the validation task in this study followed the sequence: (1) Calibration of parameters in the major components of the model, to obtain the 'most valid' model. (2) Statistical testing of each component to check structural<sup>1</sup> acceptability of the model. (3) Effecting structural changes, where required. (4) Recalibration and testing, and finally (5) validation against new data.

#### 7.2 MODEL REFINEMENT AND VALIDATION PROCEDURES

Data were set aside before model construction for use in calibrating parameters in the various components of the model. A major reason for calibrating the model originated from the observation that a range of values could be derived from the literature for many of the parameters. For example, reports of the partial efficiency of energy use by the ewe for lactation ranged from 0.59 to 0.75 (see Section 6.3.4). By calibrating the model, choice of parameter value was rationalised on the basis of the best agreement between simulated

<sup>1</sup>Model structure in this context refers to functional forms used in the model.

responses and observed results from a major, and 'separable', component of the system. A second reason for calibrating was that it appeared to allow the structural validity of the model to be tested since no other combination of parameter values could improve the model's predictiveness. If the calibrated model failed statistical tests then by implication either an important variable must have been omitted or one or more functional relationships must have been —incorrect.

Despite the existence of published reports on whole sheep grazing system studies (e.g. Suckling, 1975; Joyce et al., 1976; Bircham et al., 1977; Rattray et al., 1978), there were two reasons for calibrating individual components of the model. First, insufficient reported data on inputs and outputs from the above studies made them unsatisfactory for calibration, and second even if these limitations had not existed there were too many parameters to be calibrated in one attempt.

The end point for calibration was determined by minimising the value of the function:  $C = \sum (\bar{Y}_i - \bar{X}_{ij})^2$ , where  $\bar{Y}_i$  was the actual observation corresponding to the simulated observaton  $\bar{X}_{ij}$ . A constrained non-linear minimisation routine with search criteria (subroutine E04JAF in the PR1ME nag library), was used to minimise this function. Constraints were imposed on parameter values to ensure that the routine did not attempt to fit parameter values which were infeasible in the biological sense.

Acceptance of the calibrated model components was based on statistical tests against the calibration data.<sup>2</sup>

Where an alteration to the structure (i.e. functional forms) of a

<sup>2</sup>See the following section for discussion on the statistical tests.

component was required, the altered component was recalibrated to the original calibration data. Following acceptance of the calibrated component, a limited number of subjective assessments of validity were made against new data. No formal Turing type test (Greig, 1979) was conducted since, although it is acknowledged that the greatest impact of a model will only be realised following acceptance by experts in each of the disciplines involved (e.g. Miller, 1983), at this stage this model was largely a personal tool and it was felt to be sufficient to develop the modeller's confidence in it. Less formal exposure of model performance (e.g. at Massey University and MAF seminars, and on a one-to-one basis with interested consultants and members of the Massey Department of Agricultural Economics and Farm Management) did however form part of the subjective validation process.

### 7.3 STATISTICAL TESTS

The task of empirically comparing model to real system performance is made difficult by the fact that there are no generally accepted statistical tests for testing the goodness-of-fit of models (Van Horn, 1971). It was considered that this situation warranted a review of some of the issues faced in this study before proceeding to a description of the testing undertaken as part of model calibration and validation.<sup>3</sup> A general example is used to illustrate the discussion.

The true (real system) model in a single output variable  $Y_i$  was considered, written in the form:

$$Y_i = R(Z_i) + u_i$$

<sup>3</sup>Note that non-statistical means of testing goodness-of-fit are reviewed in Section 3.4.

where  $R(Z_i)$  is the mean of  $Y_i$ , conditioned on the levels of a vector of variables  $Z_i$ , and  $R$  is the unknown system of mathematical functions and parameter values describing the relationship between the  $Z_i$  variables in the real system. For a number of reasons which may include; inability to specify the full set of  $Z_i$  variables or to accurately observe their values, real biological systems output for any set of values for the (specified)  $Z_i$  variables, will be stochastic (i.e. output is a random variable). Hence a random component,  $u_i$ , will be associated with observed values of  $Y_i$ .

A simulation model<sup>4</sup> estimating the true model can be expressed as:

$$X_{ij} = M_j(Z_i) + v_{ij}$$

The objective in modelling is to build a simulation model such that the model output  $X_{ij}$  and real system output are indistinguishable. Part of the science of modelling involves the choice between alternative models, hence the subscript  $j$  has been used in the context of the simulation model.

For the  $j$ th model to be valid in relation to the above, ideally the following conditions would hold.

- (i) The system of relationships in  $R$  and  $M_j$  would be identical with identical parameter settings;
- (ii) the distributional properties of  $u_i$  and  $v_{ij}$  would be identical;

where the following was true

- (iii) the set of  $Z_i$  variables in the real and modelled system were identical;

<sup>4</sup>A simulation model is used for the purposes of this discussion although the 'constructed' model of a system could take a variety of forms.

(iv) the values for the variables in  $Z_i$  were identical between the real and modelled system.

Obviously the above specifies a stochastic simulation model. With a deterministic simulation model the objective is to estimate  $R(Z_i)$ .

In practice we will only be able to observe a sample of ( $n > 1$ )  $Y_i$  values corresponding to each set of levels of the variables in  $Z_i$ , and we are forced to assume that the sample mean  $\bar{Y}_i$  is the best available estimate for  $R(Z_i)$ . The corresponding estimate from the  $j$ th deterministic simulation model is:

$$\bar{X}_{ij} = M_j(Z_i)$$

A number of statistical goodness-of-fit tests that might be useful in comparing  $M_j(Z_i)$  with  $R(Z_i)$  (i.e. in examining condition (i)) are now discussed. Since the model is deterministic condition (ii) cannot be examined, and conditions (iii) and (iv) are assumed to hold.

### 7.3.1 Simple t tests

Student's t test has been suggested by a number of people (e.g. Mihram, 1972; Shannon, 1975).

For a single setting of the  $Z_i$  variables,  $\bar{X}_{ij}$  is obtained from the  $j$ th simulation model as an estimate of  $R(Z_i)$ . From the real world a sample  $n (> 2)$  of observed values are obtained:

$$(Y_{i1}, Y_{i2}, \dots, Y_{in}),$$

with a sample mean  $\bar{Y}_i$ .

The sample (real) data and the Student's t test can be used to obtain the significance level (SL) associated with the hypothesis:

$$R(Z_i) = \bar{X}_{ij}.$$

$$SL = \Pr[|t| > |t^*|; \text{ where } \bar{X}_{ij} = R(Z_i)], \text{ and}$$

$$t^* = \frac{\bar{Y}_i - \bar{X}_{ij}}{se\bar{Y}_i}$$

In this test the SL provides the measure of goodness-of-fit. The larger the value of SL the better the goodness-of-fit. This procedure can be repeated for different levels of the variable vector  $Z_i$ .

A more sensitive goodness-of-fit test will result from pooling error variance estimates obtained from the real model output at the different settings of  $Z_i$ . This can be done where the  $u_i$  are independent and Normally distributed with variance  $\sigma^2$ . The pooled error mean square (EMS) is easily obtained from an analysis of variance with each level of  $Z_i$  being a 'treatment'. The value for  $se\bar{Y}_i$  then becomes<sup>5</sup>

$$\left(\frac{EMS}{n}\right)^{1/2}.$$

Where we have a sample of  $n$  observed values at each of  $q$  value settings for  $Z_i$  we can obtain a pooled goodness-of-fit measure for the model ( $M_j$ ) using the F distribution. Consider the mean square:

$$\frac{n \sum (\bar{Y}_i - \bar{X}_{ij})^2}{q}$$

Under the hypothesis:  $R(Z_i) = \bar{X}_{ij}$ , each of the terms  $(\bar{Y}_i - \bar{X}_{ij})^2$  has expectation  $\sigma^2/n$ .

Thus the mean square, above, has expected value  $\sigma^2$  with  $q$  degrees of freedom. The statistic:

$$F^* = \frac{\frac{n \sum (\bar{Y}_i - \bar{X}_{ij})^2}{q}}{EMS}$$

should follow the F distribution with  $q$  and  $q(n-1)$  degrees of freedom, and

$$SL = \Pr[F > F^*; \text{ when } \bar{X}_{ij} = R(Z_i) \text{ for all } i]$$

<sup>5</sup>Confidence intervals (e.g. 95% C.I.) can also be obtained for  $R(Z_i)$ :  $\bar{Y}_i \pm t_{\alpha} se(\bar{Y}_i)$ . If  $\bar{X}_{ij}$  falls within this CI we would not reject the hypothesis  $R(Z_i) = \bar{X}_{ij}$ , at the  $\alpha\%$  significance level.

provides the measure of goodness-of-fit. This goodness-of-fit measure will be denoted, the "pooled F test".

### 7.3.2 Regression Models

Many people have suggested and used, regression of  $\bar{Y}_i$  on  $\bar{X}_{ij}$  to measure goodness-of-fit in deterministic models (e.g. see Anderson, 1974; Fick 1980), following Aigner (1972). However Cohen & Cyert (1961), from whence Aigner (1972) derived the premise for his proofs, suggested the reverse regression validation test (i.e. regression of  $\bar{X}_{ij}$  on  $\bar{Y}_i$ ).

In support of Aigner's interpretation,  $\bar{X}_{ij}$  can be seen as an estimate of  $R(Z_i)$  that is under the control of the modeller who is specifying the relationships in  $M_j$ , and secondly  $\bar{Y}_i$  has characteristics of a random variable which are usually associated with the dependent variable in regression. Under the hypothesis  $R(Z_i) = \bar{X}_{ij}$ , then  $\bar{Y}_i$  will be randomly distributed about  $\bar{X}_{ij}$  according to the model:

$$\bar{Y}_i = \bar{X}_{ij} + \bar{u}_i.$$

Under an alternative hypothesis, say  $R(Z_i) = a + b\bar{X}_{ij}$ , then  $\bar{Y}_i$  will be randomly distributed about  $a + b\bar{X}_{ij}$  according to the model:

$$\bar{Y}_i = a + b\bar{X}_{ij} + \bar{u}_i.$$

The F test can be used to test significance for the null hypothesis:

$a = 0, b = 1$  versus the alternative hypothesis  $a \neq 0$  and/or  $b \neq 1$ .

The sum of squares  $\sum_q (\bar{Y}_i - \bar{X}_{ij})^2$  is partitioned into two

components (see Fig. 7.1):

$$\sum_q (\bar{Y}_i - \bar{X}_{ij})^2 = \sum_q (\hat{Y}_i - \bar{X}_{ij})^2 + \sum_q (\bar{Y}_i - \hat{Y}_i)^2$$

with 2 and  $(q-2)$  degrees of freedom, and where  $\hat{Y}_i = \hat{a} + b\bar{X}_{ij}$  is obtained by least squares regression of  $\bar{Y}_i$  on  $\bar{X}_{ij}$ .

Under the assumption that  $R(Z_i) = \bar{X}_{ij}$ , then

$$\frac{\sum (\hat{Y}_i - \bar{X}_{ij})^2 / 2}{\sum (\bar{Y}_i - \hat{Y}_i)^2 / q-2} \sim F(2, q-2)$$

Where there is no independent estimate of  $\sigma^2$  (the variance of the real observations), the above regression provides a statistical goodness-of-fit test for the hypothesis  $R(Z_i) = \bar{X}_{ij}$  against the alternative hypothesis:  $R(Z_i) = a + b\bar{X}_{ij}$ . This situation should be contrasted with the previously described t tests and pooled F test where the alternative hypothesis was  $R(Z_i) \neq \bar{X}_{ij}$ .

A problem in this situation is that we could fail to reject the hypothesis  $R(Z_i) = \bar{X}_{ij}$  (i.e. fail to invalidate the model) purely because the selected alternative  $R(Z_i) = a + b\bar{X}_{ij}$  was invalid (i.e. variation of  $\bar{Y}_i$  about  $\hat{Y}_i = \hat{a} + b\bar{X}_{ij}$  was of the same order as variation of  $\hat{Y}_i$  about  $\bar{X}_{ij}$ ). Clearly this is quite unsatisfactory and where there are no estimates of variance ( $\bar{Y}_i$ ), then any goodness-of-fit measure for  $M_j$  must be purely subjective, (unless perhaps when  $\bar{Y}_i = \bar{X}_{ij}$  for all  $i$ , but then one would be suspicious that  $\bar{Y}_i$  was not a random variable).

However, given an independent estimate of  $\sigma^2$  (EMS) and previous rejection of  $M_j$  by the pooled F test criterion, it is possible to perform a lack-of-fit test on the model:  $R(Z_i) = a + b\bar{X}_{ij}$ : since under this hypothesis

$$\frac{\sum (\bar{Y}_i - \hat{Y}_i)^2 / q-2}{\text{EMS}/n} \sim F(q-2, \text{d.f. for EMS})$$

This test could be used if it was desired to examine alternative relationships between  $R(Z_i)$  and  $\bar{X}_{ij}$  which may provide clues to what was wrong with  $M_j$ .

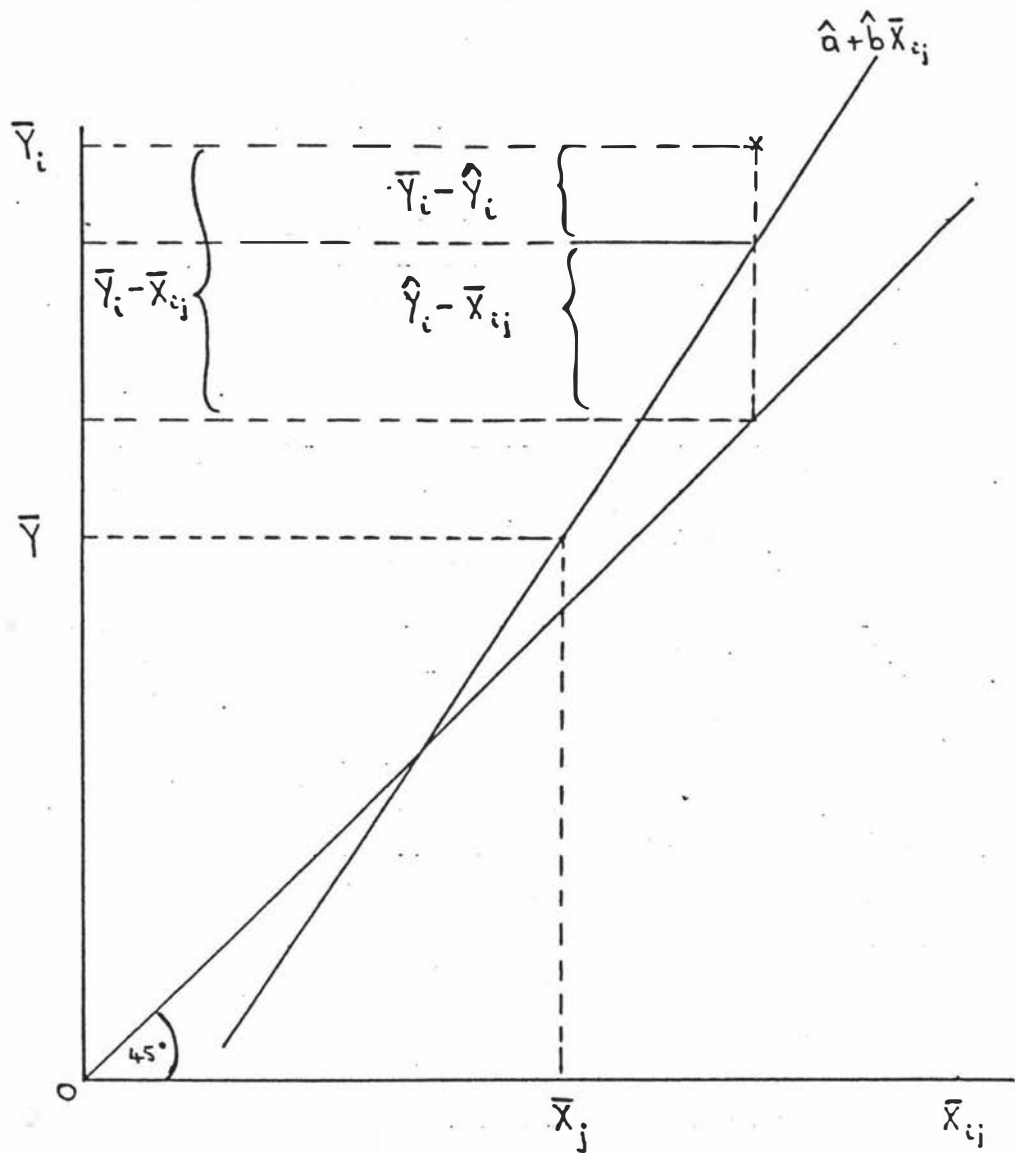


Figure 7.1 A graphical representation of the partition of  $(\bar{Y}_i - \bar{X}_{ij})$  into  $(\bar{Y}_i - \hat{Y}_i)$  and  $(\hat{Y}_i - \bar{X}_{ij})$ .

### 7.3.3 Model Revision

Assume  $M_j$  has not been validated and that the model  $R(Z_i) = a + b\bar{x}_{ij}$  has been judged acceptable by some lack-of-fit test. The least squares estimate of this model is:

$$\hat{Y}_i = \hat{a} + b\bar{x}_{ij}.$$

There is a desire for diagnostic purposes to test the hypotheses:

$(a \neq 0, b = 1)$  and  $(a = 0, b \neq 1)$  against the alternative hypothesis

$(a \neq 0, b \neq 1)$ . In other words, is the simulation model output  $\bar{x}_{ij}$  in

error by a 'constant' amount (i.e.  $a \neq 0$ ) or a proportional amount

(i.e.  $b \neq 1$ )? Decomposition of the sum of squares

$\sum_q (\hat{Y}_i - \bar{x}_{ij})^2$  (i.e. variation of  $\hat{Y}_i$  about  $\bar{x}_{ij}$  - see Fig. 7.1) into:

$$\sum_q (\hat{Y}_i - \bar{x}_{ij})^2 = q(\bar{Y} - \bar{x}_j)^2 + (b - 1)^2 \sum x_{ij}^2$$

(where  $\bar{Y}$  is the mean of the  $\bar{Y}_i$  values,  $\bar{x}_j$  is the mean of the  $\bar{x}_{ij}$  values,  $x_{ij} = \bar{x}_{ij} - \bar{x}_j$ , and  $\hat{Y}_i = \hat{a} + b\bar{x}_{ij}$ ) enables the hypothesis

$R(\bar{Z}) = \bar{x}_j$  to be tested against the alternative:  $R(\bar{Z}) \neq \bar{x}_j$ ,

where  $R(\bar{Z})$  is the mean real model response over the  $q$  set of levels for the variable vector  $Z_i$ .

Under the assumption that  $R(\bar{Z}) = \bar{x}_j$ , the term  $q(\bar{Y} - \bar{x}_j)^2$  has expected value: Variance  $(\bar{Y}_i) = \sigma^2/n$ . Under the assumption

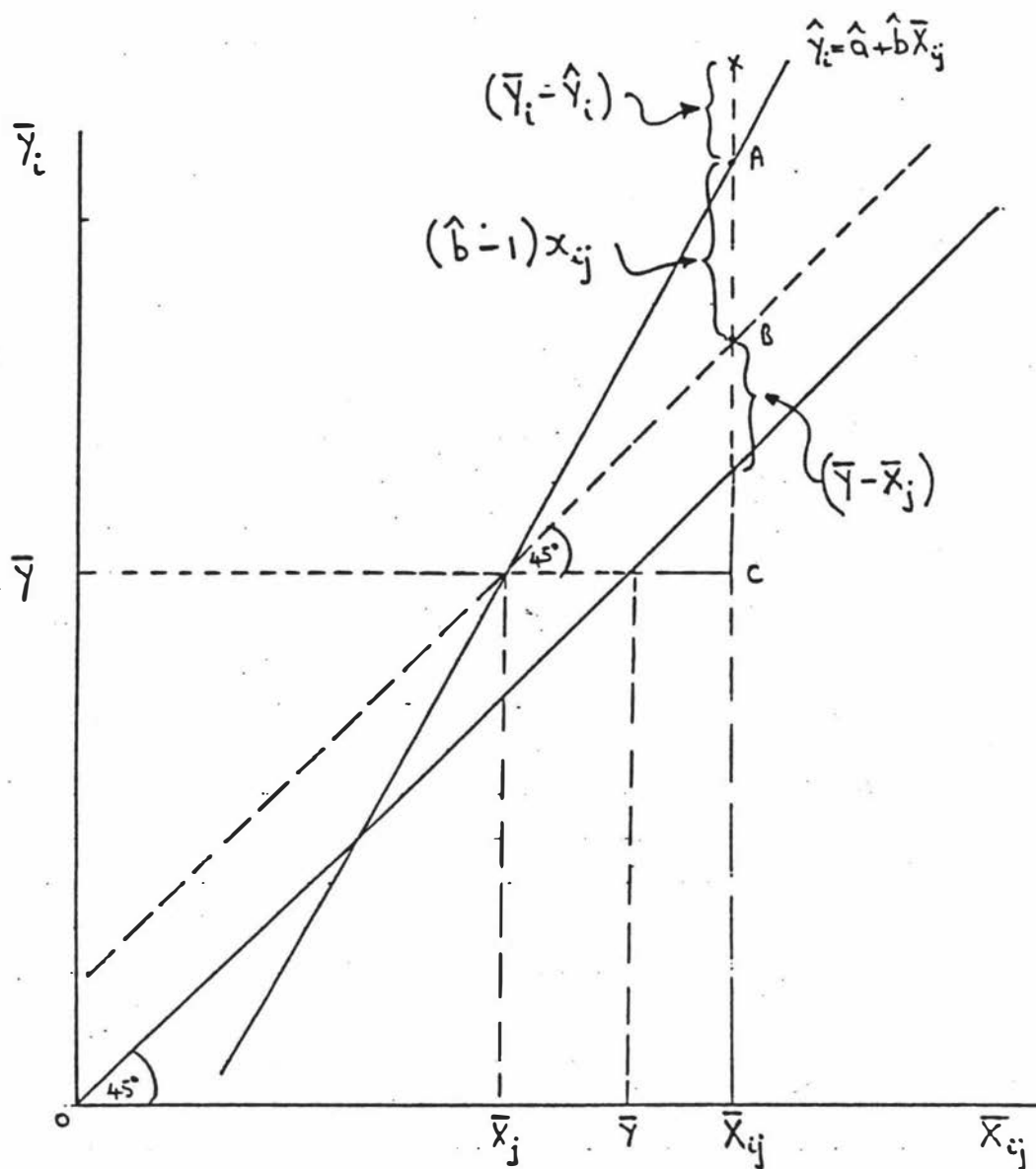
$$R(Z_i) = a + b\bar{x}_{ij}$$

$$\frac{q(\bar{Y} - \bar{x}_j)^2}{\sum (\bar{Y}_i - \hat{Y}_i)^2 / q - 2} \sim F(1, q-2)$$

The test of the hypothesis:  $b = 1$  is based on the sum of squares:

$$(b - 1)^2 \sum x_{ij}^2.$$

A graphical presentation of the above partition of  $(\hat{Y}_i - \bar{x}_{ij})$  is given in Fig. 7.2, and a mathematical proof is given in Appendix B.



$$\left. \begin{aligned} AC &= \hat{b} x_{ij} \\ BC &= x_{ij} \end{aligned} \right\} AB = (\hat{b} - 1) x_{ij}$$

(If  $\hat{b} = 1$ , the estimated line becomes the dotted line. If in addition,  $\bar{x}_j = \bar{y}$ , the estimated lines becomes the 45° line.)

Figure 7.2 A graphical representation of the partition of  $(\hat{y}_i - \bar{x}_{ij})$

### 7.3.4 Analyses in the present study

In this study statistical tests were confined solely to goodness-of-fit of the calibrated model to the data to which it was calibrated.<sup>6</sup> Validation goodness-of-fit tests were made purely subjectively (see Section 3.4.3) because with most sets of validation data available, too many variables in the vector  $Z_i$  required assumptions regarding their settings. This is a problem, discussed in Chapter 9, where real data cannot be collected specifically for model validation.

Calibrating the simulation model produced  $R(Z_i) = \bar{X}_{ij}$  (i.e.  $\hat{a} \approx 0$ ,  $\hat{b} \approx 1$  for the model  $\bar{Y}_i = \hat{a} + \hat{b}\bar{X}_{ij}$ ). The question which remained was whether the variation  $\sum (\bar{Y}_i - \bar{X}_{ij})^2$  was 'acceptable'. This was tested by the pooled F test, where an independent estimate of  $\sigma^2$  was available. Where an independent estimate of  $\sigma^2$  was not available, as occurred in a number of cases, the acceptability of the variation  $\sum (\bar{Y}_i - \bar{X}_{ij})^2$  had to be assessed purely subjectively.

## 7.4 CALIBRATION OF THE PASTURE-SOIL COMPONENTS

Two data sets for pasture calibration were generously made available by Dr C.J. Korte, (the full data set reported on by Korte et al., 1982), and Mr M.G. Lambert (data from Ballantrae HCRS published in Lambert et al., 1983).

Korte's data, which were used to calibrate parameters controlling flow rates into and out of the green and dead pasture pools, originated from a flat, quite highly fertile site, and were produced under a series of grazing treatments. His trial was conducted for two consecutive years commencing early September each year and terminating in July. Treatments were grazed at pre-determined pasture heights by either lax or hard grazing, (Korte et al., 1982). Levels of green and

<sup>6</sup>Reasons for this were discussed in Section 7.2.

dead DM were measured pre- and post-grazing, and at regular intervals between grazings.

Accumulations of green and dead DM were used separately to calibrate growth and senescence, and senescence and decay rates, respectively. By using measured states of the green pool during dead pool calibration, previous inaccuracies in predicting green DM accumulation would not affect dead pool calibration results.

Weather data to run the model came from the Palmerston North DSIR climate station, approximately 8 miles from the experimental site.

#### 7.4.1 Green pool calibration

##### 7.4.1.1 Methods

Eight major parameters were selected for initial calibration of green DM accumulation. A description of the parameters and their initial values are given in Table 7.1. The number of parameters fitted, and their initial value in relation to their calibrated values, greatly affected the time taken to reach a solution. Further, it was necessary to scale some parameters to make them continuous in increments of 0.0001, (e.g. days) and where two parameters in the same function were being fitted, e.g. the intercept and the slope in a linear function, it was necessary to calibrate one for a series of pre-determined values of the other.

Fifty-one regrowths measured over two years were selected from Korte's data. The variance  $\sigma^2$  was obtained for each year by analysis of variance, by considering each regrowth (i.e. setting of  $Z_i$ ) as a 'treatment' (q). There were different numbers of replicates (n) for each treatment between years. In year 1,  $q = 29$  and  $n = 3$  and in year 2,  $q = 22$  and  $n = 4$ . Estimates of EMS for each year were:

TABLE 7.1: Parameter description and value for the original green calibration

Parameter Name	Description and Effect of Parameter	Initial Value	Calibrated Value
PSLOPE	Potential growth rate (soil fertility) parameter. (See Section 5.2.1.1)	0.04	0.057
MR	MR* mean air temperature (°C) = Relative maintenance respiration rate in g/g Green DM/day (See Section 5.2.1.1)	0.0005	0.001*
VEG	Efficiency of vegetative growth, relative to efficiency of reproductive growth = 1 (See Fig. 5.2)	0.76	0.6
LCT	Length of reproductive growth phase (days) (See Fig. 5.2)	110	45†
VLAIFC	Controls curvature of exponential function relating growth rate to LAI during vegetative growth, 0.95 = steep; 0.1 = flat (See Fig. 5.3)	0.9	0.89
RLAIFC	As above, but for reproductive growth (See Fig. 5.3)	0.5	0.95*
ALPHA	Senescence Rate (g/g Green DM/day) (See Section 5.2.2)	0.007	0.0064
DRTD	Fraction of available soil water below which basic senescence rate increases due to drought (See Section 5.2.2)	0.18	0.3*

\* Upper bound

† Lower bound

$$EMS_1 = 234.0 \quad \text{d.f.} = 58$$

$$EMS_2 = 127.07 \quad \text{d.f.} = 66$$

Statistically, the variance in each year was not the same

(SL = 1%):

$$F = \frac{234.04}{127.07} = 1.84 \quad \text{d.f.} = (58, 66).$$

However it was decided to pool the errors over the 2 years since it was considered that 2 years data was probably insufficient to test equality of variances between years.

$$\text{The pooled EMS} = \frac{ESS_1 + ESS_2}{(n-1)q_1 + (n-1)q_2} = \frac{13574.56 + 8386.9}{58 + 66} = 177.1$$

Owing to unequal numbers of replicates ( $n$ ) between 'treatments' it was also necessary to estimate the mean square:

$$\frac{\sum n_i (\bar{Y}_i - \bar{X}_{ij})}{q}$$

(i.e. corrected for the number of replicates in  $Y_i$ ) for testing by pooled F test. Weighted least squares regressions of  $\bar{Y}_i$  on  $\bar{X}_{ij}$  were also conducted.

#### 7.4.1.2 Results

Minimisation of  $C^7$  for average daily green accumulation rate produced the set of solution parameter values shown in Table 7.1. Table 7.2 presents results of the regression analysis for this 'Original Green' calibration.

Despite the fact that the model was calibrated it still failed the pooled F test owing to the variation  $\sum (\bar{Y}_i - \bar{X}_{ij})^2$  being unacceptably large (SL = 1%).

$$F = \frac{\sum n_i (\bar{Y}_i - \bar{X}_{ij})^2 / q}{EMS} = \frac{451.63}{177.1} = 2.55 \quad (\text{d.f.} = 51, 124)$$

<sup>7</sup>C represents the sum of squares of differences between observed and simulated results - see Section 7.2.

TABLE 7.2: Regression analysis of various pasture components†

Calibration	a	SEa	b	SEb	r <sup>2</sup>	No. regrowths (q)	Function Value of $\chi^2$ $\sum (\bar{Y}_i - \bar{X}_{ij})^2$	$\sum n_i (\bar{Y}_i - \bar{X}_{ij})^2$	Variance $\bar{Y}_i$	Probability of greater F given a = 0, b = 1
Original Green	-1.06	3.11	1.03	0.06	0.86	51	7063.7	23033.2	177.1	>0.25
Restructured Green	-0.55	2.02	1.0	0.04	0.93	51	3037.2	10582.3	177.1	>0.25
Dead	-1.03	1.29	1.01	0.08	0.74	51	4183.2	13695.0	272.4	>0.25
Reverse Green	3.04	1.95	0.94	0.04	0.93	51	3527.3	11565.6	177.1	>0.1, <0.25
Reverse Dead	-0.91	1.37	0.98	0.09	0.71	51	4650.4	15100.4	272.4	>0.25
Ballantrae Period 1	2.21	1.97	0.90	0.08	0.95	10	140.13			>0.25
Ballantrae Period 2	4.08	2.40	0.92	0.08	0.89	19	728.4			>0.1, <0.25
Ballantrae Period 3	4.68	4.35	0.88	0.12	0.88	9	355.9			>0.25

†Regression of  $\bar{Y}_i = a + b\bar{X}_{ij}$

Inspection of the individual simulated results showed that the model tended to over-estimate production following lax grazing and under-estimate it following hard grazing. In addition, this trend was most evident for summer and autumn regrowths. This suggested that the green cover (LAI) - growth rate, and the pasture senescence functions were not as simple as had been assumed. In an attempt to reduce pasture growth rate at high LAI's, the respiration parameter was pushed to its upper bound, meanwhile the senescence parameter remained relatively low, but DRTD was set to its upper bound. This meant that senescence was above the basic rate for a considerable period during summer and autumn.

The preceding information provided the basis for discussions on deficiencies in model structure with Dr Korte. Several important points emerged.

Hard grazing a sward to 1000-1100 kg DM/ha green residual cover following emergence of the reproductive growing point removes most of the reproductive tillers and converts the sward back to a vegetative state. Swards that remain reproductive beyond this point have a higher senescence rate owing to shading of basal leaves by stems and new leaf, and eventually due to stem death.

In periodically grazed swards, LAI is unlikely to be as high in a recently grazed sward as in a spelled sward of the same green cover. Further, as total green cover increases for any given LAI, the amount of light intercepted by stem increases (Korte, 1982).

Suitable data were not available to quantify these affects. so a 'black box'<sup>8</sup> was designed to account for them. Relative growth of a sward (LGF) was related to current green cover using a family of

<sup>8</sup>See Section 3.4.1.

exponential functions. The relevant exponential function was determined from both residual green cover at the last grazing and whether the sward was vegetative or contained reproductive stem (see Fig. 7.3).

The base curves in Fig. 7.3 show the growth factor for a sward immediately after grazing. This increases as green cover increases, but it approaches a higher level in previously hard grazed than in previously laxly grazed swards.

The functions are described by Equation 7.1.

$$\text{LGF} = 1 - \text{EXP}(-\text{GCRF} * \text{LAI}) \quad (7.1)$$

where the parameter GCRF reflects the influence of post-grazing residual green cover (PGGC)<sup>9</sup> and sward morphological state:

$$\text{GCRF} = \text{VINT} - \text{VSLP} * \text{PGGC} \quad (7.2)$$

for vegetative swards and

$$\text{GCRF} = \text{RINT} - \text{RSLP} * \text{PGGC} \quad (7.3)$$

for swards containing reproductive stem.

Values for VINT, RINT, VSLP and RSLP were obtained from recalibration to Korte's data.

Swards were assumed to show reproductive stem 75 days after inflorescence initiation (Korte, pers. comm.). The parameters RINT and RSLP were assumed to apply to grazing after this time, until the sward was 'cleaned out' (i.e. grazed below 1050 kg GDM/ha). Senescence rate was also assumed to differ over this period. Two senescence rate parameters were defined, RALPHA for reproductive and VALPHA for vegetative swards. Values for these were also obtained by recalibration to Korte's data.

<sup>9</sup>Bounds were placed on the PGGC parameter at 3000 kg GDM/ha, the maximum in Korte's data.

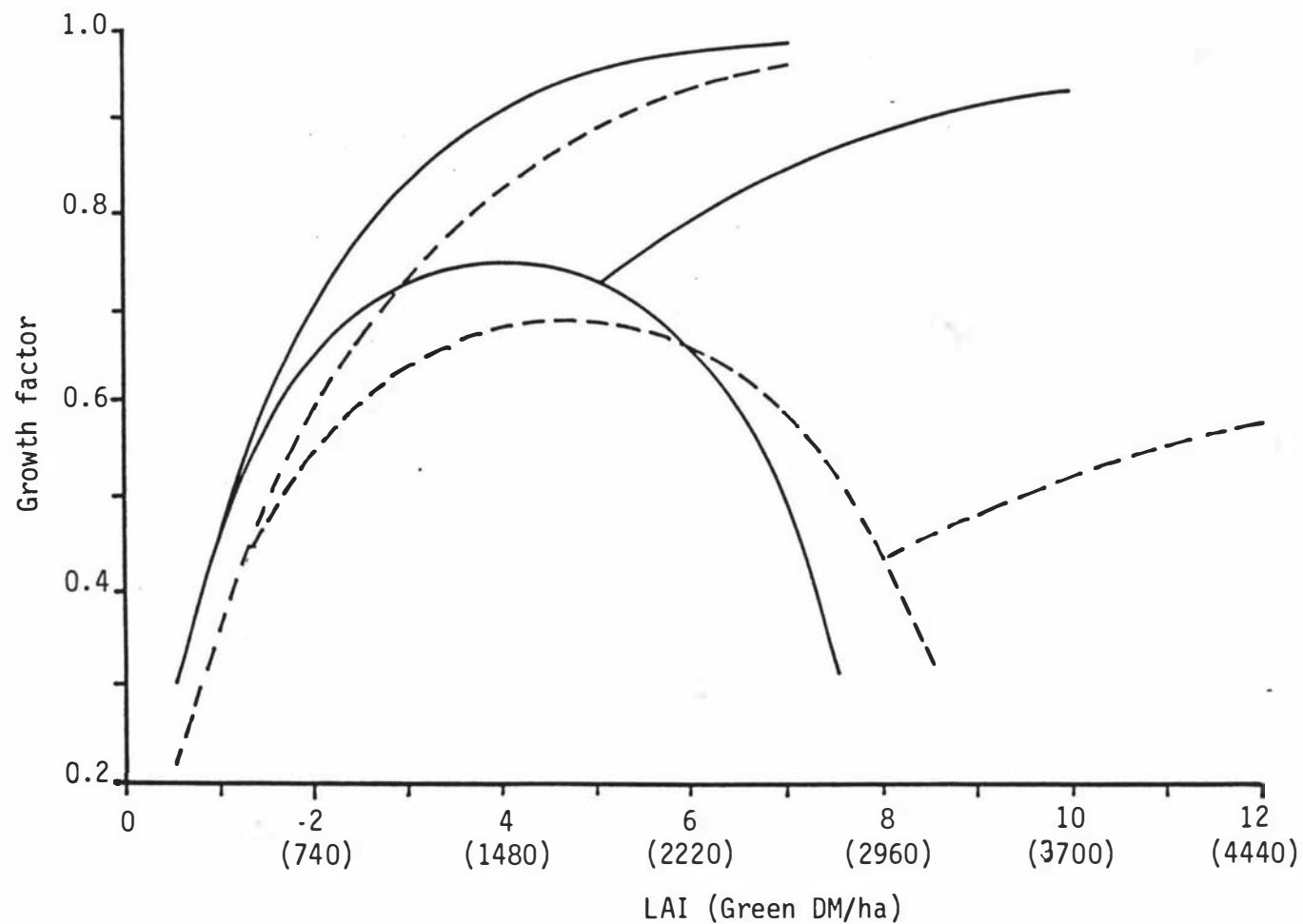


Figure 7.3 Adjusted growth rate-LAI relationship for periodically grazed swards. Base curves refer to residual green DM/ha for vegetative (—) and reproductive (--) swards.

Eleven parameters were calibrated in the restructured model. These included PSLOPE, MR, VEG and DRTD from Table 7.1, VINT, RINT, VSLP, RSLP, VALPHA and RALPHA and WDT, the parameter controlling the magnitude of the increase in senescence rate at zero soil water. LCT in Table 7.1 was not calibrated. Calibration data were divided on the basis of either being reproductive or vegetative regrowths (Korte, pers. comm.).

Considerable improvement occurred in the minimised function value under the new structure (3037 vs 7063 - see Table 7.2) and the model passed the pooled F test

$$F = \frac{207.54}{177.1} = 1.172 \quad (\text{d.f.} = 51, 124).$$

New parameter values are presented in Table 7.3. and actual and simulated values are plotted in Fig. 7.4.

TABLE 7.3: Calibrated parameter values for the restructured green component

<u>Parameter Name</u>											
<u>Calibrated Value</u>											
PSLOPE	MR	VEG	RSLP	VSLP	RINT	VINT	VALPHA	RALPHA	DRTD	WDT	
0.040	0.0001†	0.80	0.144E-3	0.234E-3	0.5	0.7	0.0065	0.0131	0.18†	3.07	

\* Upperbound

† Lowerbound

It was concluded that this form of the model was satisfactory for predicting the dynamics of the green pool under periodic grazing. Apart from the respiration parameter which was forced to its lower bound, probably due to the 'black box' construction incorporating factors affecting respiration, parameter values were as expected.

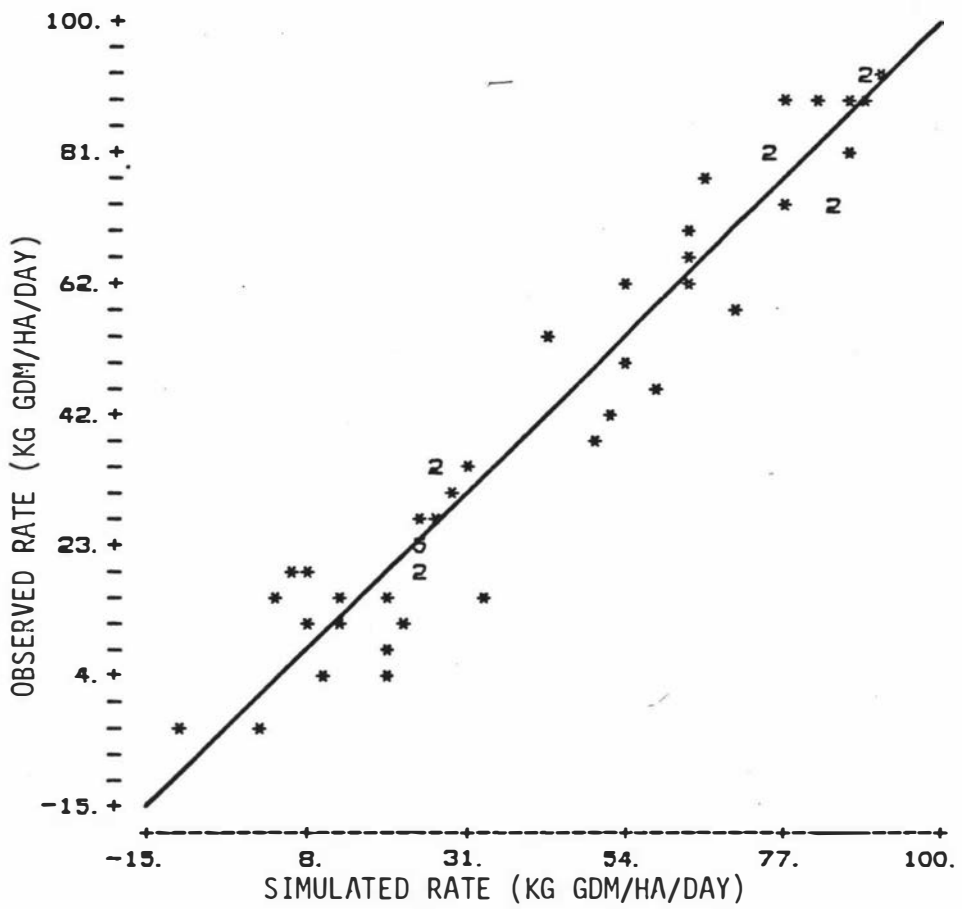


Figure 7.4 Observed and simulated green herbage accumulation rates. The equation observed rate = simulated rate is given by the solid line.

The growth factor was lower in reproductive than in vegetative swards when green cover was low. Reproductive senescence rate was higher than vegetative, and the senescence rate factor at zero soil water (WDT), remained at 3. The results of Hunt's experiments, which provided the initial parameters for pasture senescence rates<sup>10</sup> may be explained in the above terms if soil water levels were low during autumn in his trial, and recalling that his spring experiment commenced with a vegetative sward which became reproductive.

Korte's data represented swards subjected to periodic grazing only. Conditions in set-stocked swards tend to vary much less at a given cover (Hodgson & Maxwell, 1981), hence growth rate can be more reliably represented as a continuous function of green cover. A simple linear function, derived from Hodgson *et al.* (1981), was included for set-stocked swards, but it was assumed that growth rates would decline due to shading by stem at high green covers (Fig. 7.5).

#### 7.4.2 Dead pool calibration

Accumulated green DM from Korte's data was used as input for dead pool calibration. The senescence rate parameters plus the proportion of newly senesced dead DM which was readily decomposable (SOL), initially 43 percent, and the relative amount of dead DM consumed by earthworms per day (WORM) (plus or minus basic consumption rate shown in Fig. 5.10), were calibrated.

The value of C following 'dead' calibration was larger than following the 'restructured green' calibration (4183 vs 3037, Table 7.2). However there was quite large unexplained variation between replicates in the observed data for dead DM accumulation

<sup>10</sup>See Section 5.2.2.

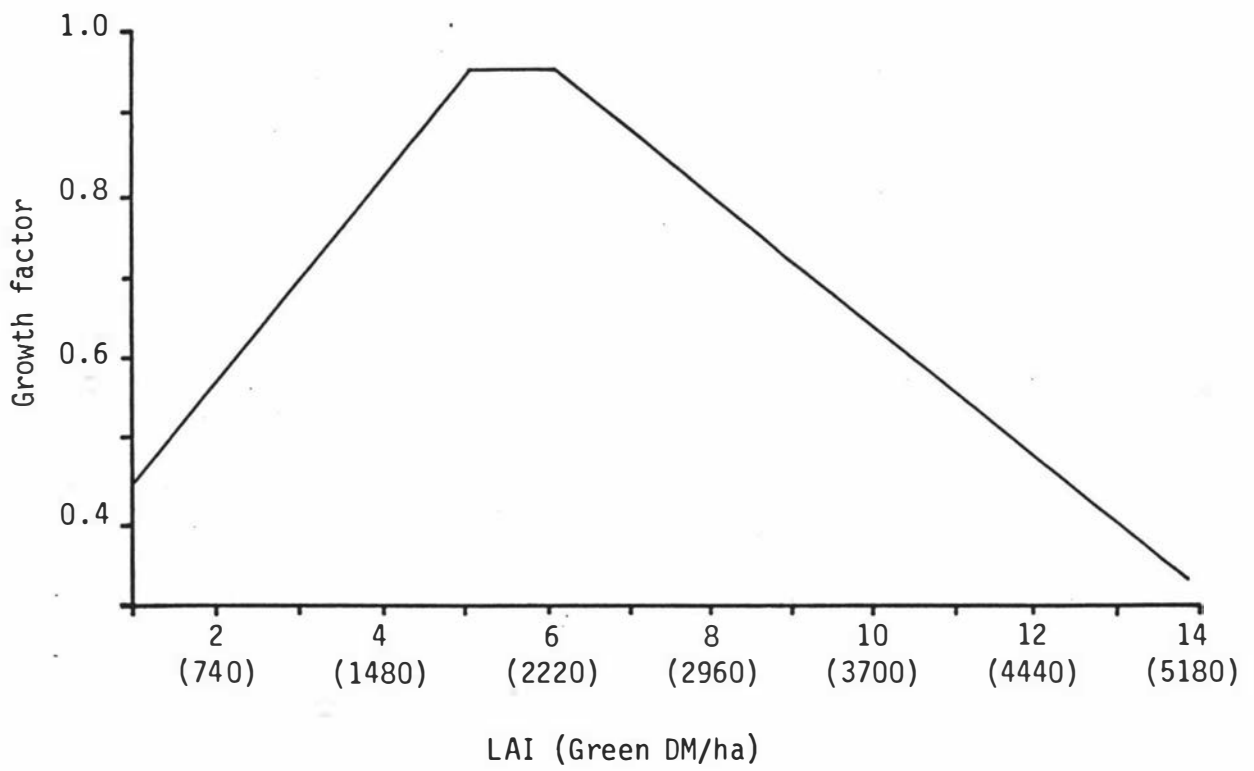


Figure 7.5 Assumed growth rate-LAI relationship in set stocked swards.

(pooled EMS = 272.4). Consequently the variation  $\sum (\bar{Y}_i - \bar{X}_{ij})^2$  was considered acceptable, as assessed by the pooled F test:

$$F = \frac{273.82}{272.4} = 1.01 \quad (\text{df} = 51, 124).$$

The results of regression analysis and a plot of observed and simulated dead DM accumulation rates are given in Table 7.2 and Fig. 7.6, respectively.

Calibrated parameter values following dead pool calibration are given in Table 7.4

TABLE 7.4: Calibrated parameter values for the dead component

<u>Parameter Name</u>					
<u>Calibrated Value</u>					
VALPHA	RALPHA	DRTD	WDT	WORM	SOL
0.0062	0.016	0.20	4.5	+0.35E-2	0.44

There was remarkable similarity in the calibrated values of VALPHA and DRTD between the 'restructured green' and 'dead' pool calibrations, but values for RALPHA and WDT were not in as good agreement (compare Tables 7.3 and 7.4).

To help choose which set of senescence rate parameters to use in the model, first the growth rate parameters in the 'restructured green' component were recalibrated with fixed senescence rate parameters from the 'dead' calibration (i.e. those in Table 7.4). Second, the decay rate parameters in the dead component were recalibrated with fixed senescence rate parameters from the 'restructured green' calibration (i.e. those in Table 7.3). These were called the reverse green and reverse dead calibrations, respectively.

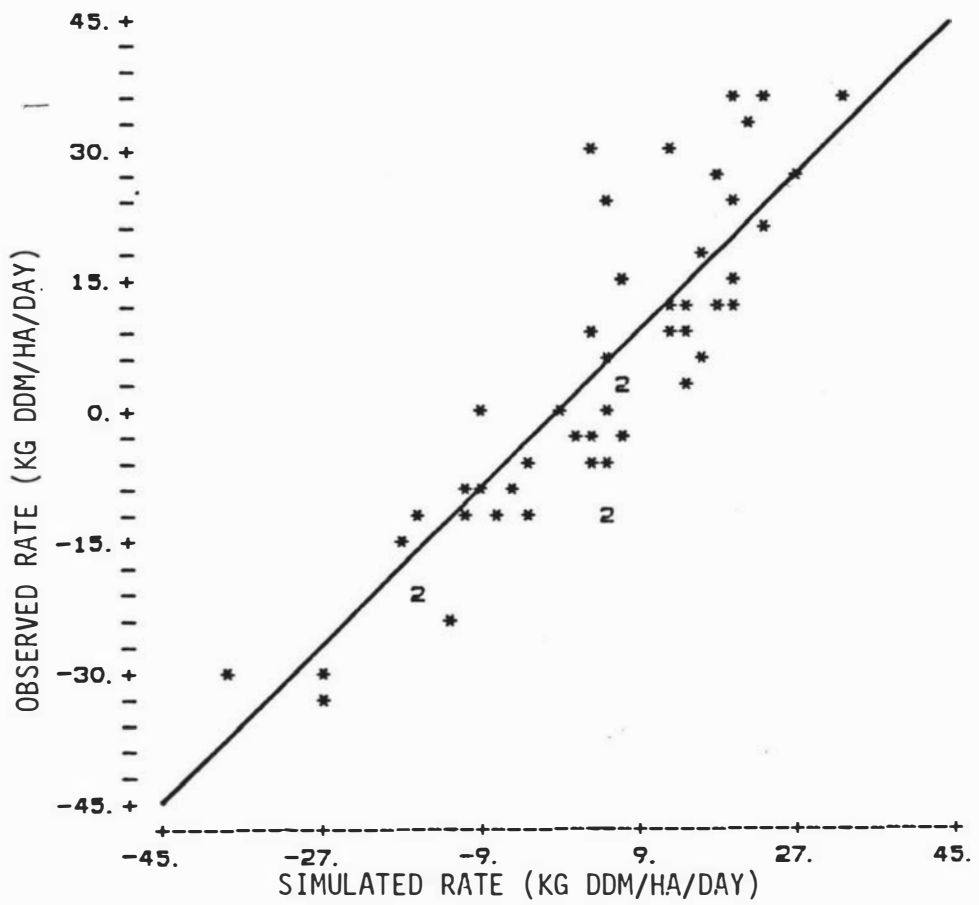


Figure 7.6 Observed and simulated dead herbage accumulation rates. The equation 'observed rate = simulated rate' is given by the solid line.

The objective for the reverse calibrations was to gauge the sensitivity of C, for the green and dead components, to the respective sets of senescence rate parameters.

### 7.4.3 Reverse Calibration Results

Parameter values for growth and decay rates altered only slightly in the reverse calibrations (compare Table 7.5 with Tables 7.3 and 7.4). The value of C showed a greater percentage increase to reverse green calibration than to reverse dead calibration (+16.1% vs +11.1%) (Table 7.2). This result, coupled with the greater importance of the green component to animal production, prompted the decision to use the growth and senescence parameters from the 'restructured green' calibration (Table 7.3), and the decomposition parameters from the reverse 'dead' calibration (Table 7.5).

TABLE 7.5: Parameter values for the reverse calibrations

<u>Parameter Name</u>		<u>Reverse Green</u>								
<u>Calibrated Value</u>										
PSLOPE	MR	VEG	RSLP	VSLP	RINT	VINT	RALPHA	VALPHA	DRTD	WDT
0.039	0.0001	0.80	0.145E-3	0.233E-3	0.5	0.7	0.0062	0.016	0.20	4.5
<u>Parameter Name</u>		<u>Reverse Dead</u>								
<u>Calibrated Value</u>										
VALPHA	RALPHA	DRTD	WDT	WORM	SOL					
0.0065	0.0131	0.18	3.07	+0.33E-2	0.43					

#### 7.4.4 Hill Country Rate of Growth Calibration

The data from Ballantrae HCRS were a time series of net pasture growth rates (green plus dead DM) for different slopes and aspects.

Soil fertility increased through time on the data sites (Lambert pers. comm.), so the time series was arbitrarily divided into three periods with different levels of soil fertility.

The model was calibrated to the three parameters that varied with soil fertility and pasture composition. These were, PSLOPE, VEG, and DAYREP (the day of initiation of reproductive growth). Other parameters were assumed to have the values derived from the previous calibration. The model was run using the appropriate years' climate data from Ballantrae, except where full climate data were unavailable (i.e. 1975 to 1979). In these years rainfall data were available from Ballantrae, but sunshine hours and temperature data were supplied from Palmerston North DSIR, with corrections applied to temperature for the altitude difference (see Section 5.3). Pasture growth rates for three slope classes, and three aspects, were averaged. Trimming height for regrowths was assumed to be 400 kg GDM/ha, plus the appropriate proportion of dead DM.

With this set of observed data, as with all remaining sets in this chapter, there were no accompanying estimates of  $\sigma^2$  for  $\bar{Y}_i$ , and the observed data given were assumed to equal  $\bar{Y}_i$ . Subjective estimates were made of the acceptability of the calibrated model, since no pooled F test could be conducted.

Trends in parameter values were as postulated in Section 5.2.1.1 (see Table 7.6). As soil fertility increased; (1) PSLOPE increased, (2) the relative difference between vegetative and reproductive growth potential decreased, and (3) reproductive growth commenced earlier.

The relationship between PSLOPE and VEG was recalculated from

the information in Table 7.6. This was:

$$\begin{aligned} \text{IF (PSLOPE.LT.0.025) VEG} &= ((\text{PSLOPE}-0.02)/0.02)* 0.67+ 0.6 \\ \text{ELSE VEG} &= 0.8 \end{aligned} \quad (7.4)$$

TABLE 7.6: Parameter values following the 'hill country' calibration

Period Dates	Parameter Name Calibrated Value	PSLOPE	VEG	DAYREP
1. (1/8/72-9/12/74)		0.021	0.61	265
2. (9/12/74-10/4/78)		0.022	0.73	254
3. (10/4/78-11/6/79)		0.025	0.80	253

Results of regression analysis are given in Table 7.2 for each of the three calibrations.

A graph of simulated versus field measurements (Fig. 7.7) indicated the accuracy of the calibrated model, except in the winter of 1977 when it consistently under-estimated production. The reason for this was unclear but it may have been due to differences in radiation levels between the field and weather data sites ( $\approx$  20 miles apart) in this winter.

## 7.5 VALIDATION OF THE PASTURE COMPONENT

A number of subjective evaluations were made of the calibrated pasture model's<sup>11</sup> performance to extend confidence in using it in new situations. Subjective evaluations of validity were required either because all available data had been used in model construction and development, or because of the reasons stated in Section 7.3.4.

<sup>11</sup>Subsequently referred to as the model in this section.

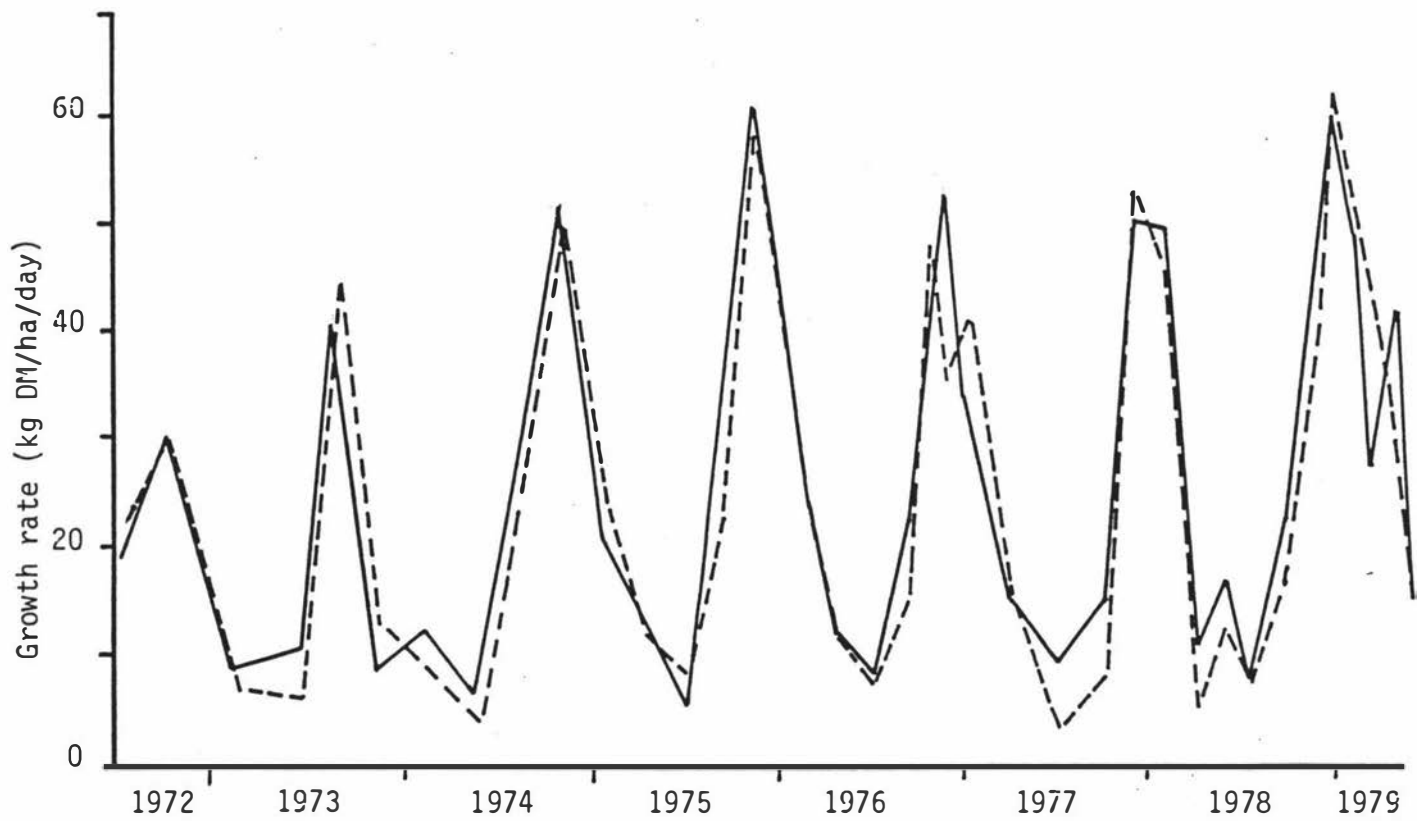


Figure 7.7 Observed (—) and simulated (---) net pasture growth rates for Ballantrae between 1972 and 1979.

The first evaluation was of the effect of increasing soil fertility (i.e. PSLOPE) on the annual pattern of net production under cutting. Climate data came from a 'representative' year from the Ballantrae data.

As soil fertility (PSLOPE) increased the spring peak in production was moved forward, with similar levels of production being maintained in late spring (Fig. 7.8). This is supported by field observations (Lambert pers. comm.).

A second experiment was designed as a series of trials to extend confidence in the model-predicted effects of different defoliation regimes on net pasture production. Relevant trials were conducted in the field by Tainton (1974), and his results were used as an aid to subjective assessment of model performance.

To approximate defoliation by grazing, harvested dry matter was assumed to be 90% green and 10% dead. First, late autumn/winter production was compared under two harvesting intervals (42 and 63 days), by two harvesting intensities, 500 (hard = H) and 1200 kg DM/ha residual (lax = L), commencing on April 15. Results are presented in Table 7.7 and show that; (1) the amount of green DM harvested under lax grazing was greater than under hard grazing in the first regrowth, but that in subsequent regrowths this result was reversed, and (2) as harvest interval was lengthened the balance was tipped in favour of hard grazing. The model also indicated that net growth rate can be less than green accumulation rate in early winter.

The above reflect the balance between growth, which was lower following hard grazing, and senescence, which was higher in lax grazed swards. As climatic conditions became increasingly restrictive to

Table 7.7: Results of the winter grazing trial†

Days in rotation	Hard Grazing				Lax Grazing			
	Growth Rate	Total Accum. Rate	Green Accum. Rate	Dead Accum. Rate	Growth Rate	Total Accum. Rate	Green Accum. Rate	Dead Accum. Rate
42	19.9	14.3	16.1	-1.8	26.5	17.2	18.0	-0.8
42	7.9	4.8	4.7	0.1	10.3	4.0	3.5	0.5
42	11.0	8.2	7.5	0.7	13.8	7.7	6.7	1.0
Mean	12.9	9.1	9.4	-0.3	16.9	9.7	9.4	0.3
63	17.2	11.8	12.5	-0.7	21.8	12.8	12.5	0.3
63	10.3	7.0	6.7	0.3	12.7	6.0	5.7	0.3
Mean	13.7	9.4	9.6	-0.5	17.2	9.4	9.1	0.3

† Units kg DM/ha/day

growth, green accumulation rate on lax swards declined relative to that on hard, since the former approached ceiling yield. The above results are in accord with observations from the field. However the model would not account for the slight increased winter production, noted by Tainton (1974), in hard grazed swards previously lax grazed in autumn. This was probably due to effects of increased root reserves built up in these swards, and was not accounted for in the model. However, the omission is likely to have very little effect in the total grazing model owing to the small size of the effect and the limited number of paddocks that could be treated in this way.

A second trial compared production in late spring and early summer under two harvesting intensities (750 and 1800 kg DM/ha residual) in a crossover experiment. The simulation commenced on November 26 and ran for 10 weeks, with the crossover after 4 weeks. Pre-treatment sward conditions were 3350 kg DM/ha and 87 % green DM.

Net accumulation of green DM in late spring was higher under hard grazing (Table 7.8) because of a higher growth rate in the late stages of the regrowth, and less senescence. The above are in agreement with Tainton's (1974) calculations.

In summer Hard-Lax (HL) swards produced slightly less green DM than Hard-Hard (HH) swards. This is at variance with swards described by Tainton (1974) which produced the same amount. Disagreement is likely to be due to different grazing residuals between Tainton (1974) and the above.

Simulated patterns of DM accumulation in the HH and LL treatments are presented in Fig. 7.9.

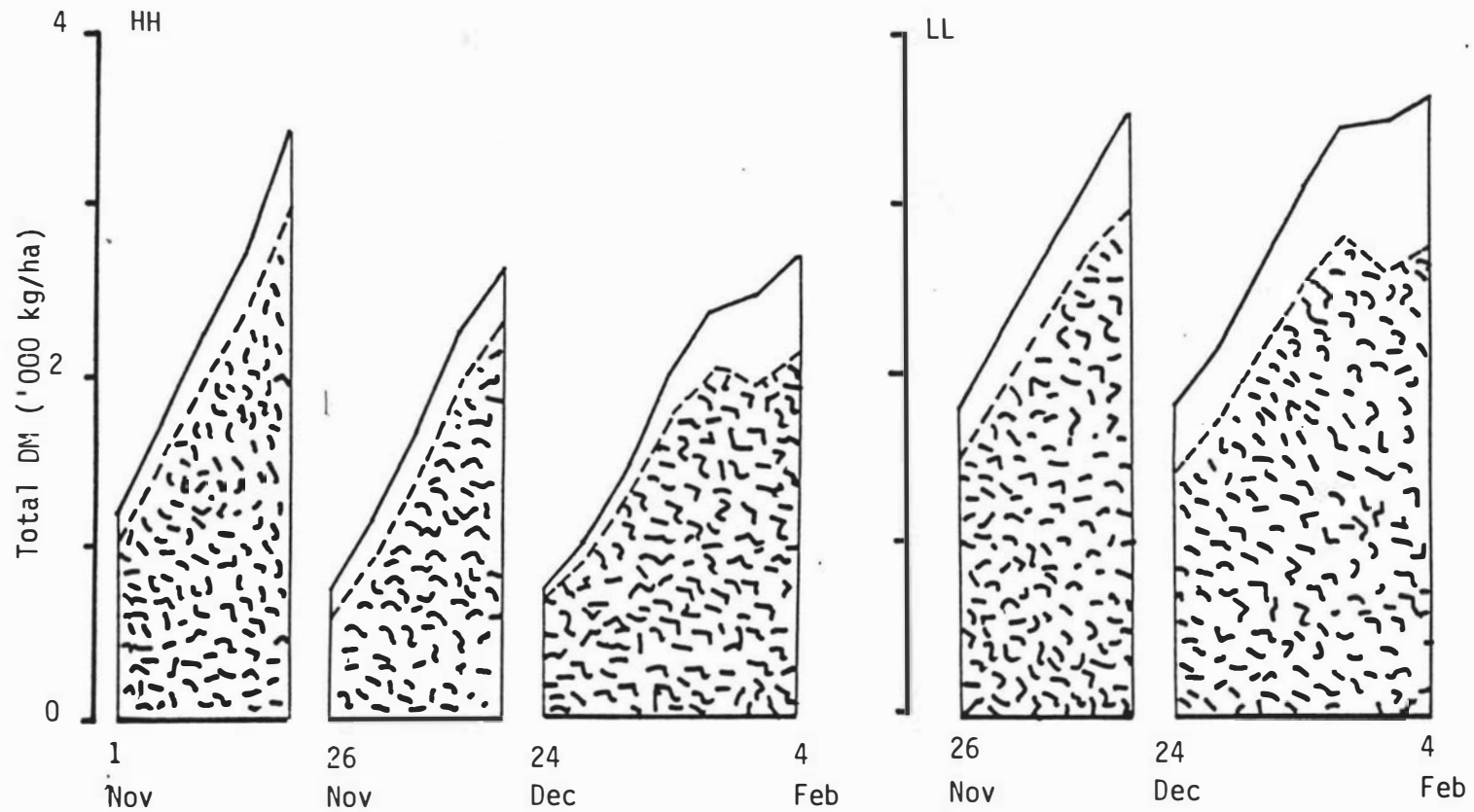


Figure 7.9 Simulated pasture cover on LL and HH treatments in late spring and summer. Green DM, speckled. Dead DM, plain.

TABLE 7.8: Results of the spring/summer grazing trial†

	Growth Rate	Total Accum. Rate	Green Accum. Rate	Dead Accum. Rate	Decay Rate
Spring					
Hard	68.4	65.7	59.2	6.5	2.8
Lax	64.5	59.7	49.7	10.0	4.8
Summer					
HH	49.2	44.1	34.6	9.5	5.1
HL	49.5	41.2	27.2	14.0	8.3
LH	48.0	42.8	34.6	8.2	5.2
LL	50.1	41.6	28.6	13.1	8.4

† Units kg DM/ha/day

The above simulations showed the relative insensitivity of green herbage accumulation to a range of defoliation regimes as noted in many field studies (e.g. Hodgson & Maxwell, 1981), and appeared to add to the confidence in the model.

A final simulation was designed to assess the model's stability under the extreme of zero grazing (Fig. 7.10). Results were conceptually realistic with total DM reaching a ceiling in summer which could not be sustained over winter. Hence total DM levels declined, with the expected change in green, dead composition occurring. It was concluded that the model was stable in this extreme situation.

## **7.6 CALIBRATION AND VALIDATION OF THE ANIMAL COMPONENTS**

Since a number of animal states, such as suckling lamb weight and ewe fertility, owed direct dependence to states determined by ewe energy balance, the parameters controlling energy balance in the ewe were calibrated against data where intake was known accurately. Subjective assessments of model validity were then made using data from grazing trials. No assessment was made of the reproduction component since it was widely based on the best New Zealand data and well represented within the limitations on liveweight prediction.

### **7.6.1 Non Pregnant, Non Lactating Sheep**

There was considered to be little point in calibrating the parameters KM and KF since a general consensus on their values had been reached in the literature. Subjective validation of the model for intake and liveweight gain of non lactating, non pregnant sheep was therefore proceeded to directly using a number of New Zealand

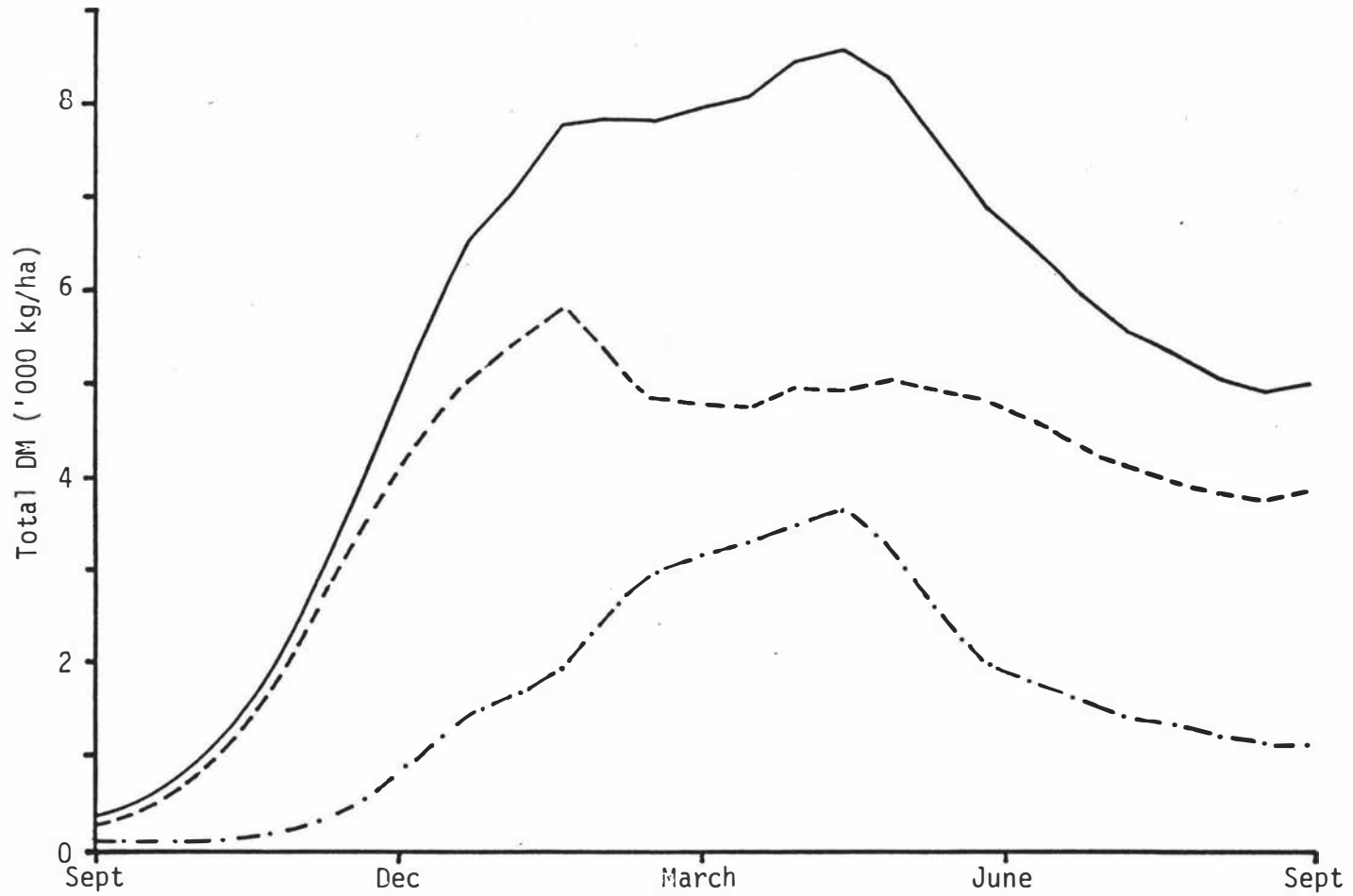


Figure 7.10 Simulated green (---), dead (-.-.-) and total (—) pasture yield with no harvests.

pasture allowance studies. Details of these comparisons are given in Appendix C.<sup>12</sup>

Overall correspondence between actual and simulated results was considered quite reasonable given the wide diversity in pasture type and age of stock in the field trials. But as a general observation, the model tended to overstate weight loss at low allowances, where accessibility was low e.g. trial 1 of Smeaton et al. (1981). Two possible reasons for this were (1) the unsuitability of KM at very low levels of intake (e.g. Graham et al., 1976), and (2) the unsuitability of the factor affecting maintenance at low levels of green DM where pastures were long and contained a lot of dead DM. The original factors were derived principally for short pastures.

Over-estimation of simulated liveweight gains for some periods of Thomson's experiment with lambs, may have been due to the effect of cold weather during part of his trial (Thomson et al., 1980), which was not accounted for in the simulation. Intakes were markedly at variance at high allowances but the simulated intakes were close to published estimates of requirements for the levels of liveweight gain achieved (e.g. Ulyatt et al., 1980).

#### 7.6.2 Pregnancy

The model was organised to accept as input a given feed intake and was run over two periods in late pregnancy, mimicking two trials reported by Rattray & Trigg (1979). Data in these trials were obtained from ewes serially slaughtered in late pregnancy, at approximately days 98 and 142, and days 93 and 135, in trials 1 and 2

<sup>12</sup>The maintenance parameter for grazing flat land was assumed to be 1.3 times that of pen fed animals. In some instances assumptions were required for pasture quality. They are stated in Appendix C.

respectively. The parameters calibrated are listed in Table 7.9. The maintenance parameter was fitted separately since ewes in trial 2 were shorn. The function minimized was the squared percentage difference in ewe empty body weight plus the squared percentage difference in foetal litter weight. Potential birth weight was predicted from the observed data.

TABLE 7.9: Description and value of calibrated parameters in the pregnancy component

Parameter Name	Description and Effect of Parameter	Initial Value	Calibrated Value
MINC1	Maintenance increment factor for pen fed woolly ewes	1.1	1.14
MINC2	As above, but for shorn ewes	1.4	1.79
KCM	Efficiency of energy use for conceptus maintenance	0.8	0.80*
KP	Efficiency of energy use for conceptus plus mammary gland gain	0.25	0.40*
Kmob	1/kmob = factor describing increased efficiency of mobilised body energy over diet energy	0.5	0.75

\* Upperbound

Fitted parameter values are presented in Table 7.9, results of regression analyses are given in Table 7.10 and observed and simulated ewe and foetal litter weights are shown in Fig . 7.11. The calibrated parameters suggested greater efficiency of dietary energy use in pregnancy and reduced efficiency of mobilised energy use, in comparison to original parameter values. Statistically, the hypothesis  $\bar{Y}_i = \bar{X}_{ij}$  was rejected (SL = 2.5%) for foetal litter weight

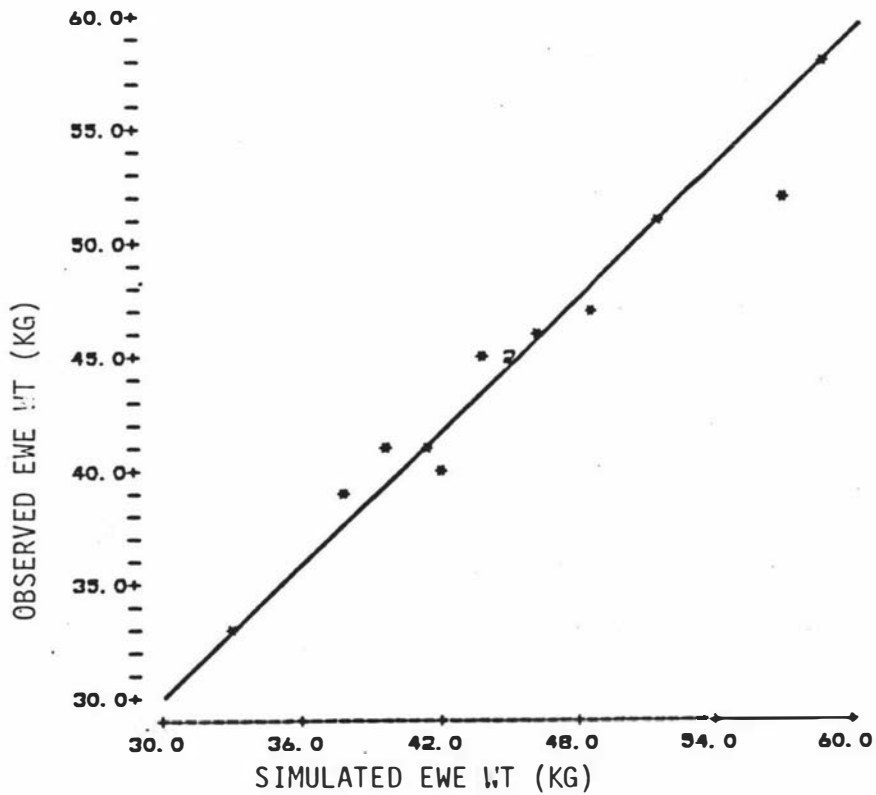
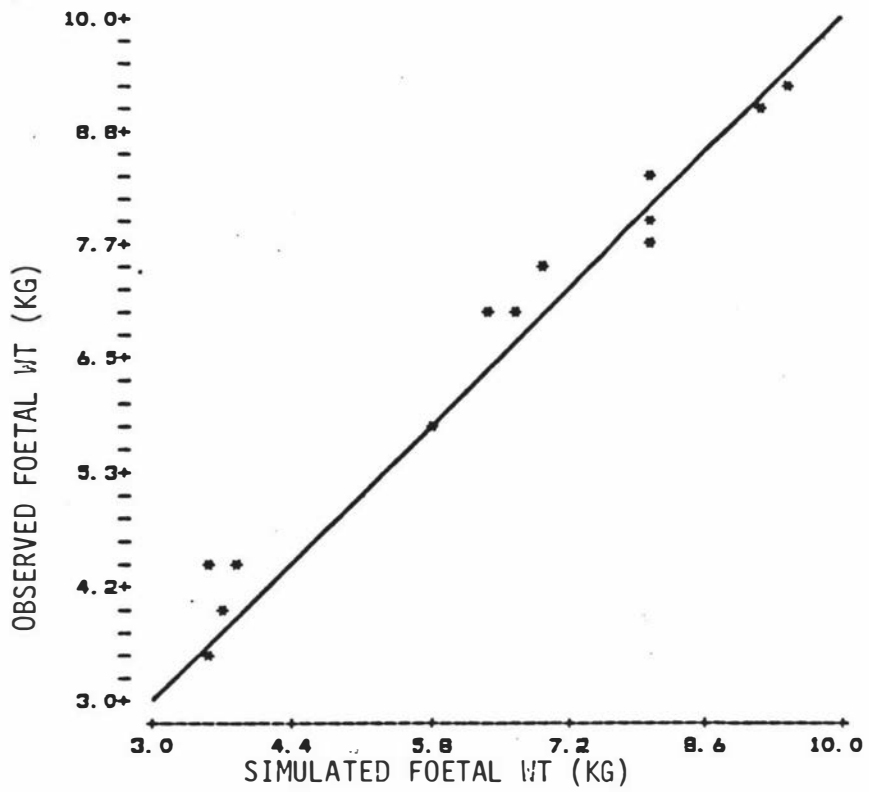


Figure 7.11 Observed and simulated foetal litter weight (top) and empty, fleece free conceptus free ewe body weight (bottom). The equation observed rate = simulated rate is given by the solid lines.

(Table 7.10) but from Fig. 7.11 model predictions were considered to be quite acceptable for the purposes of this study.

Overall gross efficiency of energy use for pregnancy ranged from 22 to 28 % using the above parameters. These were slightly higher than estimates in the literature (e.g. Graham (1964), 20%), but were considered reasonable since the above represented efficiency, solely in the last trimester of pregnancy when the 'maintenance component' of pregnancy requirements would be lower as a proportion of total requirements, due to higher foetal growth rates.

TABLE 7.10: Regression analysis of various animal componentst

Components	a	SEa	b	SEb	r <sup>2</sup>	No. Observes.	$\sum (\bar{Y}_i - \bar{X}_{ij})^2$	Probability of greater F given a = 0, b = 1
Pregnant ewe LWT	4.67	2.67	0.88	0.06	0.96	13	35.8	>0.05, <0.1
Lamb birthweight	0.77	0.25	0.91	0.04	0.98	13	1.88	>0.01, <0.025
Lactating ewe LWT	1.29	3.49	0.97	0.06	0.85	46	396.6	>0.25
Milk production (kg)	2.16	1.45	0.96	0.03	0.95	50	860.09	>0.25

tRegression of  $\bar{Y}_i = a + b\bar{X}_{ij}$

Subjective validation of model predictions of ewe liveweight and lamb birth weight were conducted using a series of grazing trials reported by Rattray et al. (1982a). The ewe maintenance factor was set to 1.3 for flat land and pasture quality was assumed to be 11 MJME/kg DM.

The efficiency of energy use for pregnancy (KP), derived by calibration, appeared too high so the initial value of 0.25 was reinstated. Then there was considered to be reasonable agreement between observed and simulated ewe liveweights and lamb birth weights, with simulated trends following observed trends at different pasture allowances and covers (Table 7.11). Simulated intakes were also encouragingly similar at low allowances, and appeared reasonable (in relation to published requirements) at higher allowances despite being under-estimates of observed apparent intakes. In all, these results gave the modeller confidence in model performance in late pregnancy.

### 7.6.3 Lactation

Calibration was conducted against data of Peart from a series of trials in which he made a comprehensive study of the effects of nutrition on ewe milk production and liveweight change (Peart, 1967, 1968a, 1968b, 1970). A description of the parameters calibrated is given in Table 7.12. The parameters in the buffering ability equation affected the parameter D, in the functional form adopted in Section 6.3.4.

$$D = (\text{CONST} + \text{WL} * \text{week of lactation} - \text{LW} * \text{WT}) \quad (7.5)$$

where WT is fleece-free ewe liveweight. Beyond week 6 of lactation, week of lactation = 6 and above ewe liveweight 45 kg, WT = 45. Other parameters are described in Table 7.12.

TABLE 7.11: Comparison of model predictions of pasture intake during pregnancy and ewe liveweight and litter weight at lambing, with those of Rattray *et al.* (1982a)†

Pasture Cover (kg DM/ha)	Pasture Allowance (kg DM/h/d)	Intake kg DM/h/d		Ewe liveweight (kg)		Litter Birthweight (kg)	
		Actual	Simulated	Actual	Simulated	Actual	Simulated
1100	0.7	0.55	0.42	43	43.5	6.7	6.4
	1.0	0.75	0.63	44	46.2	6.6	6.5
	1.4	1.02	0.91	47	48.7	6.8	6.5
	1.9	1.38	1.09	54	51.1	6.7	6.5
	3.0	1.68	1.25	57	52.5	7.0	6.8
	4.3	2.20	1.35	59	53.7	6.9	7.0
1445	1.0	0.78	0.70	46	47.3	6.0	6.3
	2.4	1.48	1.30	51	53.5	6.6	7.0
	3.7	1.40	1.46	56	55.3	6.4	7.2
	4.9	1.89	1.53	57	56.0	6.4	7.3
	6.9	1.70	1.58	57	56.1	6.8	7.4
2700	0.7	0.64	0.52	46	46.3	6.6	6.5
	1.0	0.88	0.78	48	49.0	6.7	6.6
	1.4	1.08	1.04	50	51.5	7.1	7.3
	2.0	1.54	1.34	55	54.7	7.0	7.4
	3.0	1.83	1.52	57	55.9	7.2	7.4
	4.4	1.94	1.65	59	56.3	7.6	7.4
2895	1.1	0.93	0.87	47	49.4	6.3	6.3
	2.2	1.55	1.40	56	55.2	6.4	7.2
	3.4	1.40	1.59	58	56.6	6.5	7.4
	4.7	1.96	1.69	58	57.2	6.6	7.4
	6.6	2.00	1.74	61	57.5	6.6	7.4

† Litter size corrected to 1.5 lambs/ewe

TABLE 7.12: Description and value of calibrated parameters in the lactation component

Parameter Name	Description and Effect of Parameter	Initial Value	Calibrated Value
AS	A, R, and C are Parameters controlling the shape of the potential milk yield function (see Section 6.3.4) S = singles, T = twins, BWT = birth weight	0.35*BWT	1.89**
AT		0.5*(BWT+0.5)	3.77**
BS		0.5	0.43
BT		0.5	0.41
CS		-0.19	-0.18
CT		-0.19	-0.23
CONST (S)	Constants in buffering ability equation (see text)		0.2
CONST (T)			0.6
WL (S)	Week of lactation term in buffering ability equation		0.14
WL (T)			0.06
LW (S)	Liveweight term in buffering ability equation		0.0*
LW (T)			0.013
KL	Efficiency of energy use for lactation	0.65	0.62
KF	Efficiency of energy use for gain, during lactation	= KL	= KF non-lactating**
MINC	Ewe maintenance factor	1.3	1.20

\* Lowerbound

\*\* Structural changes made during calibration

The function minimised was the sum of the squared differences between observed and simulated ewe liveweight and milk production. It became apparent early on that different sets of parameter values applied for ewes rearing twins and singles, so calibration was conducted on this basis.

The parameter values giving best fit to the data are given in Table 7.12 and observed and simulated ewe liveweight and milk production are plotted in Fig. 7.12.

Changes to parameter values which influence the pattern of potential production merely reflect the difference between the initial data used and the present data, and may be breed affected. However Peart's data showed a consistent lack of correlation between lamb birth weight and the parameter 'A', except at very low birth weights (< 3.5 kg), hence the derivation of a constant. This ties in with recent observations by Rattray et al. (1982b) in the field. Equations 6.17 and 6.18 in Chapter 6 were therefore replaced by the parameters AS and AT in Table 7.12, where birth weight (BWT) was above 3.65 kg, below 3.65 kg the following applied, (calculated from Peart (1967))

$$AT = AT * (1 - (3.65 - BWT) * 0.185) \quad (7.6)$$

$$AS = AS * (1 - (3.65 - BWT) * 0.185). \quad (7.7)$$

Results of regression analyses in Table 7.10 point to the acceptability of the structure of the lactation component.

Subjective assessment of model predictions of ewe and lamb performance under grazing was made by simulating the trials conducted by Rattray et al. (1982b). Pasture quality was assumed to be 11.3 MJME/kg DM and the maintenance factor was again assumed to be 1.3. Comparison between simulated and observed litter weight at weaning

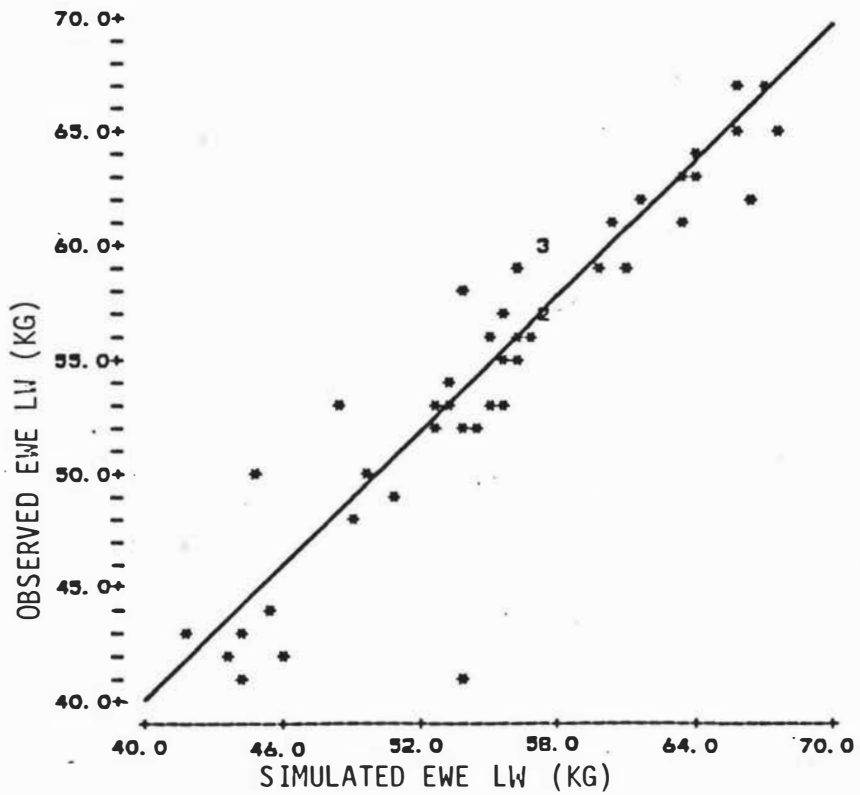
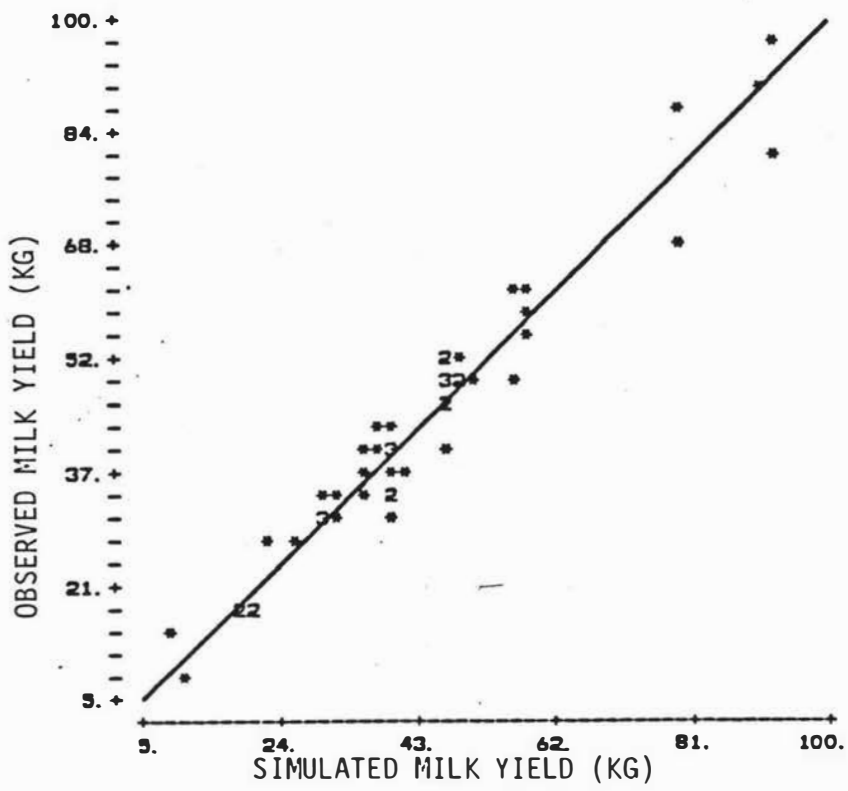


Figure 7.12 Observed and simulated milk yield (top) and ewe liveweight (bottom). The equation observed rate = simulated rate is given by the solid lines.

suggested good agreement between the two (Table 7.13). Simulated intake and ewe weaning weights also showed acceptable trends.

These comparisons established a good deal of confidence in the lactation, lamb growth component of the model.

#### 7.6.4 Wool

Comparisons between actual and simulated wool growth rates were made in the foregoing evaluations where possible (e.g. see Appendix C). Of necessity, wool production for each treatment was considered to be in equilibrium at the start of the simulated trial. This was obviously inadequate for trial 2 comparisons of Sumner and Rattray (1980), where carryover effects of previous nutrition were obvious. With this exception, which was not a problem with the model, the comparisons were satisfactory.

To allow inspection of wool growth rate predictions in the more familiar terms of annual fleece weight, the model was organised to predict hogget fleece weight (12 months growth) from intakes designed to achieve four liveweights by January 1st. Also, single and twin-bearing ewe fleece weight were predicted from the respective requirements for a 55 kg ewe. The linear relationship between hogget liveweight and fleece weight, noted by Hawker (1981b), was apparent (Fig. 7.13). Predicted fleece weights for single and twin-bearing ewes were 4.45 and 4.4 kg, respectively. Predicted fleece weight for twin-bearing ewes given the same intake as their single-bearing contemporaries was 4.25 kg. The annual rhythm of ewe wool growth is shown in Fig. 7.14. These predictions showed that model predictions of wool growth were realistic.

TABLE 7.13: Comparison of model predictions of pasture intake during lactation, and ewe and litter weaning weights, with those of Rattray *et al.* (1982b)†

Pasture Cover (kg DM/ha)	Pasture Allowance (kg DM/h/d)	Intake kg DM/h/d		Ewe liveweight (kg)		Litter weaning weight (kg)	
		Actual	Simulated	Actual††	Simulated	Actual	Simulated
2100	2.0	1.5	1.46	43.0	41.8	25	22.6
	4.2	2.0	2.04	49.8	50.8	31	30.9
	5.8	2.0	2.23	54.0	54.1	31	32.4
	8.2	1.8	2.35	57.2	56.2	34	33.6
	10.2	2.3	2.40	56.1	56.8	35	34.2
2300	2.0	1.6	1.39	45.5	43.4	24	21.7
	4.1	2.1	2.03	50.9	52.9	29	30.2
	6.0	1.9	2.24	53.0	56.4	31	32.4
	8.1	2.0	2.35	56.2	58.3	34	33.7
	10.7	2.3	2.42	57.2	59.2	34	34.4
3600	2.0	1.6	1.43	43.0	41.6	23	22.0
	4.1	1.9	2.10	49.8	51.9	28	30.9
	6.1	1.6	2.32	54.1	55.6	30	33.2
	8.1	1.9	2.42	51.9	57.2	32	34.3
	10.3	2.4	2.47	57.2	58.0	34	34.8
4140	2.0	1.6	1.43	48.7	43.8	25	22.2
	4.1	2.1	2.07	50.9	53.8	30	30.6
	6.0	2.4	2.30	54.1	57.2	32	32.8
	7.9	2.2	2.40	53.0	58.9	34	34.0
	10.6	2.3	2.46	55.1	59.9	34	34.8

† Litter size corrected to 1.5 lambs/ewe

†† Fasted LWT\*1.06

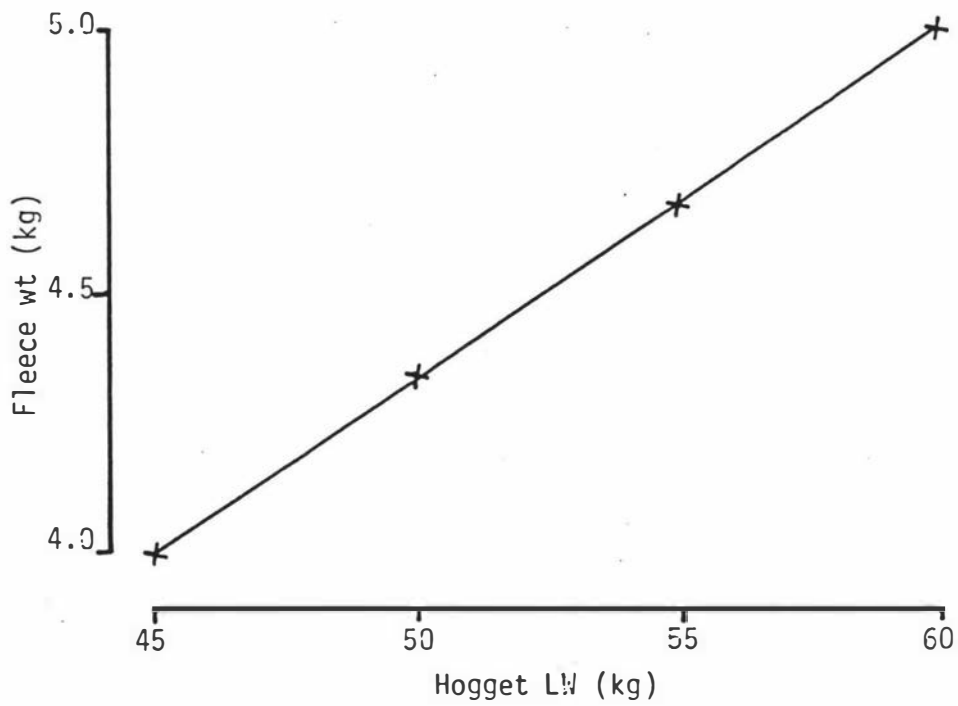


Figure 7.13 Simulated hogget liveweight-annual fleece weight relationship on January 1.

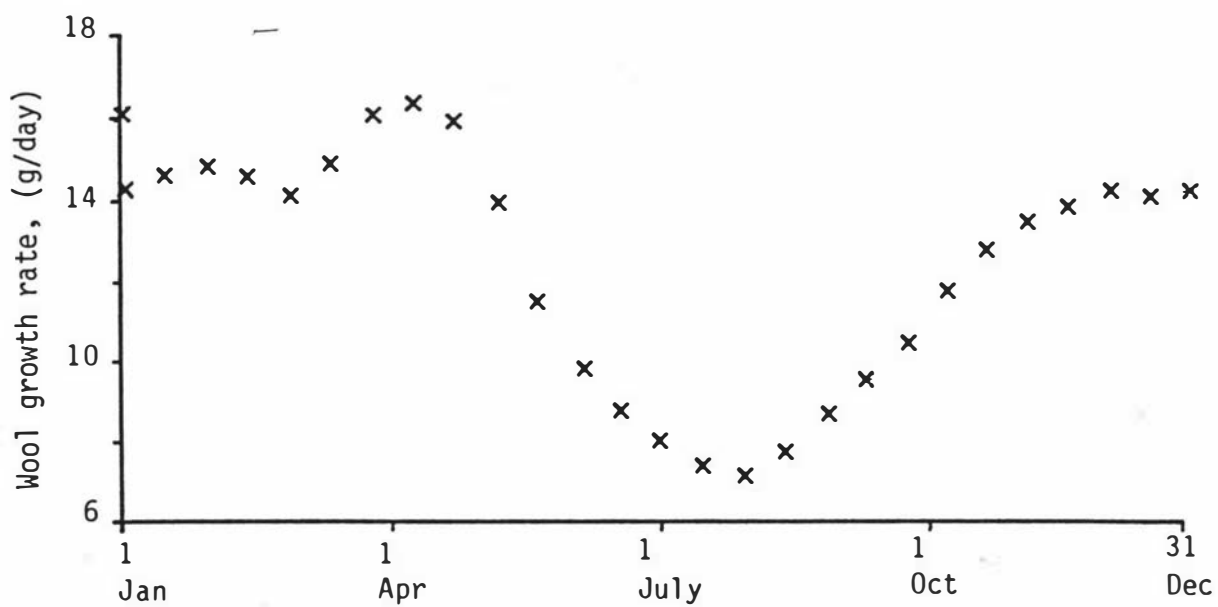


Figure 7.14 Simulated annual pattern of wool growth rate (greasy) for ewes.

## 7.7 SUMMARY

Model development undertaken by calibrating major parameters against sets of real data, and subsequent validation tests made on the various components of the model were described in this Chapter. Both statistical (which were described in some detail) and subjective goodness-of-fit tests were used to assess the acceptability of calibrated model structure. Of necessity, model validity was determined in a purely personal and subjective manner. This personal judgement was however backed by the apparent acceptance of the model by a range of 'experts' at three seminars, where model predictions were under scrutiny.

The 'developed' model was considered valid in the sense that it appeared to show the required realism (determined subjectively) for the purpose of evaluating alternative grazing management strategies on North Island hill country.

## Chapter 8

### EXPERIMENTATION

#### 8.1 INTRODUCTION

Having validated components of the model within predefined limits, and gained confidence in its ability to predict system performance, the next step was to investigate opportunities for increasing system performance. This was undertaken in two stages.

In the first stage, the effects of different management decisions on system productivity and profitability were assessed. Maximum profitability was estimated for a range of different conditions. An attempt was then made to estimate those management decisions that would produce maximum profitability across a range of seasons. These are referred to as the optimal management decisions. It must however be recognised that these optimal decisions are limited to a given set of conditions.

In the second stage, increases to maximum profitability, from introducing innovations and hypothetical new technology in to the system, were investigated. Innovations included strategic use of nitrogen and immunisation of ewes to increase ovulation rate, while hypothetical changes to various limiting processes were made to assess the benefits from having the technology to bring about the assumed change.

To conclude the analyses, the sensitivity of profitability under optimal grazing management decisions was investigated in relation to changes in some parameters which had not been calibrated.

## 8.2 EFFECTS OF MANAGEMENT DECISIONS

### 8.2.1 Experimental Design

A major problem was the potential size<sup>1</sup> and complexity of an experiment where several stock classes were considered. An evolutionary approach to experimentation<sup>2</sup> was considered, to reduce the number of treatments required. However this approach requires a large amount of real time to interact with the model in obtaining an understanding of management effects on system output. To reduce the size of the experiment to manageable proportions, the scope of the system was curbed to include just the breeding ewe flock, selling all lambs as stores. This meant that the effects of management decisions related to seasonal priorities for feed between the ewes and other classes of stock<sup>3</sup> could not be studied.

Management decision variables studied included grazing rotation length at three specified times of the year, proportion of the farm retired from grazing during late spring for pasture control, lambing day and stocking rate. Each decision variable was represented at one of three levels. The basic experimental design was a third replicate of a 3 \* 6 factorial (see Appendix D). Within each stocking rate the levels of the other decision variables were chosen independently, since for example, what may have been a feasible lambing day at a low stocking rate may not have been so at a high stocking rate.

<sup>1</sup>Problems of size are discussed in Chapter 3 and include amount of computer time required and difficulties with interpreting large volumes of results.

<sup>2</sup>Using an evolutionary approach to experimental design a decision is made on each treatment in sequence, based on knowledge gained from the previous experiments.

<sup>3</sup>An example would be adjusting ewe stocking rate seasonally to make more or less land available for grazing by other classes of stock (e.g. McCall, 1984).

A hypothetical farm of surveyed area 100 ha, divided into 30 equally sized paddocks, was assumed. Stocking rates were calculated on a surveyed area basis although actual land area was assumed to be 115 ha. to account for the additional area associated with the uneven terrain of hill country (G.W. Sheath pers. comm.).

The year was divided into five periods. These were:

(1) The first 30 days of lambing where alternatives were set-stocking, or a 15 or 30-day rotation, to ration the feed built up by the winter rotation.

(2) The period of high pasture growth rates, from mid-November until January 20, when three different portions<sup>4</sup> of the farm were retired from grazing in an effort to maintain control, and hence pasture quality, on the grazed area. Ewes and lambs remained set-stocked on the grazed area until lamb selling, at which time ewes commenced on a rotation, spending 1 day per paddock.

(3) From January 20 until 4 weeks prior to tugging, when a series of shifts based on 2 days/paddock was employed. Each shift was to the paddock with the highest level of DM/ha. This ensured previously retired paddocks, where present, were 'cleaned up' first and high quality controlled feed was built up for flushing.

(4) The flushing phase, which extended for 6 weeks. Alternatives were a 15 or 30-day rotation to flush the ewes, or a 60-day rotation where flushing was sacrificed to build-up feed for starting the winter rotation.

(5) The winter period, which commenced following flushing and terminated at the start of lambing. Three alternative rotation lengths were studied. These were a 60 (relatively fast), 90, and a

<sup>4</sup>The actual alternatives studied varied with stocking rate.

120-day (long) rotation, designed to transfer different amounts of feed through until lambing.

All lambs were sold on a common date. Initially this was December 31, but was subsequently changed to January 20.<sup>5</sup>

Rotation length at flushing was chosen as the variable to be incompletely represented in the fractional factorial design. Estimates of the missing combinations of the full factorial were predicted by regression analysis from a fourth order polynomial, fitted to the data. An optimum lambing day was estimated for each combination of the grazing decision variables from the appropriate second order polynomial in terms of lambing day. The decision not to derive optima for the grazing decision variables was based on the reasoning that they were not truly continuous, since levels were constrained to be multiples of the number of paddocks in the system. A four dimensional response surface was therefore constructed for each stocking rate based on the gross margin for each combination of the four grazing decision variables, and the optimum lambing day for each combination (examples of these response surfaces are given in Appendix F).

At any stocking rate three physical response variables were of interest in assessing the influences of management on production. These were ewe fleece weight, lamb selling weight, and lambing percentage. To account for these response variables simultaneously they were combined into a single gross margin index which was adjusted for costs attributable to stocking rate. The index was:

<sup>5</sup>See Section 8.2.3.3 for further discussion on these decisions.

$$GM = WWHA * 3.2 + WLS * PPG - SR * 11.44$$

where: GM was gross margin (\$/ha), WWHA weight of wool/ha (kg), WLS weight of lamb sold/ha (kg), PPG price/kg of lamb at selling, and SR winter stocking (ewes/ha).

Assumed dollar values for WWHA, PPG and SR are explained in Appendix E.

### 8.2.2 Climatic Variability

The site simulated was Ballantrae HCRS. Detailed climate data from Ballantrae did not cover a sufficient period of time to allow climatic variability to be calculated using historical results, so arbitrary years were constructed to represent the major variations in climate (e.g. Miller, 1983). This was done from available data with the aid of long-term climate summaries.

An average year, made up of a series of average months, was characterised by relatively cold winters, warm late springs, and moist summers and autumns. Major departures from the average were either late or early starts to spring, produced by variation in radiation and temperature between August and October, and wet or dry late summer-early autumns. Accordingly, four additional years were constructed from these combinations. Harsh extremes which occur very infrequently were avoided.

Having created representative years it remained to decide how they should be sampled. The method adopted was to allow the model to run until the system reached equilibrium for each year. This approach yielded information on the potential variability between the extremes of the best situation of a series of good years, and the worst

situation of a series of poor years. Net pasture growth rates under simulated 6-weekly cutting are given in Table 8.1 for each year type.

The potential growth rate parameter (PSLOPE) was set at 0.027 to produce annual yields of DM/ha similar to, or slightly above, levels on the most fertile sites at Ballantrae (Lambert *et al.*, 1983). This was considered to be a level close to the potential on well developed NIHC farms.

**TABLE 8.1:** Net pasture growth rates (kg DM/ha/day) in representative years under simulated 6 weekly cutting

Year Type		Average	Wet Autumn	Dry Autumn	Early Spring	Late Spring
Date						
Beginning	Middle					
1/9	21/9	24.4	24.4	24.4	28.4	23.9
13/10	2/11	66.7	66.7	66.7	68.5	61.0
24/11	14/12	77.0	76.9	77.3	77.2	72.6
5/1	25/1	45.0	58.7	29.1	45.2	43.9
16/2	8/3	40.9	62.2	34.7	41.2	40.4
30/3	19/4	31.1	35.2	26.5	31.2	30.7
11/5	31/5	16.6	16.8	16.6	16.7	16.5
22/6	12/7	6.8	7.3	7.2	6.2	7.2
3/8	17/8	19.7	18.7	18.7	22.8	13.8
Annual kg DM/ha		13536	15166	12410	13871	12845

### 8.2.3 Results of Management Experiments

A major objective of grazing management is to manipulate feed supply and demand in order that animal requirements may be best met from the pattern of pasture growth. Owing to the importance of climate in determining the basic pattern of pasture growth, the effects of grazing decisions were first studied for an average

year to provide a bench mark against which optimal decisions in other years . . . could be compared.

#### 8.2.3.1 Average Year Results

For each of the stocking rates, 14, 16 and 18 ewes/ha, the experiment outlined in Section 8.2.1 was conducted. Examples of the response surfaces for each stocking rate, expressed in terms of gross margin/ha at the optimum lambing day for each combination of grazing decision, are presented in Appendix F. The relationship between lambing day and gross margin, for the best and worst combinations of grazing decisions at each stocking rate (circled in Appendix F), are shown in Fig. 8.1.

Maximum gross margin increased with stocking rate, up to 18 ewes/ha. The range in gross margin between the 'best' and 'worst' management within each stocking rate, also increased with stocking rate, implying that improved management attracted greater rewards at high stocking rates.

Since the highest gross margin, and the greatest sensitivity to management were recorded at 18 ewes/ha, effects of management at this stocking rate are described in some detail first.

The set of management decisions that gave maximum gross margin at a stocking rate of 18 ewes/ha were: a long winter (120 day) and early spring (30 day) rotation, relatively early lambing (day 241), retiring one-sixth of the farm (5 paddocks) from grazing between mid-November and mid-January, and a long rotation during flushing (60 days).

The former two decisions had the greatest impact (see Fig. 8.2), particularly when combined with early lambing. Increasing the length of the winter rotation, and continuing a rotation into early spring,

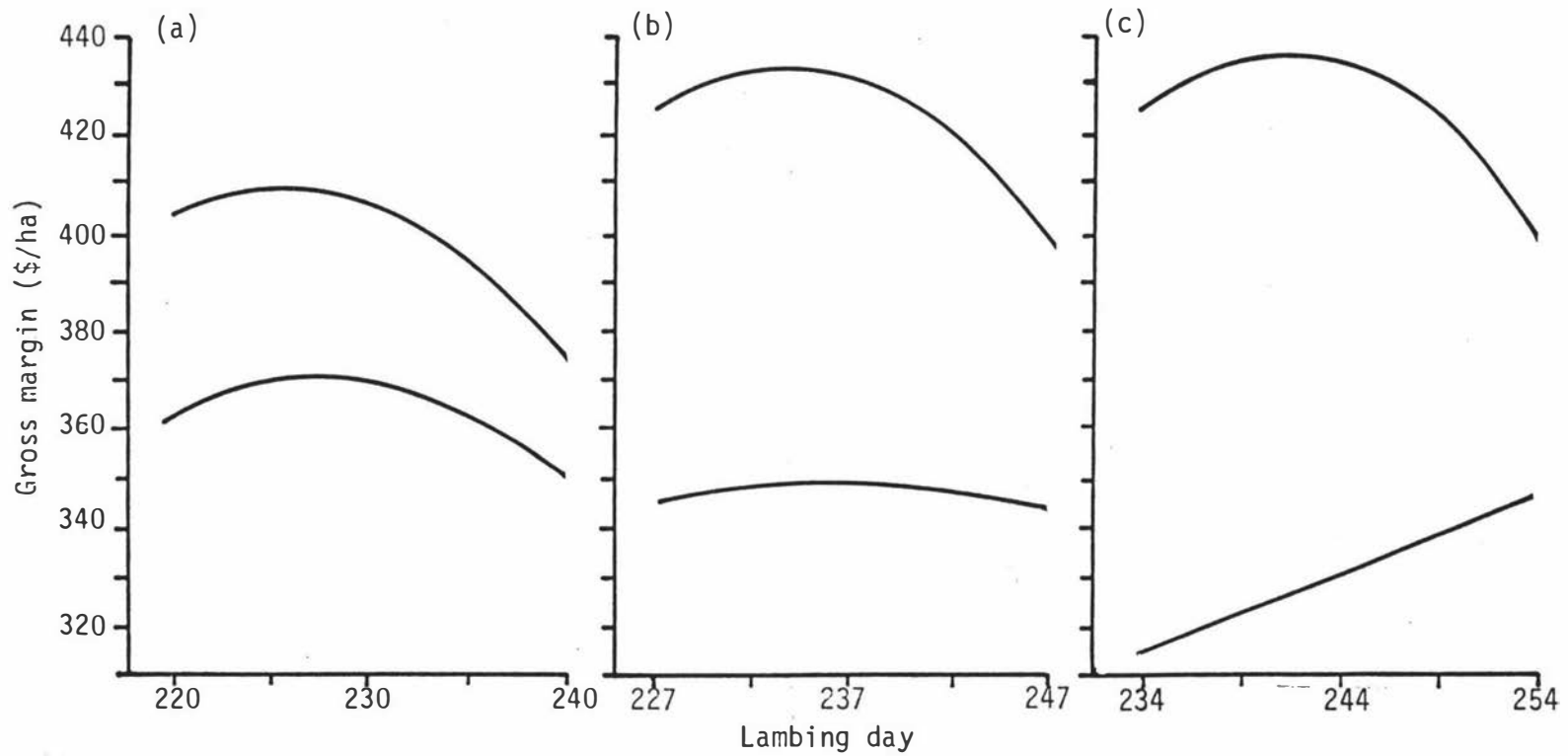


Figure 8.1 The relationship between lambing day and gross margin for the best and worst combination of grazing decisions studied, at stocking rate 14(a), 16(b) and 18(c) ewes/ha.

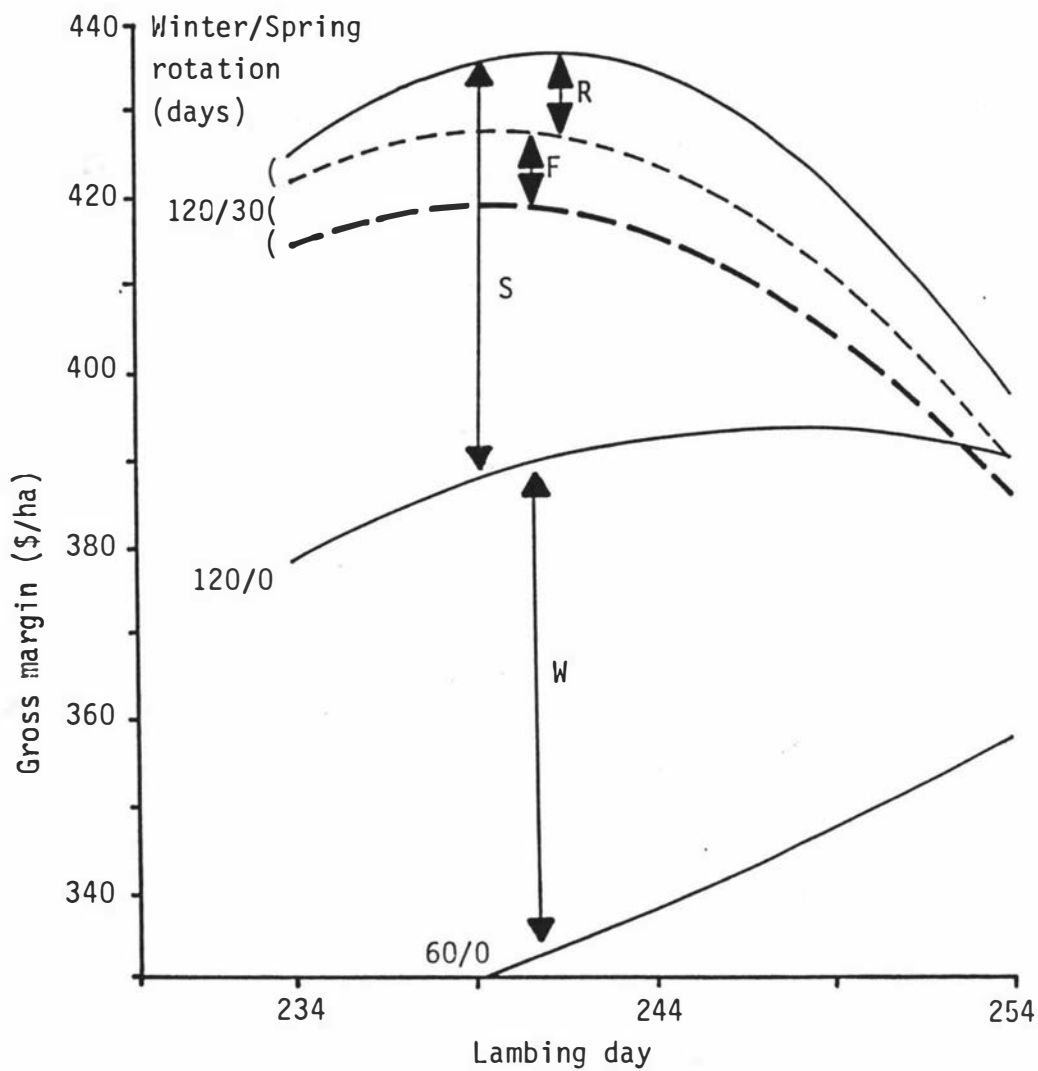


Figure 8.2 Relationships between lambing day and gross margin for selected combinations of grazing decisions at 18 ewes/ha (average year). Decisions for number of paddocks retired in spring, and length of flushing rotation were 5/60 (-), 0/15 (thin ---) and 0/60 (thick ---). Letters R, F, W and S represent differences due to different retiring, flushing, winter and spring decisions, respectively.

greatly improved the performance of early lambing systems. In later lambing systems the effect was not as great.

The results of six treatments were chosen to reveal the physical reasons behind the above observations. The treatments included three combinations of winter/spring rotation length (120/30, 120/0 and 60/0) by two lambing days, day 234 and day 254. Rotation length at flushing was not identical between treatments because certain treatments were missing from the data owing to the use of the fractional factorial design. However all other decisions were identical between treatments.

Grazing decisions and physical response variables for the above treatments are given in Table 8.2. Some additional physical results are shown in Fig. 8.3 (treatments 1 and 3) and 8.4 (treatments 4 to 6).

**Table 8.2:** Grazing decisions and physical components of production for treatments 1 to 6

Treatment No.	Winter Rotation (Days)	Spring Rotation (Days)	Lambing Day	No. Paddock Retired	Flushing Rotation (Days)	Lamb Selling LWT (kg)	Lambing %	Ewe FLWT (kg)
1	120	30	234	0	60	27.4	104.3	4.67
2	120	0	234	0	30	25.1	101.4	4.59
3	60	0	234	0	15	21.0	103.2	4.66
4	120	30	254	0	15	25.1	109.1	4.47
5	120	0	254	0	60	25.0	106.9	4.46
6	60	0	254	0	30	23.1	107.3	4.54

Increased pasture cover at lambing resulted from the long winter rotation at both lambing days, and rationing of feed into early lactation ensured that cover was retained until spring growth

	Treatment No.	(kg DM/ha/28 days)				
Growth	1	645	753	1259	2073	2232
	3	471	613	1215	2119	2248
Consumption	1	565	771	855	1146	1197
	3	419	493	693	1038	1056

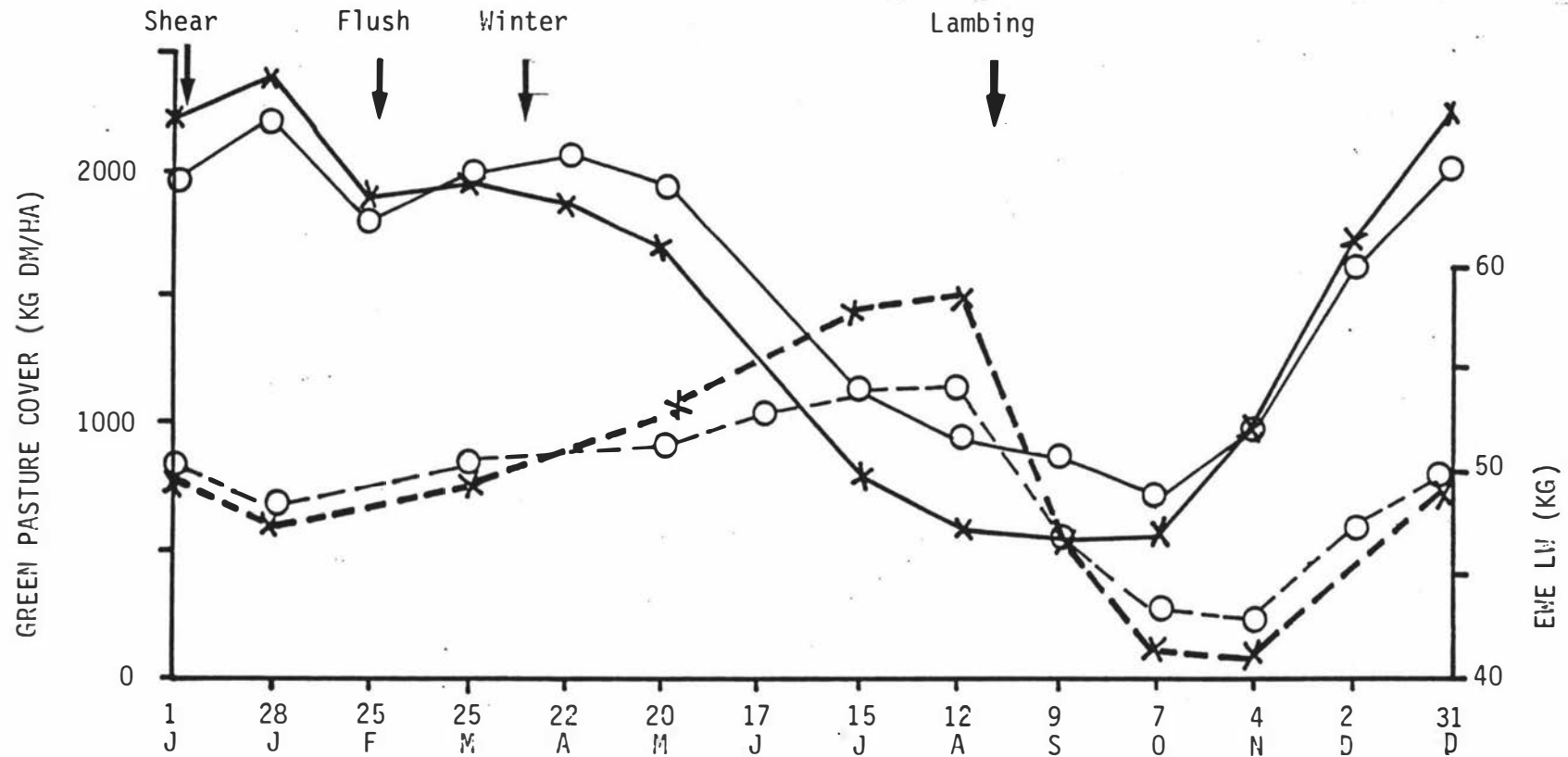


Figure 8.3 Simulated green pasture cover (—), ewe liveweight (----) and pasture growth and consumption rates for treatments 1 (O) and 3(X). Pasture cover on grazed area only.

	Treatment No.	(kg DM/ha/28 days)				
Growth	4	652	943	1501	2432	2185
	6	565	668	1264	2132	2254
	5	661	763	1349	2221	2263
Consumption	4	361	695	1069	1226	1145
	6	366	591	794	1116	1133
	5	376	799	933	1178	1161

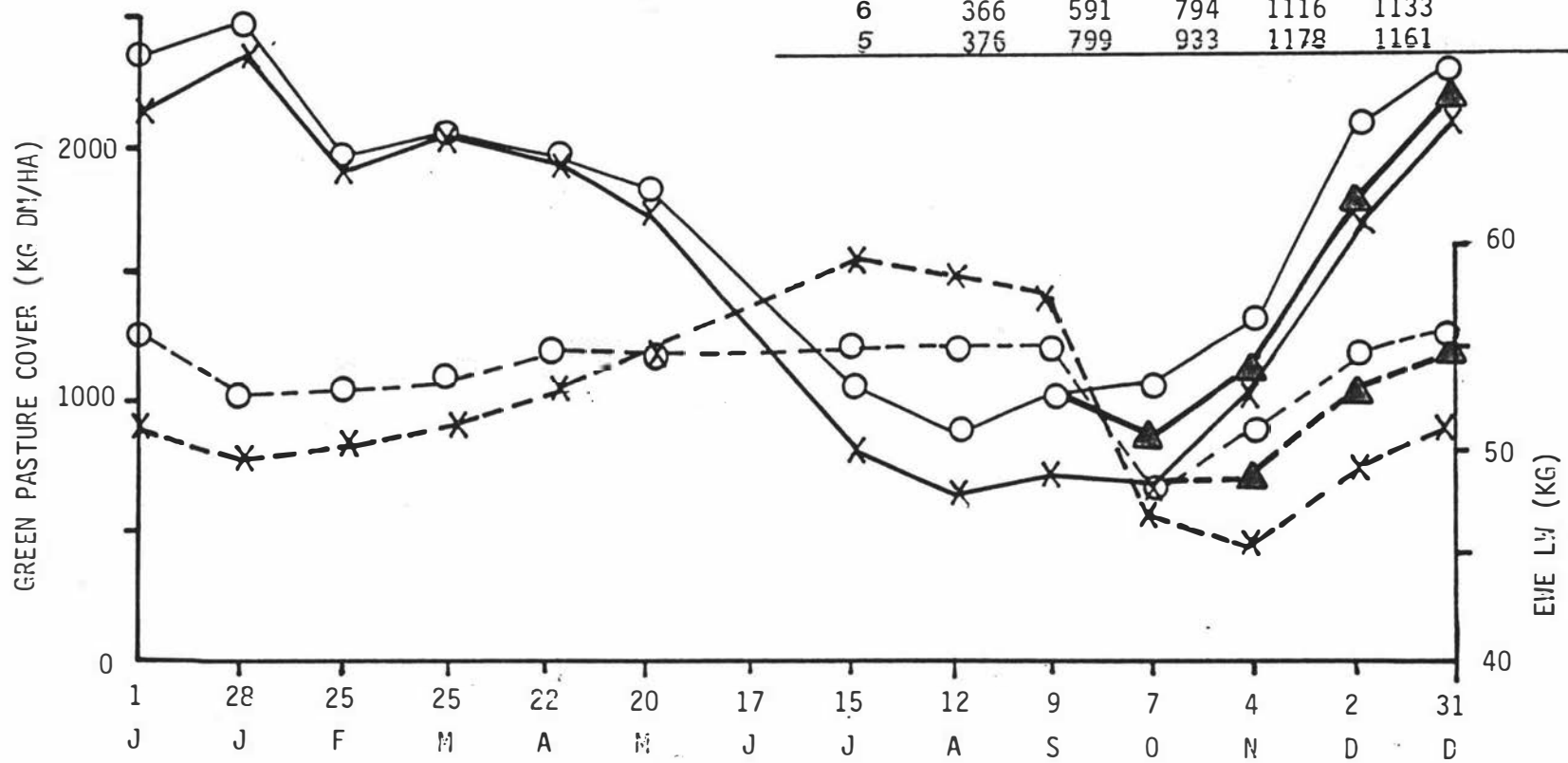


Figure 8.4 Simulated green pasture cover (—), ewe liveweight (---) and pasture growth and consumption rates for treatments 4 (O), 5 (Δ) and 6 (X). Pasture cover on grazed area only.

commenced (see Figs 8.3 and 8.4). The major effect of this increased cover was to promote greater pasture growth in early spring, which in turn supported greater consumption. As well, the energy cost to ewes of harvesting the pasture was reduced.

Following early lambing (Fig. 8.3), prolonged under-nutrition in early lactation (treatment 3) could not be completely buffered by the ewe and also depressed milk production in late lactation. As well, pasture intake by the lambs was restricted by pasture availability at the time they commenced grazing. Consequently, rumen capacity in treatment 3 lambs was less well developed so that they also achieved lower intakes when pasture availability did become non-limiting. This led to the accumulation of a greater spring surplus in treatment 3 with an associated greater decline in pasture quality. A difference of 6.4 kg (27.4 v. 21.0) existed between lambs in treatment 1 and 3 on December 31. Ewe liveweight, despite being lower pre-lambing on the treatment 1 system was higher by early October, and remained slightly higher until late April.

When lambing day was delayed further into spring (Fig. 8.4) the ewes in treatment 6 almost completely buffered their lambs through the shorter period of feed restriction, and growth was ahead of consumption by the time lambs commenced grazing. In treatment 4 the problem of controlling the spring surplus was compounded by restricting intake in early lactation through delaying set-stocking (compare treatments 4 and 5 in Fig. 8.4). The advantage gained in lamb weight through a higher pasture cover in October, in the former treatment, was lost by December 31 owing to a decline in pasture quality. Ewe liveweight remained higher in treatment 4 than treatments 5 and 6 however owing to the advantage gained in early

lactation from more of the ewes' energy needs being met from intake. This reflected in a higher lambing percentage.

Delayed lambing had two further effects. Firstly, minimum ewe liveweight in spring was higher following late lambing owing to the proximity of lambing to the onset of spring pasture growth. This reflected in higher ewe liveweights at other times of the year, and hence higher lambing percentages. Secondly, following later lambing, the effect of competition on wool growth from lactation was greater, because potential wool growth rates increase with the advancement of spring.

Benefits from the temporary retiring of pasture from grazing in late spring came from improved pasture quality on the controlled areas and were reflected in higher lamb selling weights. Generally benefits from having high quality pasture available for flushing did not materialise. This was due to the greater liveweight loss, or smaller gain, in ewes cleaning up pasture previously retired in summer, and was not compensated by the flushing response. An interaction occurred between lambing day and the level of retiring required to maintain control of the grazed area.

Figures 8.5 and 8.6 show the physical results of two treatments where either none, or one-third, of the farm was retired following early or late lambing. The grazing decisions and physical response variables are given in Table 8.3. It can be seen that following late lambing (Fig. 8.6) a greater level of retiring was required to maintain control. The same level of retiring following early lambing caused a pasture restriction in December (Fig. 8.5).

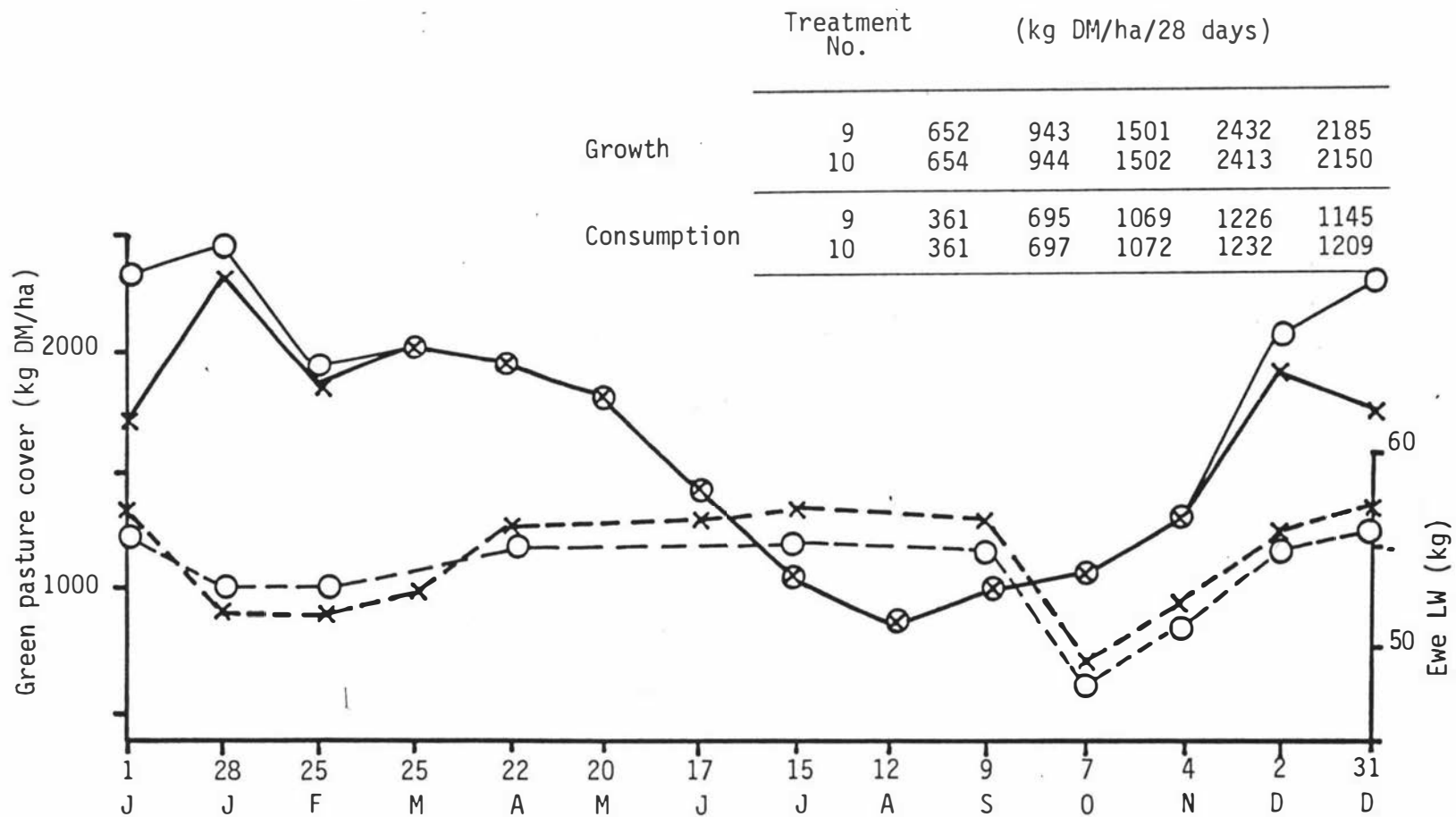


Figure 8.6 Simulated green pasture cover (—), ewe liveweight (--) and pasture growth and consumption rates for treatments 9 (O) and 10 (x). Pasture cover on grazed area only.

**Table 8.3:** Grazing decisions and physical components of production for treatments 7 to 10

Treatment No.	Winter Rotation (Days)	Spring Rotation (Days)	Lambing Day	No. Paddock Retired	Flushing Rotation (Days)	Lamb Selling LWT (kg)	Lambing %	Ewe FLWT (kg)
7	120	30	234	0	60	27.4	104.3	4.67
8	120	30	234	10	15	26.6	103.3	4.60
9	120	30	254	0	15	25.1	109.1	4.47
10	120	30	254	10	60	26.0	109.9	4.54

Finally, the net effect of different rotation lengths at flushing were small but favoured the 60-day rotation. Lambing percentage was penalised only slightly as there was no shortage of feed at this time of the year, but lamb weaning weight eventually benefited from the resulting greater volume of feed transferred into spring.

In summary, significant effects of management on the components of production were: (a) lamb selling weight responded favourably to long rotations over flushing and winter, together with an early spring rotation. This management improved nutrition of the ewes in early spring, allowing an early lambing day, to take advantage of greater lamb age at selling. Retiring sufficient area to maintain control of the grazed area in late spring also increased lamb weight. Significant effects are shown in Fig. 8.7.

(b) Lambing percentage was closely related to minimum ewe liveweight in the spring since this weight determined achievable autumn liveweights. Late lambing, and a 30-day spring rotation, improved minimum ewe liveweight in spring and hence lambing percentage. Flushing, and increased amounts of high quality pasture

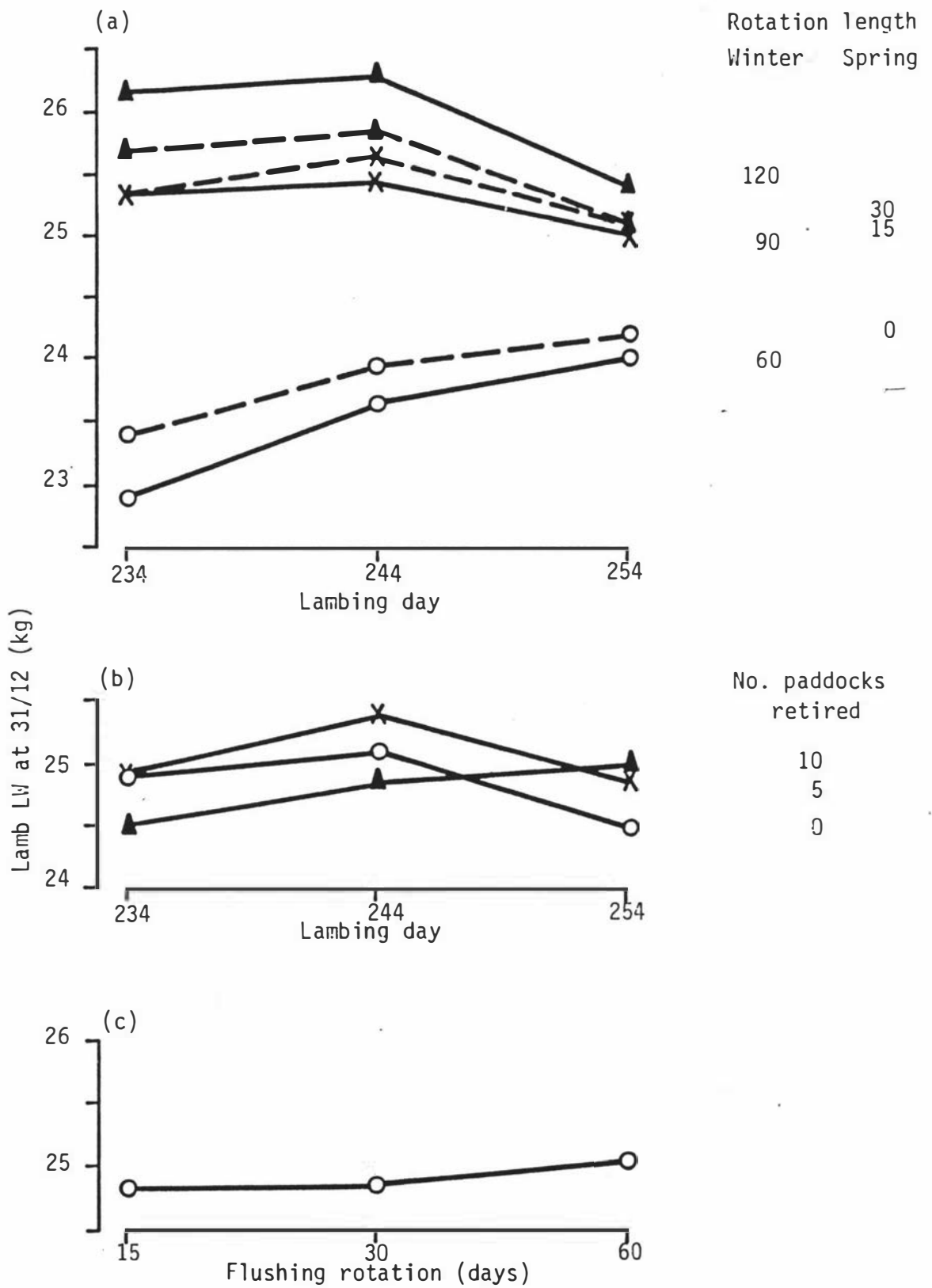


Figure 8.7 Means of significant effects on lamb selling liveweight at stocking rate 18 ewes/ha (average year). (a) Lambing day x winter rotation (-), Lambing day x spring rotation (---). (b) Lambing day x no. paddocks retired. (c) Flushing rotation.

in autumn, produced by retiring part of the farm in late spring, both gave small advantages. Mean effects are shown in Fig. 8.8.

(c) Fleece weights were depressed following late lambing. Other effects were small. Increased spring and winter rotation length had positive and negative effects respectively, and level of retiring interacted with lambing day. Significant effects are shown in Fig. 8.9.

The principles established for achieving high performance at 18 ewes/ha also applied at the lower stocking rates. However because the feed demand in early spring was not as high, responses to grazing decisions aimed at improving spring nutrition were also not as great. Despite this the earliest lambing day made possible by a long winter and spring rotation remained optimal. However at 14 ewes/ha a spring rotation was more important than the long winter rotation in achieving this goal. Control of the grazed area for the sake of lamb selling weight also remained desirable, but required a greater level of retiring at low stocking rates. The major change was the desirability of flushing at 14 ewes/ha.

Results of treatments with decisions closest to those of the estimated maximum gross margin for each stocking rate are given in Table 8.4 and for 14 and 18 ewes/ha in Fig. 8.10. Effects of stocking rate on per head performance and consumption are as expected. The trade-off between low pasture growth rates from rank pasture through late summer until mid-winter at 14 ewes/ha, and low growth rates from short pasture in spring at 18 ewes/ha, meant that greatest annual pasture growth was achieved at a stocking rate of 16 ewes/ha.

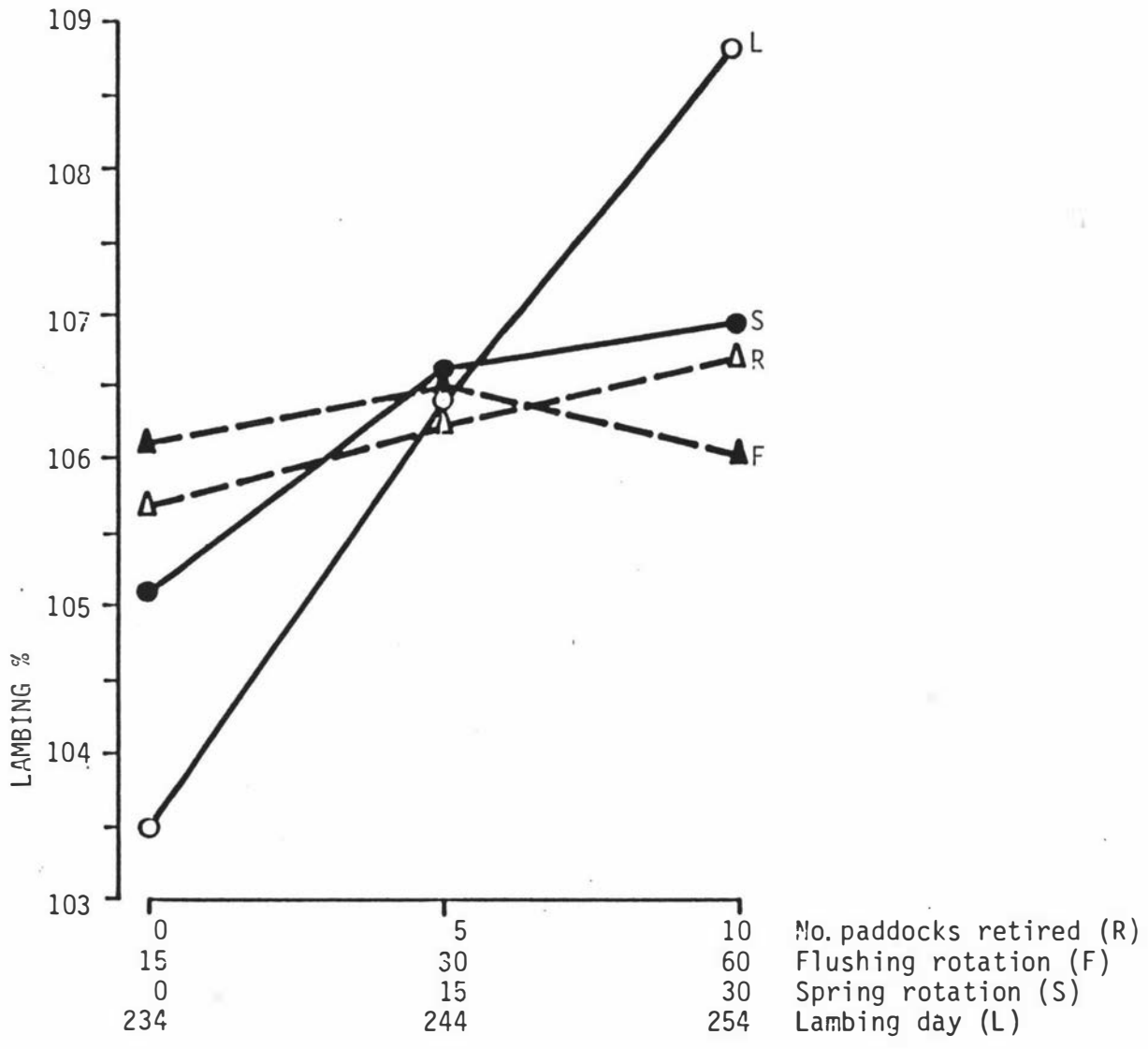


Figure 8.8 Means of significant effects on lambing percent at stocking rate 18 ewes/ha (average year).

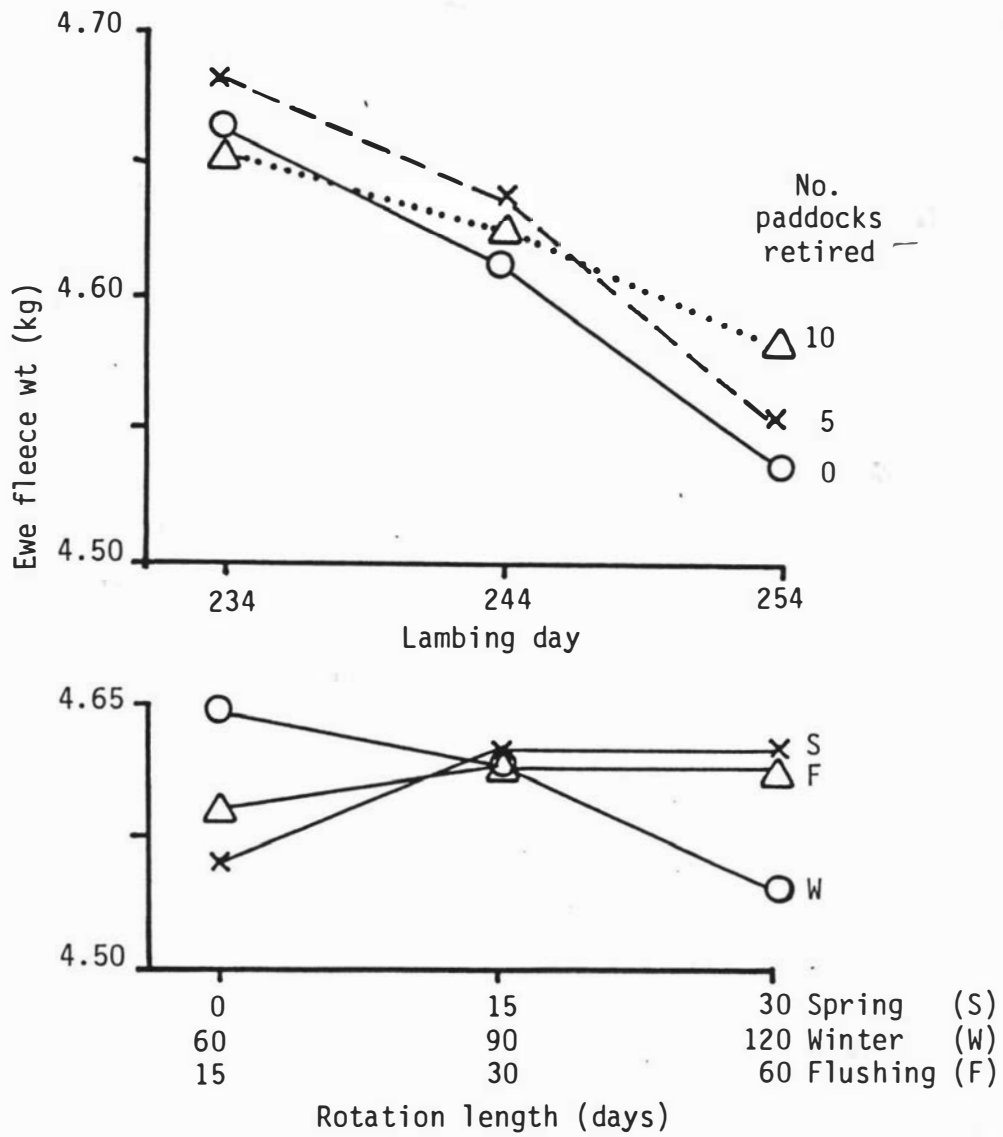


Figure 8.9 Means of significant effects on ewe fleece weight at 18 ewes/ha (average year).

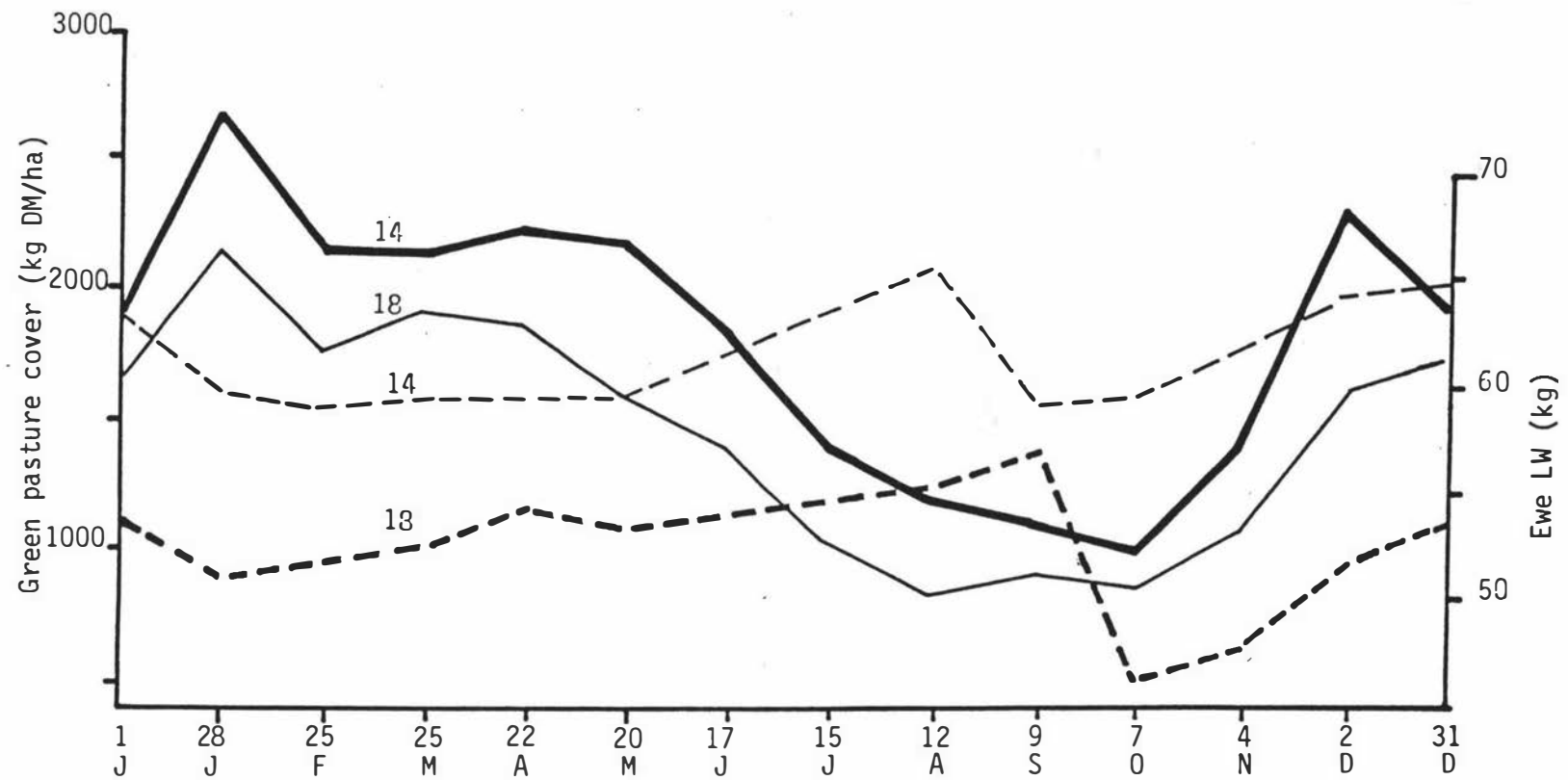


Figure 8.10 Simulated green pasture cover (—) and ewe liveweight (---) at stocking rates 14 and 18 ewes/ha. Other management decisions given in Table 8.4. Pasture cover on grazed area only.

TABLE 8.4: A summary of major results for treatments with decisions closest to estimated maximum gross margin for each stocking rate

Stocking Rate (ewes/ha)	Lambing Day	Winter Rotation (Days)	Spring Rotation (Days)	Flushing Rotation (Days)	No. Paddocks Retired	Pasture Growth (kg DM/ha)	Pasture Consumption (kg DM/ha)	Consumption (kg DM/ewe)	Pasture Utilisation Rate (%)	Lamb Selling LWT (kg)	Lambing (%)	Ewe FLWT (kg)
14	230	120	30	15	15	12985	7528	618	58.0	31.1	110.4	4.91
16	237	120	30	60	12	13115	8246	593	62.9	29.3	109.9	4.83
18	244	120	30	15†	5	12838	8567	547	66.7	26.9	107.7	4.61

† 60 day treatment 'missing'

### 8.2.3.2 Results in Non-Average Years

A summary of the maximum and minimum gross margins for each season by stocking rate combination is given in Table 8.5. The grazing decisions which produced the maximum gross margins in Table 8.5, are identified in Table 8.6. The mean trend across stocking rate remained the same as for the average year but variability about the mean maximum gross margin increased from 3 to 9% as stocking rate increased.

Irrespective of year or stocking rate the grazing decisions producing maximum gross margin included a long winter rotation, followed by a spring rotation. This management aimed at creating the best possible early spring feed supply to allow the earliest possible lambing day to be adopted so that lamb selling weight could be maximised.

The choice of lambing day had a major influence on the amount of seasonal variability expressed in gross margin, particularly at high stocking rates (see Fig. 8.11). A conservative choice of lambing day resulted in very little variability in gross margin between seasons at any of the stocking rates (Figs 8.11 to 8.13). The exception was in a dry autumn where reductions in lambing percentage and ewe fleece weight were not made up by delaying lambing (see Table 8.7).

The influence of early and late springs on spring feed supply are obvious. Additional feed generated by a wet autumn had its greatest effect by increasing cover on the farm in early spring. Flushing was included in the grazing decisions producing maximum gross margin at 16 ewes/ha in a wet autumn, but at 18 ewes/ha, a 60-day rotation remained best.

**TABLE 8.5:** Summary of maximum and minimum gross margins (\$/ha) (for the various combinations of grazing decisions studied) for each season by stocking rate combination

Year Type	Average	Wet Autumn	Dry Autumn	Early Spring	Late Spring
Stocking Rate					
14					
Maximum	410.3	407.8	384.7	416.5	399.3
Minimum	368.8	381.6	359.3	387.7	341.5
Range	41.5	26.2	64.2	28.8	57.8
16					
Maximum	434.2	453.5	393.3	457.1	394.0
Minimum	349.1	391.4	309.9	383.5	317.1
Range	85.1	62.1	83.4	73.6	76.9
18					
Maximum	437.2	462.2	391.4	466.4	390.2
Minimum	346.9	366.6	Infeasible	353.3	318.7
Range	90.3	95.6		113.1	71.5

TABLE 8.6: Decisions leading to maximum gross margin for each season by stocking rate combination

Year Type	Gross Margin \$/ha	Lambing Day	Winter Rotation (Days)	Spring Rotation (Days)	No. Paddocks Retired	Flushing Rotation (Days)
Stocking Rate						
14						
Average	410.3	226	120	30	15	15
Wet Autumn	407.8	224	120	15	15	15
Dry Autumn	384.6	228	120	30	15	60
Early Spring	416.5	224	120	30	15	15
Late Spring	399.3	228	120	30	15	60
Mean	403.6					
16						
Average	434.2	233	120	30	12	60
Wet Autumn	452.2	229	120	30	12	15
Dry Autumn	393.6	235	120	30	12	60
Early Spring	457.1	229	120	30	12	30
Late Spring	394.0	237	120	30	6	60
Mean	426.2					
18						
Average	437.2	241	120	30	5	60
Wet Autumn	462.2	233	120	30	5	60
Dry Autumn	391.4	240	120	30	5	60
Early Spring	466.4	238	120	30	5	60
Late Spring	390.2	251	120	30	5	60
Mean	429.5					

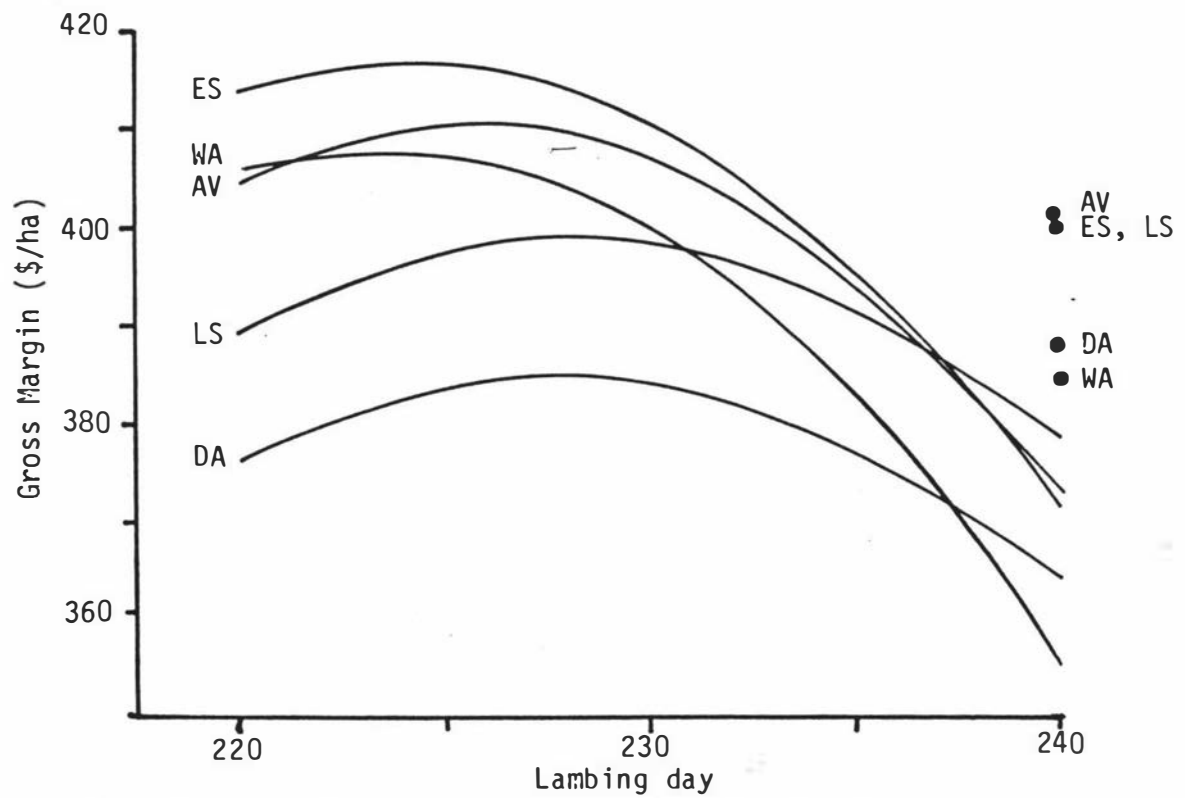


Figure 8.11 The relationship between lambing day and gross margin under the grazing decisions producing maximum gross margin for each season at 14 ewes/ha. WA = wet autumn, DA = dry autumn, ES = early spring, LS = late spring and AV = average year. Dots referred to later, in text.

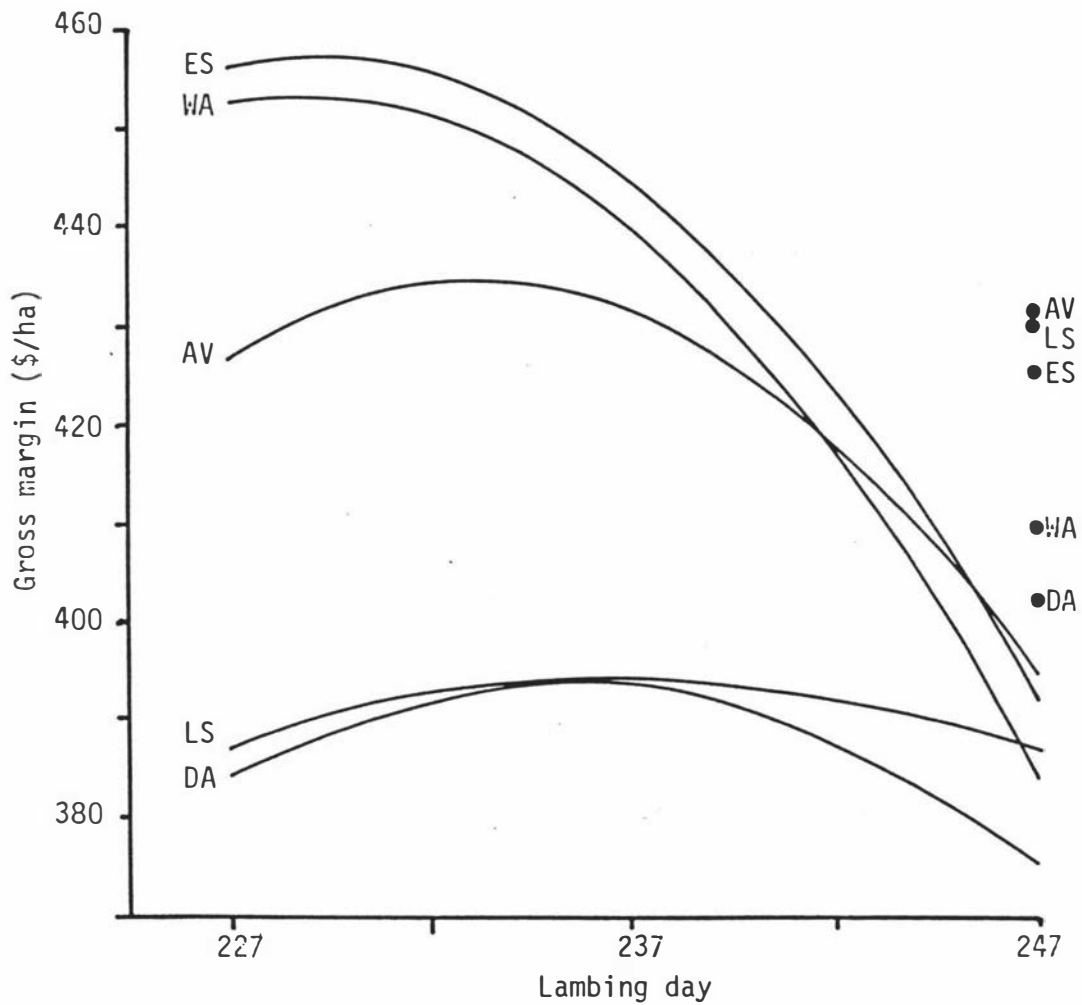


Figure 8.12 Relationships between lambing day and gross margin under grazing decisions producing maximum gross margin in each year at 16 ewes/ha. WA = wet autumn, DA = dry autumn, ES = early spring, LS = late spring, AV = average year. Dots referred to later in text.

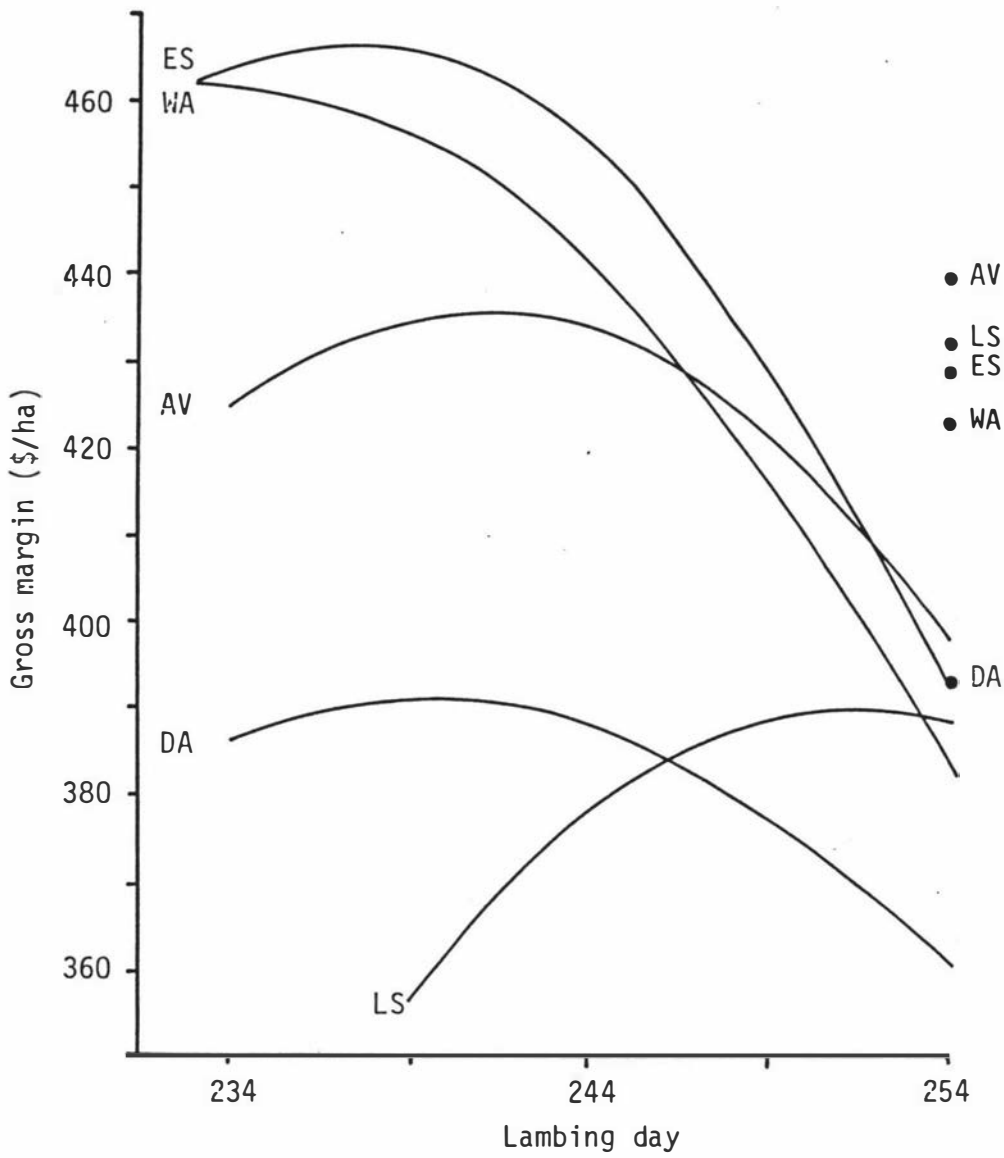


Figure 8.13 Relationships between lambing day and gross margin under grazing decisions producing maximum gross margin in each year at 18 ewes/ha. WA = wet autumn, DA = dry autumn, ES = early spring, LS = late spring, AV = average. Dots referred to later in text.

TABLE 8.7: The influence of early and late lambing on the physical components of production in each season at 3 stocking rates†

Season	Stocking Rate (ewes/ha)	Lambing Day	Lambing %	Lamb Selling LWT (kg)	Ewe FLWT (kg)	Stocking Rate (ewes/ha)	Lambing Day	Lambing %	Lamb Selling LWT (kg)	Ewe FLWT (kg)	Stocking Rate (ewes/ha)	Lambing Day	Lambing %	Lamb Selling LWT (kg)	Ewe FLWT (kg)
Average	14	220	108.4	31.4	4.96	16	227	108.6	28.5	4.88	18	234	105.1	27.0	4.69
Wet Autumn			106.9	32.2	4.87			109.0	30.9	4.90			107.3	28.3	4.76
Dry Autumn			105.1	30.0	4.86			97.7	29.4	4.56			92.2	28.8	4.36
Early Spring			108.4	32.2	4.94			109.6	30.4	4.94			107.2	28.5	4.75
Late Spring			108.6	29.8	5.00			107.0	26.5	4.82			100.4	24.0	4.58
Average		240	110.9	28.8	4.77		247	110.7	27.1	4.69		254	108.7	25.5	4.48
Wet Autumn			109.1	28.3	4.66			109.4	26.8	4.59			107.2	25.3	4.44
Dry Autumn			109.4	28.6	4.73			106.0	27.4	4.50			99.1	26.0	4.25
Early Spring			110.9	28.8	4.75			111.0	27.1	4.67			109.1	25.2	4.47
Late Spring			110.9	29.1	4.81			111.2	26.0	4.70			108.1	25.2	4.51

†Grazing decisions for winter and spring rotation and level of retiring are given in Table 8.6, length of rotation at flushing was variable

Dry autumn conditions markedly reduced pasture cover at the end of April, particularly at high stocking rates (see Fig. 8.14). A long winter rotation returned cover to average spring levels provided lambing was delayed, but the penalty was paid in ewe liveweight at lambing which, at 18 ewes/ha, left ewes in a vulnerable position with very low body reserves (Fig. 8.14). However, at high stocking rates, the alternative of reducing the length of the winter rotation spelt disaster in early spring. Ewe liveweight recovered initially but fell again in late winter on the second rotation, when pasture reserves were low. As a result of insufficient body reserves at lambing and poor spring conditions created by low pasture cover, the system collapsed. To support a faster winter rotation lambing day had to be delayed significantly.

Within stocking rates, the best level of retiring was remarkably similar between years, given the options available, except following a late lambing. Here there was a need for a greater level of retiring in good autumn and spring years, than in other years. This explains the poorer performance in these years following late lambing in Figs. 8.11 to 8.13.

The previous experiments all pointed to the importance of making grazing decisions which allowed as early a lambing day as 'possible' to be adopted. These principles applied regardless of season or stocking rate. However in the system studied, lambing day was confounded with lamb age by virtue of the decision to sell lambs on a common date. An important issue that needed to be considered at this point was the relevance of the system studied, and hence conclusions reached, in relation to the more complex systems of reality.

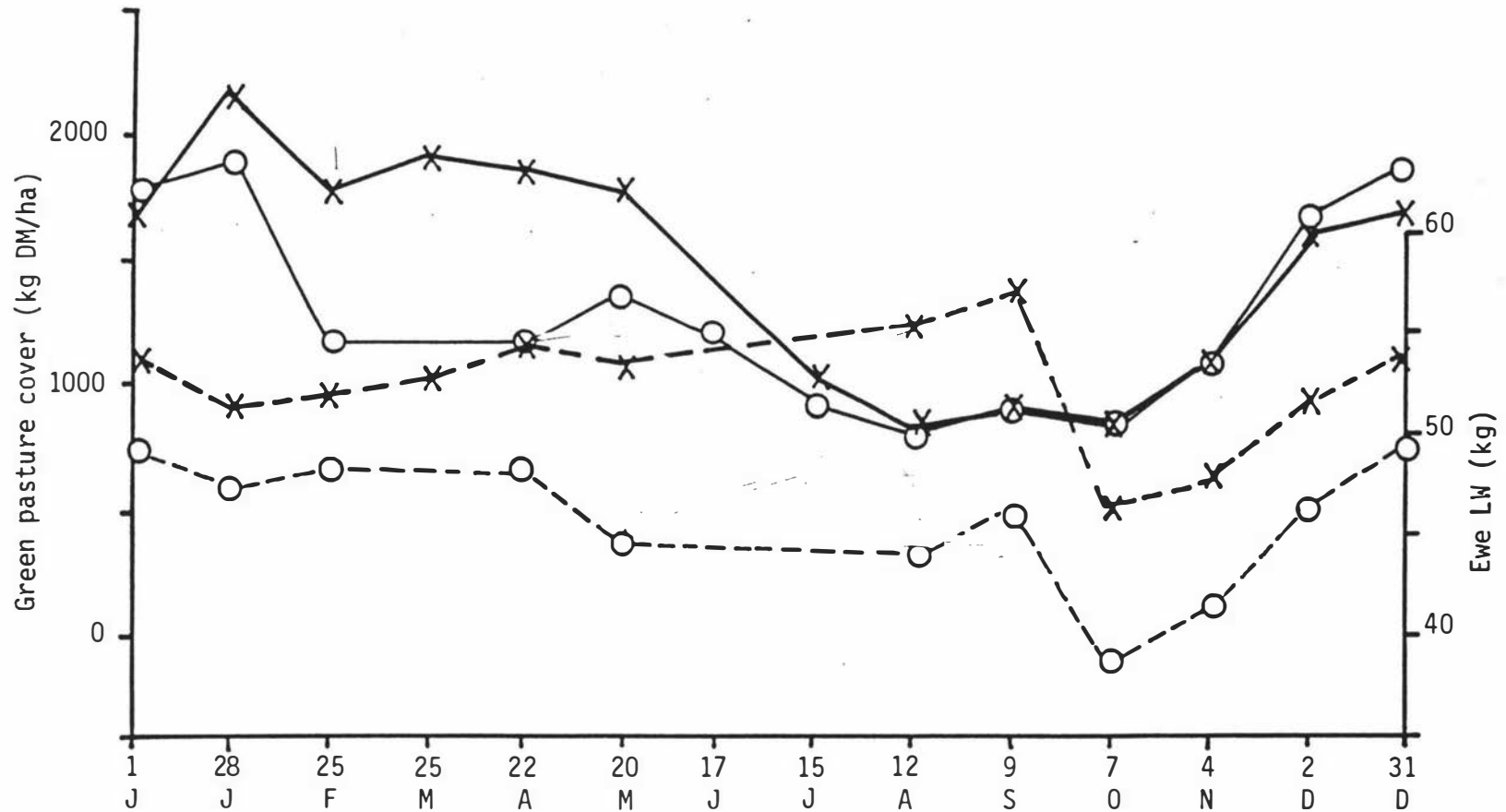


Figure 8.14 Simulated green pasture cover (—) and ewe liveweight (--) in an average (x) and dry autumn (o) year  
 Management decisions were: stocking rate 18 ewes/ha; winter rotation, 120 days; spring rotation, 30 days; flushing rotation, 60 days; 5 paddocks retired in late spring and lambing day, 244. Pasture cover on grazed area only.

### 8.2.3.3 Effects of Lamb Selling Date and Policy

The simplifying decision to sell lambs on a common date (December 31) was based on the reasoning that selling policy, in reality, would be based on feed supply around the time of sale, and not lamb age. A later date may have been better and also have allowed time for young lambs to catch up. However an alternative approach would be to sell lambs at a common age. This, in theory, would more accurately reflect the value to the system of ewe lambs retained for breeding, which will eventually be mated at a common age.

To investigate both the effects of a later lamb selling date, and selling based on age the previous experiments were repeated with selling date set at January 20. This date was chosen because early born lambs in the previous experiments and late born lambs in these experiments would be the same age at selling.

### 8.2.3.4 Results of Late Selling Experiment

The possible outcomes of later lamb selling are, where surplus feed exists, (1) conversion of surplus feed into additional lamb growth, (2) improved pasture control, and hence improved subsequent pasture growth and quality and, (3) a later optimum lambing day to take advantage of the associated higher lambing percentages and early lamb growth rates, while allowing increased time for younger lambs to catch up. Where surplus feed does not exist there is likely to be direct removal of feed from ewes and/or, a reduction in cover at lamb selling which is detrimental to subsequent ewe performance.

The second set of experiments was analysed in the same way as first set. A summary of the maximum and minimum gross margins for each season by stocking rate combination is given in Table 8.8. Decisions producing the maxima are given in Table 8.9, and the

**TABLE 8.8:** Summary of maximum and minimum gross margins (for the various combinations of grazing decisions studied) for each season by stocking rate combination; selling date January 20

Year Type	Average	Wet Autumn	Dry Autumn	Early Spring	Late Spring
Stocking Rate (ewes/ha)					
14					
Maximum	441.1	432.8	406.7	446.2	423.9
Minimum	397.4	369.9	352.0	411.6	376.1
Range	43.7	35.9	54.7	34.6	47.8
16					
Maximum	463.7	489.2	420.5	485.6	436.2
Minimum	384.8	429.0	346.6	421.3	348.7
Range	78.9	60.2	73.9	64.3	87.5
18					
Maximum	475.7	501.5	423.6	509.1	440.0
Minimum	350.4	397.7	Infeasible	391.0	294.0
Range	125.3	103.8		118.1	146.5

**TABLE 8.9:** Decisions leading to maximum gross margin for each season by stocking rate combination; selling date January 20

Year Type	Gross Margin (\$/ha)	Lambing Day	Winter Rotation (Days)	Spring Rotation (Days)	No. Paddocks Retired	Flushing Rotation (Days)
<b>Stocking Rate (ewes/ha)</b>						
<b>14</b>						
Average	441.1	225	120	30	12	15
Wet Autumn	432.8	224	120	15	12	15
Dry Autumn	406.7	228	120	30	6	60
Early Spring	446.2	224	120	15	12	15
Late Spring	423.9	227	120	30	6	30
Mean	430.1					
<b>16</b>						
Average	463.7	234	120	30	10	60
Wet Autumn	489.2	227	120	30	10	15
Dry Autumn	420.5	236	120	30	5	30
Early Spring	485.6	230	120	30	10	30
Late Spring	436.2	239	120	30	5	60
Mean	459.0					
<b>18</b>						
Average	475.7	242	120	30	5	60
Wet Autumn	501.5	237	120	30	5	15
Dry Autumn	423.6	240	120	30	0	30
Early Spring	509.1	240	120	30	5	60
Late Spring	440.0	249	120	30	0	60
Mean	469.8					

relationship between lambing day and gross margin for grazing decisions producing the maxima, appear in Figs. 8.15 to 8.17.

In all seasons and at all stocking rates both maximum and minimum gross margin improved with the later selling date (compare Tables 8.6 and 8.9). At low stocking rates (14 and 16) lamb selling weight increased in all seasons (compare Tables 8.7 and 8.10). In addition there was little effect on lambing percentage of the later selling date. Finally, there was little change to optimum lambing day because later-born lambs still did not catch up the weight difference. (Compare the difference in weight between lambing days 234 and 254 in Table 8.7, with that in Table 8.10).

At 18 ewes/ha the results were the same as above for all but the dry autumn season. In this season the decrease in pasture cover on January 20 detrimentally affected subsequent feed supply, and hence ewe liveweight in the autumn. Lambing percentage declined, and in comparison to the early selling system (see Fig. 8.18), autumn pasture growth rate was reduced, and ewe liveweight did not recover until the following December. The minimum liveweight reached by ewes in the spring was 36.5 kg in the late selling system, which is extremely light. However, a similar liveweight (36.8 kg) was recorded in one year by Suckling (1975) with no increase in death rate, for ewes in farmlot trials.

In spite of the effect on lambing percentage, the decision to sell late in a dry autumn season was vindicated economically by a favourable balance between increased lamb weight and decreased lambing percentage.

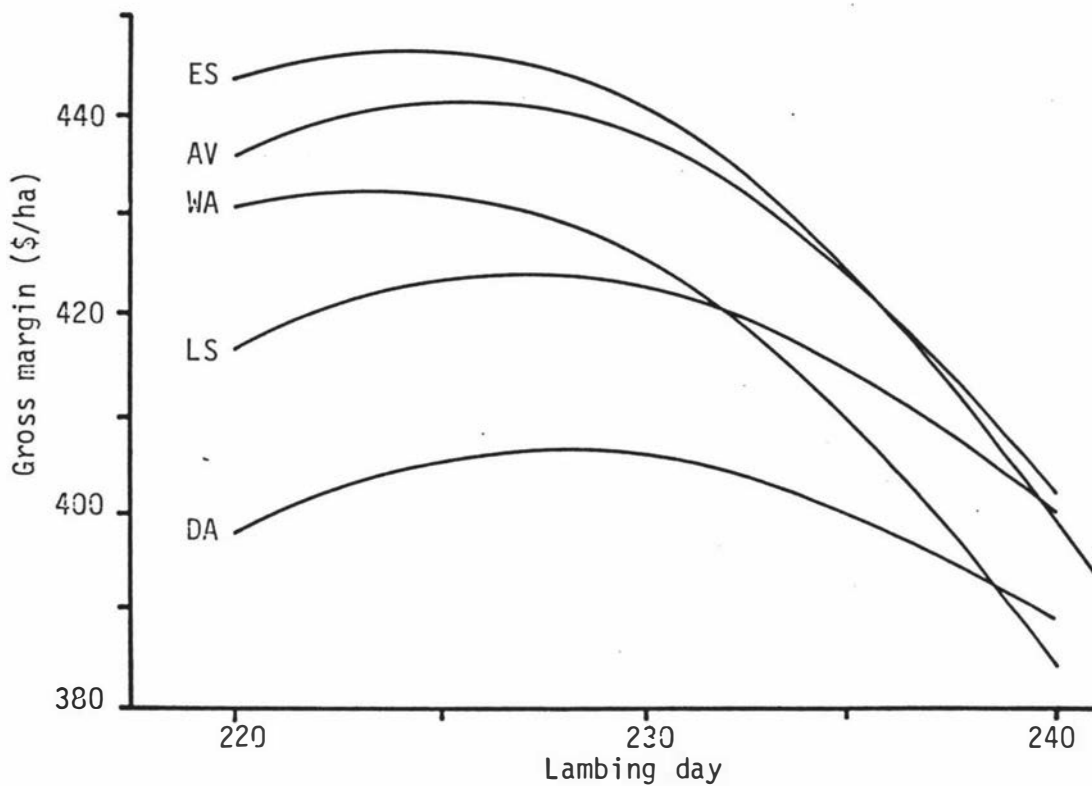


Figure 8.15 Relationships between lambing day and gross margin under grazing decisions producing maximum gross margin in each year at 14 ewes/ha. Selling date January 20. WA = wet autumn, DA = dry autumn, ES = early spring, LS = late spring, AV = average year.

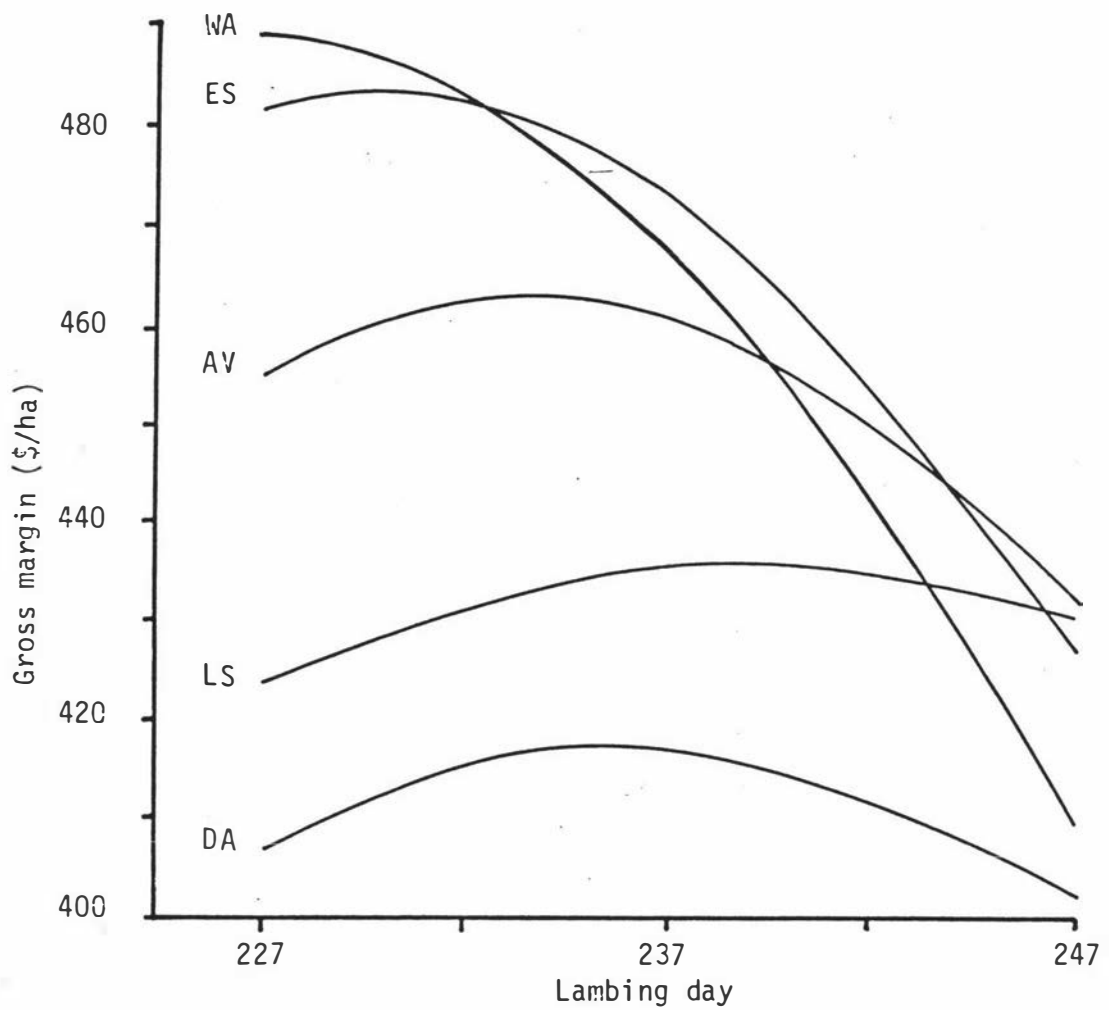


Figure 8.16 Relationships between lambing day and gross margin under grazing decisions producing maximum gross margin in each year at 16 ewes/ha. Selling date January 20. WA = wet autumn, DA = dry autumn, ES = early spring, LS = late spring, AV = average year

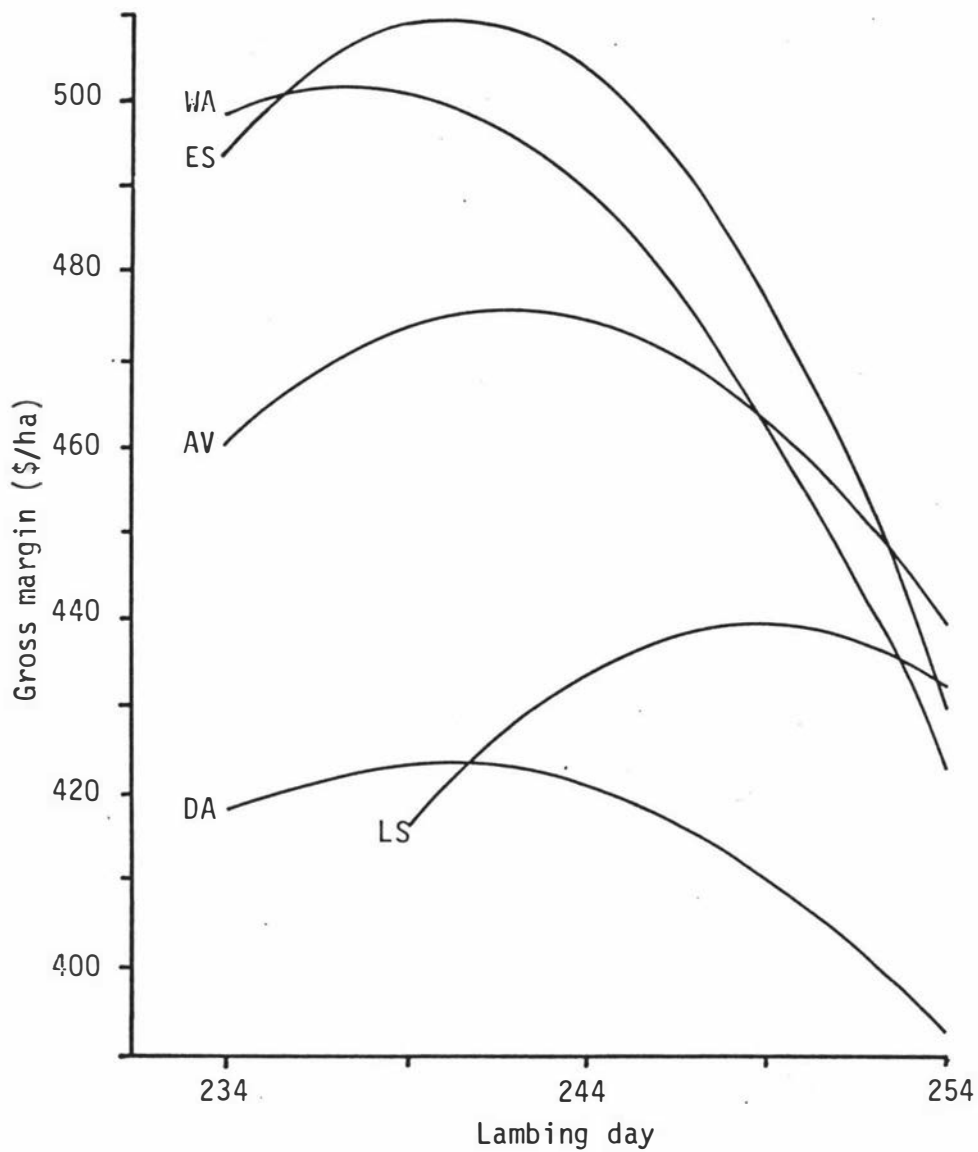


Figure 8.17 Relationships between lambing day and gross margin under grazing decisions producing maximum gross margin in each year at 18 ewes/ha. Selling date January 20. WA = wet autumn, DA = dry autumn, ES = early spring, LS = late spring, AV = average year.

TABLE 8.10: The influence of early and late lambing on the physical components of production in each season at 3 stocking rates. Selling date January 20.†

Season	Stocking Rate (ewes/ha)	Lambing Day	Lambing %	Lamb Selling LWT (kg)	Ewe FLWT (kg)	Stocking Rate (ewes/ha)	Lambing Day	Lambing %	Lamb Selling LWT (kg)	Ewe FLWT (kg)	Stocking Rate (ewes/ha)	Lambing Day	Lambing %	Lamb Selling LWT (kg)	Ewe FLWT (kg)
Average	14	220	108.6	34.1	4.96	16	227	107.0	31.2	4.83	18	234	101.7	30.0	4.65
Wet autumn			107.1	34.1	4.87			108.5	33.8	4.92			106.2	31.2	4.78
Dry autumn			105.8	31.9	4.88			98.8	31.5	4.61			90.1	31.8	4.40
Early spring			108.4	34.8	4.93			108.6	33.0	4.89			104.4	31.5	4.70
Late spring			107.9	32.6	4.96			105.1	29.6	4.81			97.3	28.2	4.57
Average		240	110.6	31.1	4.77		247	110.1	29.7	4.70		254	108.1	27.9	4.49
Wet autumn			108.9	30.2	4.68			108.1	28.6	4.60			105.8	27.2	4.48
Dry autumn			108.8	30.5	4.75			103.3	29.8	4.46			97.9	28.0	4.26
Early spring			110.6	31.0	4.75			110.4	29.5	4.68			108.5	27.4	4.48
Late spring			109.6	30.9	4.76			109.8	28.2	4.68			106.3	27.5	4.47

†Grazing decisions for winter and spring rotation and level of retiring are given in Table 8.9

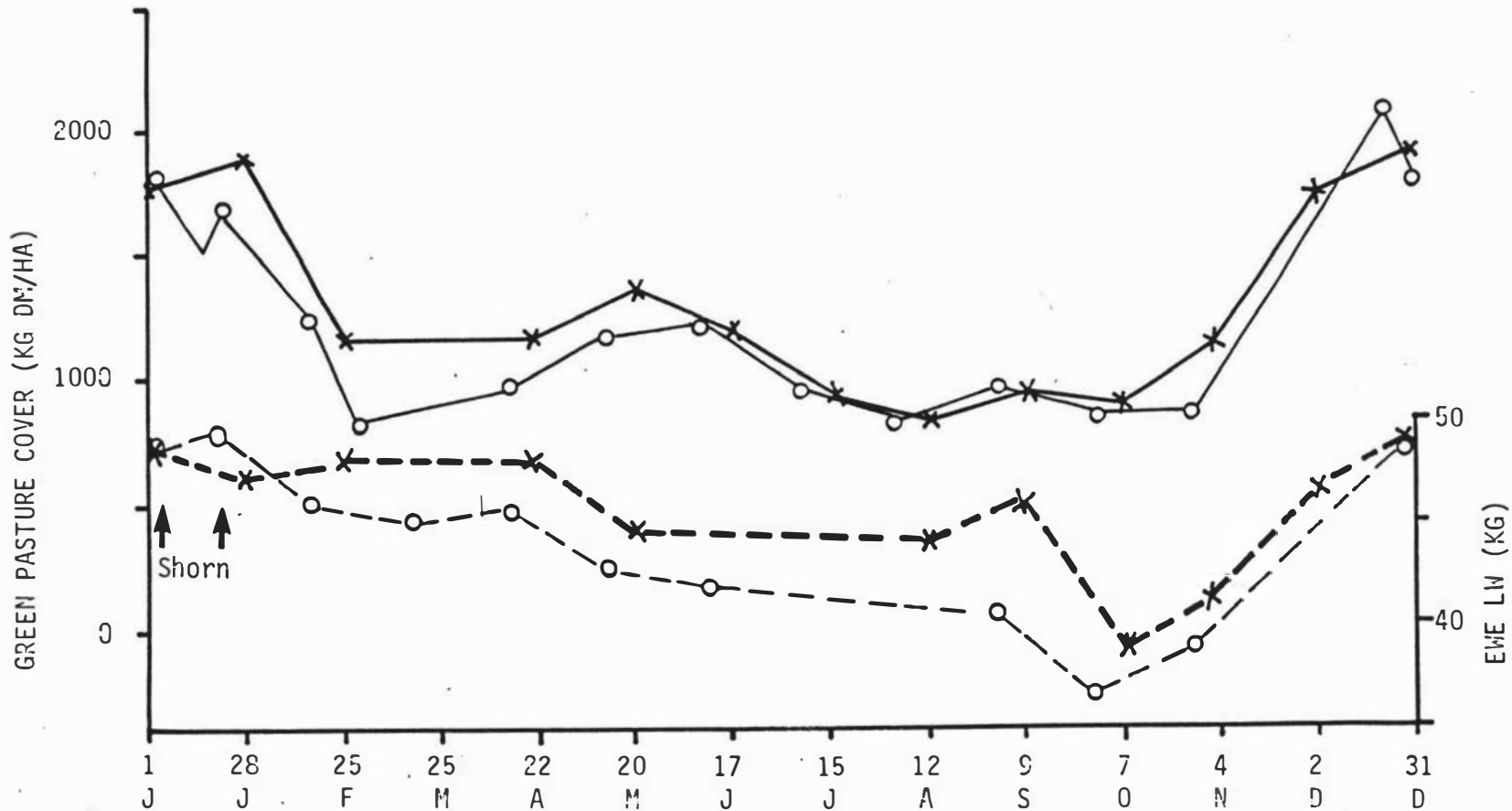


Figure 8.18 Simulated green pasture cover (—) and ewe liveweight (---) in a dry autumn with early (X) or late (O) lamb selling dates at 18 ewes/ha. Other management decisions were lambing day - 244, winter rotation - 120 days, spring rotation - 30 days, flushing rotation - 60 days, number of paddocks retired - 5. Lambing % - early 95.4, late 90.6, lamb selling liveweight, early 28.1 kg, late 31.3 kg. Pasture cover on grazed area only.

The reason for the negligible effect of later selling on ewe performance in other seasons and at low stocking rates was as anticipated, a combination of improved utilisation of feed in late summer, and improved pasture growth rates and reduced pasture senescence in autumn. Fig. 8.19 shows pasture cover and ewe liveweight for early and late selling systems at 18 ewes/ha in an average year. By mid-winter pasture cover and ewe liveweight were similar for both systems.

In conclusion, delaying selling date did not affect previous conclusions about optimum management decisions in any season, except for requiring reductions to the level of retiring. The effects on ewe performance of delaying selling date still further into autumn were becoming apparent from results in a dry autumn at 18 ewes/ha.

#### 8.2.3.5 Selling by Age

An indication of changes that would occur if the system was altered to sell lambs at a given age was gained by plotting the appropriate predicted gross margins for the late lambing and selling date, on to Figs 8.11 to 8.13 from the earlier experiments.

In all cases the attractiveness of later lambing improved, meaning that there are likely to be two important differences from previous conclusions. First, sensitivity of gross margin to lambing day would not be as great, and second optimum lambing day would occur later. These differences illustrate an important point regarding the relationship between the system studied and conclusions reached about the importance of different management decisions. It was decided, however, that since more lambs are likely to be sold than retained on most NIHC farms, the initial choice of system more accurately reflected factors affecting lambing day and selling policy.

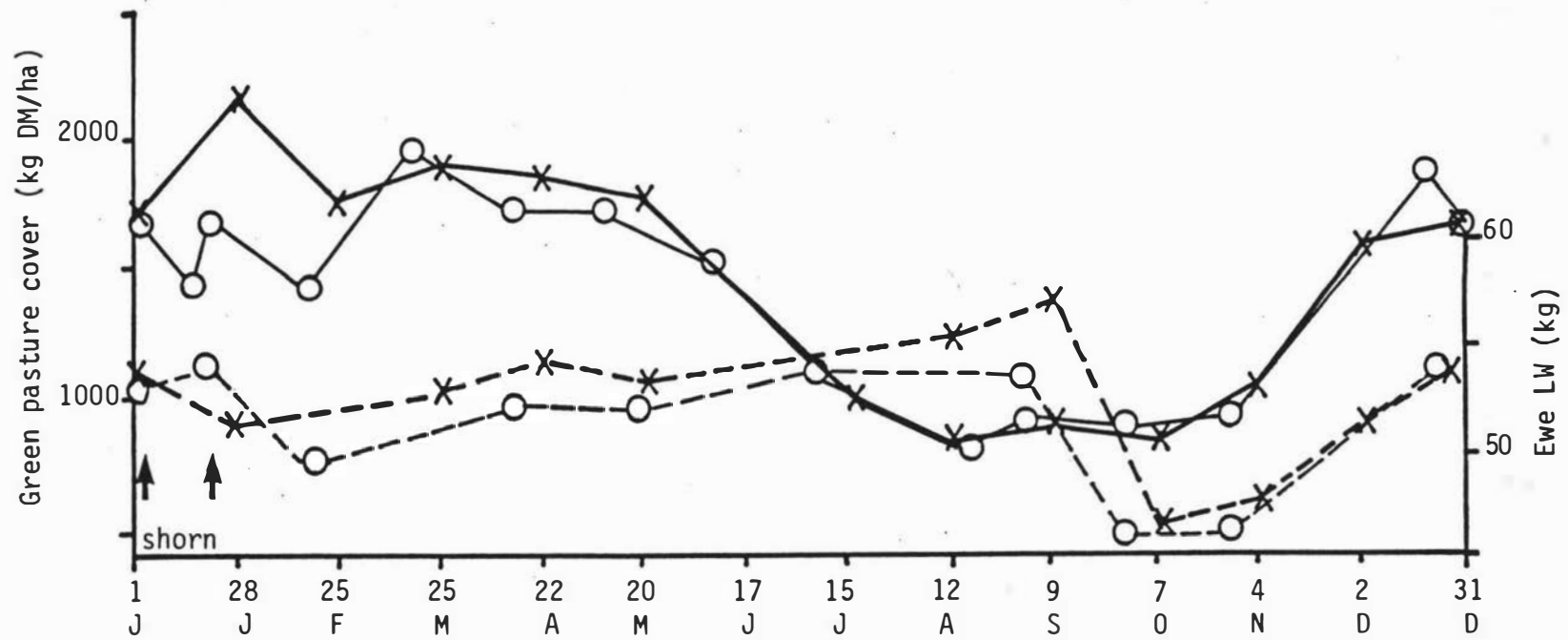


Figure 8.19 Green pasture cover (—), and ewe (liveweight (---)) in an average year with an early (X) and late (O) selling date. Management decisions as in Fig. 8.18. Pasture cover on grazed area only.

#### 8.2.4 Optimal Strategies

So far, optimum management decisions have been described for each year. In reality, not all of the decisions defined as optimal for each year can be implemented because some decisions must be made before the year has been revealed. For example stocking rate, lambing day, and length of winter rotation will have been decided before it is known what the spring will bring, and spring control measures will be in place before late summer-autumn conditions become apparent.

An optimal management strategy needs to maximise output over all years.

Interest was confined to the late selling system since it was clearly superior to the early selling system. The cost<sup>6</sup> of non optimality was derived for each years' optimal management plan, when implemented in every other year. These are shown in Table 8.11. In general, average and poor year strategies proved best when costs were averaged over all seasons.<sup>7</sup> In particular, greater costs occurred when the level of retiring was too great for a year than when it was too low. When the average year plan was changed to incorporate the late spring level of retiring, mean cost was reduced to \$12.43 and \$14.01/ha, at stocking rates 16 and 18 respectively.

Flexibility does however exist to change strategies in the knowledge of seasonal variability, as for example by reducing the level of retiring in a late spring. Costs were therefore derived

<sup>6</sup>Cost was defined relative to maximum gross margin in a particular year.

<sup>7</sup>This assumes each year is received with equal frequency.

**TABLE 8.11:** Reductions from maximum gross margin as a result of implementing optimal decisions for each year

Year Type Decisions	Average	Wet Autumn	Dry Autumn	Early Spring	Late Spring	Mean
14†						
Average††	0	0.80	10.48	0.99	2.29	2.91
Wet Autumn	1.33	0	14.17	0	5.00	4.10
Dry Autumn	19.00	28.97	0	26.55	2.68	15.44
Early Spring	1.33	0	14.17	0	5.00	4.10
Late Spring	14.37	19.48	1.14	20.48	0	11.09
16						
Average	0	18.58	13.49	4.64	39.68	15.28
Wet Autumn	14.32	0	25.66	4.97	53.61	19.71
Dry Autumn	4.67	34.03	0	16.51	3.96	11.83
Early Spring	7.40	3.84	17.75	0	45.60	14.92
Late Spring	10.25	52.32	3.20	28.05	0	18.76
18						
Average	0	11.47	23.0	1.40	41.87	15.55
Wet Autumn	14.92	0	45.2	12.93	73.61	29.33
Dry Autumn	0.90	6.22	0	11.81	51.94	14.17
Early Spring	6.26	19.57	31.0	0	21.87	15.74
Late Spring	21.67	64.69	9.6	49.25	0	29.02

† Stocking rate (ewes/ha)

†† Optimal decisions for these years are given in Table 8.9

in each year when the average year strategy was applied, but with allowances to alter management decisions in the light of knowledge of the season. Decisions open to alteration included, mating day and rotation length at flushing in variable autumns, and spring rotation length and level of retiring in variable springs.

The cost associated with being unable to predict season in advance was very low at all stocking rates (Table 8.12), provided the unexpected season was reacted to appropriately.

Two main conclusions arise from the above analyses. The first is that the best average year strategy was an appropriate strategy to apply across all seasons when flexibility to cope with the seasons was taken into account. The second was that 18 ewes/ha remained the most favourable stocking rate, although the margin was only \$10/ha over 16 ewes/ha. Estimated maximum gross margins, averaged across seasons, were \$428, \$455 and \$465/ha for stocking rates 14, 16 and 18 ewes/ha respectively.

### 8.3 EFFECTS OF INNOVATIONS AND POSSIBLE NEW TECHNOLOGY

The results up until now have been used to establish a bench mark of maximum system performance under the type of management decisions currently employed on most NIHC farms. In this section an attempt was made to investigate the effects of constraints preventing further increases to performance.

Innovations such as strategic use of nitrogen, introduction of temporary crops (e.g. cereal oversowing, Sithamparanathan (1979)) and establishment of specialist pastures, may be profitable. New technology may increase the physiological potential of existing pastures and animals by genetic, chemical or physical means.

TABLE 8.12: Losses from maximum gross margin using average year decisions but taking account of seasonal flexibilities\*

Decisions Stocking Rate/ Year Type	Lambing Day	Winter Rotation (Days)	Spring Rotation (Days)	No. Paddocks Retired	Flushing Rotation (Days)	Loss from Maximum Gross Margin (\$/ha)
14						
Average	225	120	30	12	15	0
Wet Autumn	224	120	15	12	15	0
Dry Autumn	228	120	30	12†	60	9.30
Early Spring	225†	120	15	12	15	0.99
Late Spring	225†	120	30	6	15†	1.24
16						
Average	234	120	30	10	60	0
Wet Autumn	227	120	30	10	15	0
Dry Autumn	236	120	30	5†	30	13.20
Early Spring	234†	120	30	10	60†	6.64
Late Spring	234†	120	30	5	60	2.14
18						
Average	242	120	30	5	60	0
Wet Autumn	237	120	30	5	15	0
Dry Autumn	240	120	30	5†	30	13.50
Early Spring	242†	120	30	5	60	1.40
Late Spring	242†	120	30	5	60	10.96

†Non optimal decisions unable to be changed

\*These decisions formed the optimal grazing decisions for subsequent analyses

The model was used to examine potential rewards to introducing the above in an effort to provide a basis for establishing productive courses of action for future research and development.

Three types of experiment were undertaken. First, the strategic use of nitrogen, an innovation for many NIHC sheep farms, was appraised. Second, the possible role of the new ewe fertility immunisation technology was evaluated. Finally, a number of experiments were conducted in which sensitivity of the system was evaluated in relation to factors affecting potential production from pasture and animals.

The previously defined optimal management decisions at 18 ewes/ha (Table 8.12) were taken as the base from which to start. However to account for possible changes to the stocking rate, per head performance relationship in the new systems, stocking rates of 16 and 20 were also studied. Control management decisions used at 16 ewes/ha were those given in Table 8.12. Management assumed at 20 ewes/ha was the same as at 18 ewes/ha except for lambing day, day 254, and number of paddocks retired, 0. Limited changes to previously optimal grazing decisions were also investigated, owing to the possible unsuitability of these decisions in the new systems.

### **8.3.1 Strategic Use of Nitrogen**

The effects of using nitrogen were simulated by injecting feed into the system in early spring, the period most sensitive to variations in feed supply.

Green DM was added to paddocks with the highest cover on September 1, at 2 rates, 250 and 500 kg DM/ha, over 1/3 or 2/3 of the farm.

Over all seasons, 18 ewes/ha remained optimal for all levels of feed injected. At 20 ewes/ha the system collapsed in the spring when preceded by a dry autumn. This could not be avoided even with the highest level of feed injection. The remaining discussion is therefore confined to the effects at a stocking rate of 18 ewes/ha.

System response to adding 250 kg DM/ha to 2/3 of the farm and 500 kg DM/ha to 1/3 of the farm was very similar. The latter proved marginally better in all seasons by between \$0.35 and \$2.59/ha.

Boosting the system with different amounts of feed had the greatest effect in adverse years (Fig. 8.20). Adding feed made very little difference to gross margins in early springs or following a wet autumn. Despite beneficial effects appearing in early lamb growth rates and ewe liveweights in the above seasons, control problems in late spring were compounded. This prompted investigation into increasing the level of retiring to 8 and 10 paddocks (27 and 33% of farm area, respectively).

Increased level of retiring was not desirable at any level of feed injection for the average year but where 500 kg DM/ha was added over 2/3 of the farm, retiring 8 and 10 paddocks improved performance in early springs and in wet autumns, respectively (see Fig. 8.20).

The major physical effects of adding feed into the system are summarised in Table 8.13 for the 500 kg DM/ha over 2/3 farm treatment.

Small differences in green cover, in the order of 80 kg DM/ha, remained at the end of March, but by mid-August they were gone (0 to 40 kg DM/ha).

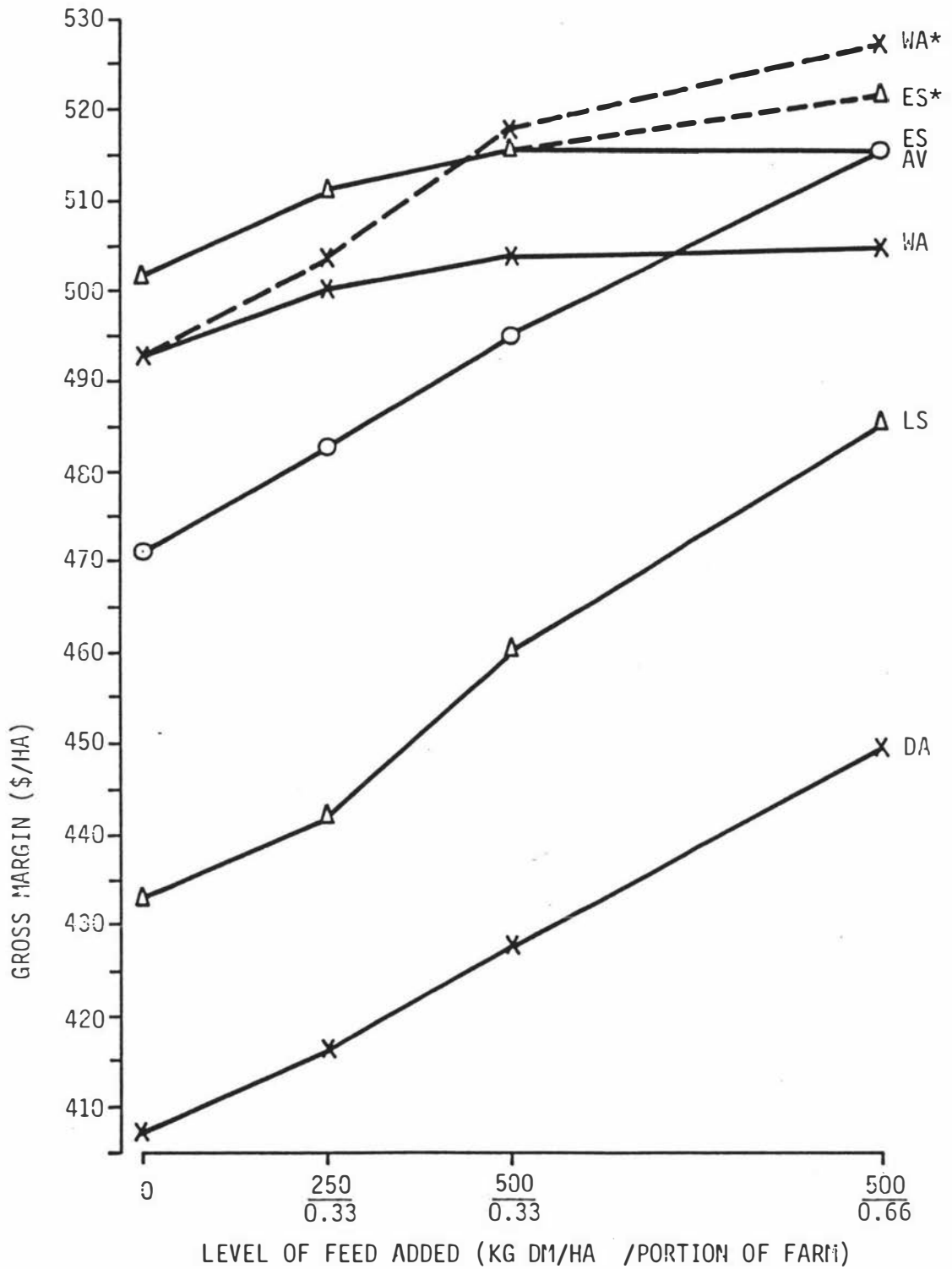


Figure 8.20 Effects of adding feed in spring on gross margin at 18 ewes/ha. WA = wet autumn, DA = dry autumn, ES = early spring, LS = late spring, AV = average. \* = additional paddocks retired - see text.

TABLE 8.13: Selected effects on system performance of 500 kg DM/ha additional feed, supplied to 2/3 of farm on September 1

		Base Levels			Effects					
Stocking Rate	Season	Growth	Consumption	Green	Growth	Consumption	Green	Lamb	Lambing	Ewe
		1/9-27/10 (kg DM/ha)	1/9-27/10 (kg DM/ha)	Cover on 27/10 (kg DM/ha)	1/9-27/10 (kg DM/ha)	1/9-27/10 (kg DM/ha)	Cover on 27/10 (kg DM/ha)	Selling LWT (kg)	%	FLWT (kg)
18	Average	1726	1587	811	+153	+264	+151	+1.7	+3.5	+0.10
	Wet Aut†	1806	1739	882	+148	+191	+205	+1.7	+2.0	+0.02
	Dry Aut	1708	1512	815	+148	+267	+133	+0.6	+6.5	+0.13
	Early Sp††	1981	1700	986	+172	+213	+200	+0.7	+1.6	+0.03
	Late Sp	1567	1381	731	+132	+282	+151	+2.3	+3.7	+0.09

† 10 paddocks retired in plus feed system - see text

†† 8 paddocks retired in plus feed system - see text

The profitability of boosting feed supply in spring obviously depends on the cost of injected feed. Nitrogen currently costs about 86 cents/kg N as urea,<sup>8</sup> not including application costs. Assuming a 10:1 response of green DM/kg N (Luscombe, 1980), the cost of injected feed using nitrogen would be 8.6 ¢/kg green DM. Net benefit per kg green DM added, in this study, is presented in Table 8.14. It is doubtful if an economic response would result from the highest feed addition following a good autumn. Costs will definitely not be recovered if a good spring results. The decision regarding nitrogen application rate can be made with complete knowledge in the former case but not in the latter.

However, assuming equal probabilities of the above years, these results suggest the potential for nitrogen to underwrite the important spring feed flow is significant.

**TABLE 8.14:** Effects on gross margin of additional feed supplied on September 1 (cents/kg DM added)

Feed added Season	Amount by Fraction of Farm kg DM/ha	250*	250*	500*	500*
		1/3 83	2/3 166	1/3 166	2/3 333
Average		13.9	14.4	13.7	13.3
Wet Autumn		12.7	14.8	14.6	10.3
Dry Autumn		10.9	12.6	12.0	12.8
Early Spring		10.1	8.1	7.9	5.8
Late Spring		17.5	20.7	19.8	17.3

<sup>8</sup>November 1983 stock firm price

### 8.3.2 Immunising Ewes

Immunising ewes against their own oestrogens to increase ovulation rates appears to hold great promise for improving system performance, but has not been tested in a complete system. The effects of artificially increasing ovulation rate to 180 and 200% were therefore examined. Twin ovulations were imposed on either 80 or 100% of the ewes. The resulting lamb weaning percentages were in the vicinity of 118 and 129%, respectively. Systems were first compared under existing optimal management for both 16 and 18 ewes/ha then a reduction in the level of retiring, delayed lambing and the consequences of set stocking at lambing, were explored.

In Table 8.15 gross margins for the control systems are compared with gross margins for the artificially increased ovulation rate systems at two lambing days and at the best level of retiring for each season (levels studied were restricted to 0, 5 or 10 paddocks). Some physical differences between the control and the two selected increased ovulation rate systems are presented in Table 8.16.

The advantage of high lambing percentage systems at 16 ewes/ha was primarily due to the need to delay lambing at 18 ewes/ha to ensure system viability in poor seasons. At 18 ewes/ha in dry autumn years, the ewe body weight, ovulation rate relationship appeared to represent a system safeguard against the later collapse of the system in spring.

At 16 ewes/ha the system was able to cope with additional lambs in early spring without undue effect on lamb weight. Consequently full advantage was gained from these extra lambs in consuming surplus spring pasture, and in comparison to the control system, lamb selling

TABLE 8.15: Gross margins for control and increased ovulation rate systems, at 2 lambing days and the best level of retiring†

Stocking Rate (ewes/ha)	Lambing Day Ovulation Rate Season	Control	234		244	
			180	200	180	200
16	Average	461.8 <sup>10</sup>	490.9 <sup>5</sup>	514.9 <sup>5</sup>	470.2 <sup>10</sup>	594.3 <sup>10</sup>
	Wet Autumn	478.9 <sup>10</sup>	515.4 <sup>10</sup>	535.8 <sup>10</sup>	459.3 <sup>10</sup>	495.1 <sup>10</sup>
	Dry Autumn	402.9 <sup>10</sup>	450.7 <sup>5</sup>	461.9	442.2 <sup>5</sup>	492.2 <sup>5</sup>
	Early Spring	483.3 <sup>10</sup>	506.3 <sup>10</sup>	541.3 <sup>5</sup>	471.5 <sup>10</sup>	462.6 <sup>10</sup>
	Late Spring	431.9	453.5	468.0	453.9 <sup>5</sup>	466.0
	Mean	451.8	483.3	504.4	459.4	484.0
	Lambing Day		242		252	
18	Average	471.6 <sup>5</sup>	501.3	518.9	486.1 <sup>5</sup>	510.0 <sup>5</sup>
	Wet Autumn	493.6 <sup>5</sup>	521.4 <sup>5</sup>	535.2	467.5 <sup>5</sup>	502.6 <sup>5</sup>
	Dry Autumn	407.5 <sup>5</sup>	448.5	nfeasibl	441.3	453.9
	Early Spring	502.9 <sup>5</sup>	526.3	558.0	447.6 <sup>5</sup>	514.1 <sup>5</sup>
	Late Spring	428.1	413.8	412.2	455.0	463.8
	Mean	460.7	482.3	-	465.5	488.9

† Superscripts represent the number of paddocks retired

TABLE 8.16: Some physical differences between control and selected increased ovulation rate systems

Stocking Rate (ewes/ha)	Year	Control Systems							Ovulation Rate = 200% Systems Lambing day 234						
		Green Cover 27/10 (kg DM/ha)	Ewe LWT 27/10 (kg)	Ewe* LWT 20/1 (kg)	Lamb LWT 20/1 (kg)	Ewe FLWT (kg)	Lambing %	Consumption 1/9-20/1 (kg DM/ha)	Green Cover 27/10 (kg DM/ha)	Ewe LWT 27/10 (kg)	Ewe* LWT 20/1 (kg)	Lamb LWT 20/1 (kg)	Ewe FLWT (kg)	Lambing %	Additional Consumption 1/9-20/1 (kg DM/ha)
16	Average	852	52.9	59.5	32.0	4.82	108.1	4768	-40	-2.6	-1.8	-1.9	0.01††	129.4	256
	Wet Autumn	998	58.0	63.1	33.0	4.85	108.7	5041	-91	-2.9	-2.1	-1.6	0.02††	129.5	234
	Dry Autumn	823	42.8	52.5	32.4	4.52	95.2	4454	-51	-2.5	-1.8	-4.2	0.08††	127.5	249
	Early spring	1039	55.6	61.8	33.3	4.83	109.1	5005	-56	-2.5	-1.7	-1.6	0.03	129.6	278
	Late spring	777	48.4	55.8	30.4	4.78	105.9	4455	-30	-2.5	-2.0	-2.6	-0.01	129.3	196
18	Lambing day 252														
	Average	811	47.1	55.1	30.2	4.64	105.3	5088	169	0.4	0.7	-2.6	-0.11	129.3	301
	Wet Autumn	882	53.7	59.9	30.6	4.74	107.6	5332	246	-0.4	-0.5	-3.4	-0.20	129.9	169
	Dry Autumn	815	38.4	49.5	31.9	4.26	89.2	4863	153	1.1	0.8	-5.1	-0.06	122.8	321
	Early Spring	986	50.2	58.1	31.5	4.68	107.6	5379	233	0	-0.4	-3.8	-0.14	129.6	128
Late Spring	731	42.5	51.0	28.1	4.59	103.6	4654	122	1.1	0.9	-2.3	-0.12	128.5	362	

\* Full woolled

† Multiply by 1.15 and divide by stocking rate to get consumption/head

†† Better pasture quality in summer and autumn improved wool growth

weight was only reduced due to the increased proportion of twin lambs. Delayed lambing, however, reduced lamb selling weight (Table 8.16) both through reductions in lamb age and the increased proportion of twins.

Additional spring consumption resulting from increased numbers of lambs only amounted to a maximum of about 5% of total consumption over the period September 1 to January 20 (Table 8.16). This nevertheless was enough to reduce the level of retiring required in most years (Table 8.15).

The model has shown, in theory, the advantage to rotational grazing over set stocking at lambing. This uses the feed built up by the winter rotation most efficiently to maximise early spring pasture growth rates. However no account has been taken of animal behavioural problems that may limit the practicability of this management, particularly at high lambing percentages. Tables 8.17 and 8.18 mirror Tables 8.15 and 8.16 for the situation where ewes are set-stocked at lambing. Profitability was reduced quite markedly as a result of set stocking at lambing (compare Tables 8.15 and 8.17). The differential between rotational and set-stocking systems increased as lambing percent increased. If increases in lambing percentage determine that ewes cannot be rotationally grazed immediately after lambing, the advantage gained from the extra lambs may be very meagre, based on the current gross margin function. Indeed at the previously optimal stocking rate (18) a loss would result.

The values in Table 8.19 reflect break-even costs per ewe for any treatment used to artificially increase lambing percent by the respective margins.<sup>9</sup> The potential for any treatment used to increase

<sup>9</sup>Because management for the increased ovulation rate systems were specified at the best level of retiring for each year the same criteria were applied to the control systems. This meant that in Table 8.18, gross margins in the control dry autumns were increased to \$417.28 and \$422.73 at stocking rates 16 and 18, respectively.

**TABLE 8.17:** Gross margins for control and increased ovulation rate systems under set stocking at lambing†

Stocking Rate (ewes/ha)	Lambing Day Ovulation Rate Year	Control	234		Control	244	
			180	200		180	200
16	Average	431.2 <sup>5</sup>	460.7 <sup>5</sup>	475.1 <sup>5</sup>	430.2 <sup>10</sup>	449.3 <sup>5</sup>	476.0 <sup>5</sup>
	Wet Autumn	463.4 <sup>10</sup>	494.6 <sup>10</sup>	514.2 <sup>5</sup>	426.4 <sup>10</sup>	464.0 <sup>10</sup>	479.0 <sup>5</sup>
	Dry Autumn	387.9 <sup>5</sup>	410.5 <sup>5</sup>	412.0	389.9 <sup>5</sup>	419.1 <sup>5</sup>	432.3 <sup>5</sup>
	Early Spring	459.6 <sup>10</sup>	487.7 <sup>5</sup>	514.9 <sup>5</sup>	442.0 <sup>10</sup>	468.7 <sup>10</sup>	491.2 <sup>5</sup>
	Late Spring	398.9 <sup>5</sup>	406.5	413.2	403.6 <sup>5</sup>	415.0 <sup>5</sup>	421.8
	Mean	428.2	452.0	465.9	418.4	443.2	460.1
	Lambing Day		242			252	
18	Average	434.0 <sup>5</sup>	456.3	468.3	439.7 <sup>5</sup>	456.7 <sup>5</sup>	476.0
	Wet Autumn	463.5 <sup>5</sup>	489.4	497.3	436.7 <sup>5</sup>	503.5 <sup>5</sup>	503.3 <sup>5</sup>
	Dry Autumn	Infeas.	Infeas.	Infeas.	389.0	413.9	Infeas.
	Early Spring	467.8 <sup>5</sup>	494.7	513.9	457.5 <sup>5</sup>	487.5 <sup>5</sup>	500.7 <sup>5</sup>
	Late Spring	388.4	368.2	364.0	396.3	407.2	403.2
	Mean	-	-	-	423.8	453.7	-

† Subscript represent the number of paddocks retired

TABLE 8.18: Some physical differences between the control† and the increased ovulation rate systems under set stocking at lambing

Stocking Rate (ewe/ha)	Year	Green Cover 27/10 (kg DM/ha)	Ewe LWT 27/10 (kg)	Ewe LWT 20/1 (kg)	Lamb LWT 20/1 (kg)	Ewe FLWT (kg)	Lambing %	Additional Consumption 1/9-20/1 (kg DM/ha)
Lambing Day 234								
16	Average	-102	-8.0	-5.7	-3.7	-0.05	128.4	- 22
	Wet Autumn	-151	-5.1	-3.8	-2.8	-0.03	129.4	181
	Dry Autumn	- 87	-6.8	-4.6	-6.5	-0.03	126.3	- 65
	Early spring	-151	-7.7	-5.4	-3.1	-0.01	129.2	35
	Late spring	- 44	-6.7	-4.9	-5.1	-0.09	128.1	-101
Lambing Day 252								
18	Average	- 11	-2.9	-2.6	-4.1	-0.13	129.0	91
	Wet Autumn	- 13	-3.7	-3.1	-3.4	-0.17	129.7	118
	Dry Autumn				Infeasible			
	Early Spring	- 33	-4.9	-4.1	-4.3	-0.17	129.3	- 8
	Late Spring	- 48	-6.5	-5.2	-5.0	-0.15	127.1	27

† See Table 8.16 for control system features

ovulation rate will obviously depend on its cost in relation to these. Returns per ewe were slender at 18 ewes/ha, and it may be seen that they favoured the early lambing day when the dry autumn season was not considered. It is possible that returns may be further improved at 18 ewes/ha in conjunction with the use of nitrogen to reduce the effects of a late spring. However, it is clear that profitability will increasingly favour the lower stocking rate where a cost is attached to increasing ovulation rate.

**Table 8.19:** Breakeven costs per ewe (\$) for increasing ovulation rate over a range of seasons

Stocking Rate Lambing Day Ovulation Rate	16 234		18 242		18 252	
	180	200	180	200	180	200
Year						
Average	1.82	3.32	1.65	2.63	0.80	2.14
Wet Autumn	2.28	3.55	1.54	2.31	-1.45	0.50
Dry Autumn	2.09	2.78	1.43	infeasible	1.03	1.73
Early Spring	1.44	3.63	1.30	3.06	-1.41	0.63
Late Spring	1.35	2.26	-0.80	-0.85	1.49	1.98
Mean	1.80	3.11	1.02	1.42†	0.76	1.40

†Dry autumn taken as 0, as wouldn't immunise in these seasons

### 8.3.3 Effects of Hypothetical Changes to Factors Affecting Pasture and Animal Productivity

Within the framework of concepts represented in the model, the relative importance of several factors affecting pasture and animal performance were investigated in relation to system performance. This was done by assessing the sensitivity of system output to changes in one factor at a time, under a given management strategy.

Increases in gross margin due to each factor were determined relative to gross margin under previously defined optimal grazing decisions at 18 ewes/ha (see Table 8.12).<sup>10</sup>

#### 8.3.3.1 Animal Factors

Effects on system profitability, of: increases to potential fleece weight, removal of the winter depression in potential wool growth rates, decreased lamb and ewe mortality rates, and increased voluntary intake, are shown in Fig. 8.21.

Levels of the factors studied were: (1) ewe mortality rate; zero mortality, (2) lamb mortality rate; 6 and 12 percentage unit reductions to model determined mortality, (3) potential wool growth rates; plus 10 and 20% at all levels of nutrition, (4) voluntary intake; plus 10 and 20%, and (5) winter potential wool growth rates; replaced by autumn potential growth rates.

Responses were considered at both 16 and 18 ewes/ha. Other management decisions remained at levels given in Table 8.12 for the respective stocking rate, except for the retiring decisions which were

<sup>10</sup>Mean gross margin across all years from simulating the decisions at 18 ewes/ha in Table 8.12 was \$460/ha. This differs from \$465/ha given in Section 8.2.4, which was an estimated value from the fitted polynomial.

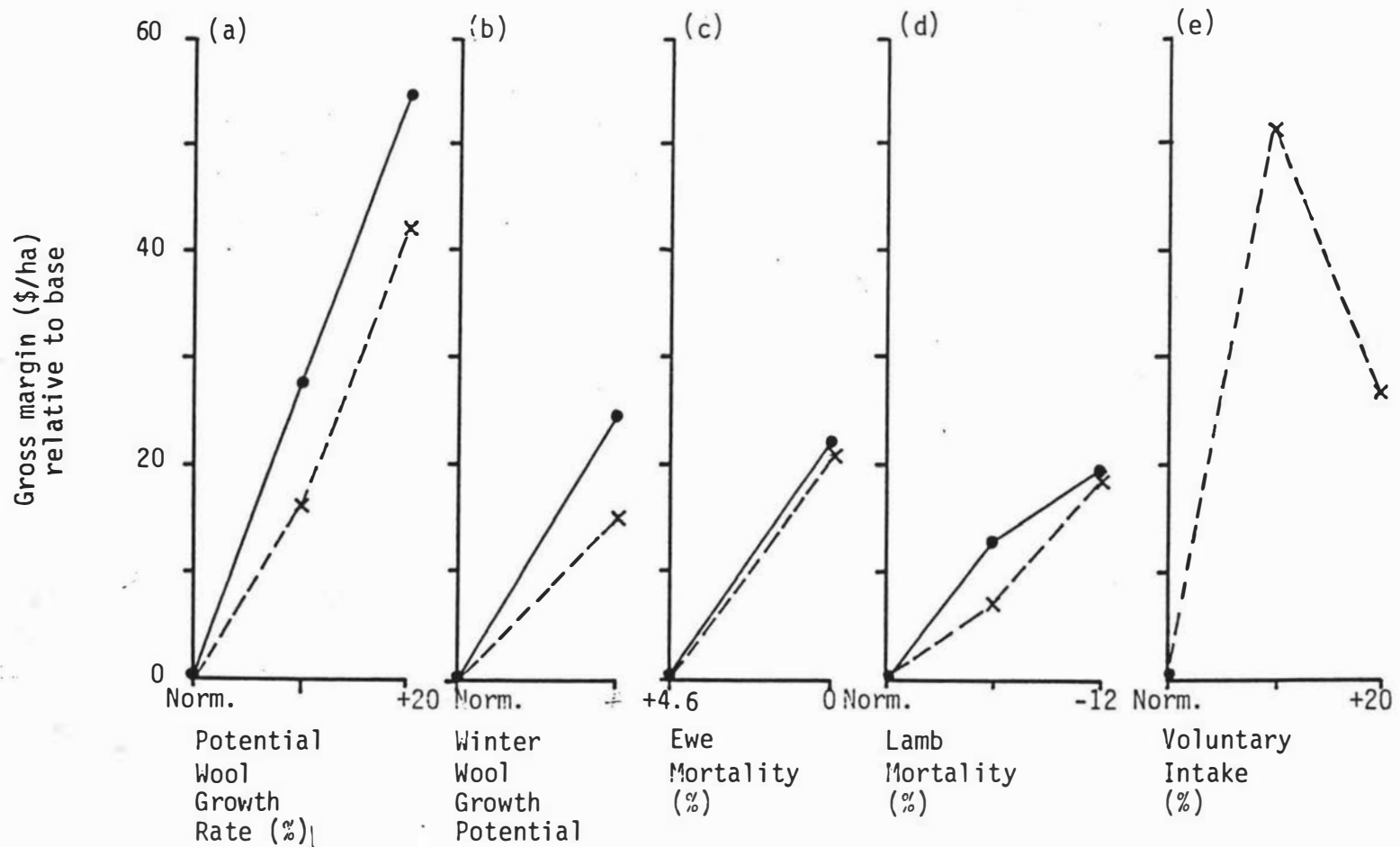


Figure 8.21 Gross margin advantage (mean over all years) for hypothetical animal factor systems, relative to base system at stocking rate 16 (---) and 18 ewes/ha (—). Base system was 18 ewes/ha with optimal grazing management decisions (see Table 8.12).

altered where necessary to ensure that the system performance was not restricted by an excessive level of retiring. Specifically, level of retiring was set to zero for the voluntary intake analyses (in control and hypothetical systems). It was also set to zero in dry autumn seasons for the reduced lamb and ewe mortality rate analyses, and in the average year for the latter analysis.

Major results from the experiment were:

(a) Increases in potential wool growth were mirrored exactly in actual wool growth at both stocking rates (i.e. plus 10 and 20%), with little or no effect on other performance parameters. Further, this result was consistent across all years (Table 8.20). The small amount of additional energy required for extra wool production caused a negligible reduction in ewe liveweight throughout the year.

(b) The removal of the winter depression in wool growth responses lifted annual fleece weight in the order of 9.5%, with once again, little effect on other performance parameters. In practice this may possibly be achieved by hormonal adjustment techniques such as thyroxine implants (Hart, 1955).

(c) Increases to voluntary intake in the present systems led to greater advantages at 16 ewes/ha than at 18 (Fig. 8.21e). At 18 ewes/ha, increases in consumption over spring and early summer excessively reduced pasture cover in the autumn. This in turn reduced fleece weights, lambing percent and gross margins in all years except wet autumns. In dry autumns, it caused the system to collapse. Similar trends began to arise at the highest level of voluntary intake at 16 ewes/ha (Table 8.20), but at the lower level substantial increases were recorded in all components of production (Table 8.21).

TABLE 8.20: Seasonal differences in gross margin, relative to control systems at best stocking rate (animal factors)

Factor	Factor Level	'Best' Stocking Rate	Year				
			Average	Wet Autumn	Dry Autumn	Early Spring	Late Spring
Potential Wool Growth Rate	+10%	18	27.4	29.2	24.7	28.1	27.7
	+20%	18	54.5	58.3	49.4	56.0	55.5
Winter Wool Growth Rate	see text	18	24.4	27.1	20.0	24.7	24.5
Voluntary Intake	+10%	16	71.9	66.6	66.9	80.3	14.5
	+20%	16	37.6	75.3	18.7	42.3	5.0
Lamb Mortality	- 6%	18	7.4	18.2	26.8	12.3	-0.3
	-12%	18	12.6	30.9	37.1	19.5	-2.4

**TABLE 8.21:** Physical differences between the control and the increased voluntary intake system at 16 ewes/ha

Year	Lamb LWT 20/1 (kg)	Lambing %	Wool Wt (kg/ha)
Average	3.5	3.8	4.2
Wet Autumn	3.6	2.0	3.7
Dry Autumn	3.6	4.1	2.6
Early Spring	4.2	2.8	4.3
Late Spring	0.8	-0.1	1.4

Effects of increased voluntary intake were greatest when there were no management controls on intake, i.e. under set stocking. Consumption over the period September 1 to January 20 increased as a percentage of annual consumption (Table 8.22). Consequently more efficient utilisation of spring feed and increased ewe and lamb growth rates resulted. Improved control over pastures in late spring was also partly responsible for improved ewe growth rates in autumn, owing to improved pasture quality. However the effect of increased voluntary intake in a late spring year was to greatly reduce spring pasture growth rates, because the increased grazing pressure suppressed the build up of pasture cover well into spring. This was the reason for poorer overall ewe and lamb responses in the late spring year.

TABLE 8.22: Effects of increased voluntary intake on consumption patterns (mean over all seasons 16 ewes/ha)

System	Annual Consumption (kg DM/ha)	Annual Growth (kg DM/ha)	% Total Consumption between 1/9-20/1	Annual Utilisation Rate (%)
Control	8172	13260	55.1	61.6
VI (+10%)	8783	12825	57.9	68.5
VI (+20%)	8438	11256	58.5	75.0

(d) The effects of decreased lamb mortality were similar to those where lambing percent was increased through increasing ovulation rate. The major difference was that the effect on ewe liveweight of rearing more lambs, was reflected in reduced ovulation rates. This meant that the full 6 and 12% increase in lambing percentage was not realised, and was particularly evident in the late spring year (Table 8.23).

Table 8.23: Physical differences between the control and the hypothetical lamb mortality (-12%) system at 18 ewes/ha

Year	Lamb LWT 20/1 (kg)	Lambing %	Wool Wt (kg/ha)	Lamb LWT (kg/ha)	Ovulation Rate (eggs/ewe)
Average	-0.9	7.7	-1.5	24.3	-0.05
Wet Autumn	-0.6	10.2	-0.5	44.0	-0.01
Dry Autumn††	-0.6	10.4	0.6	47.9	+0.03
Early Spring	-0.8	8.7	-1.3	32.1	-0.03
Late Spring	-0.2	2.1	-2.2	13.8	-0.15

†† 5 fewer paddocks retired than in control system

(e) Reduced ewe mortality resulted in an increased gross margin owing to reduced ewe replacement costs, and increased wool weights/ha. The change in lambing percentage (Table 8.24) reflected the balance between the additional lambs reared on the additional ewes and the reduction in ovulation rate connected to lower ewe liveweight in spring, caused by a higher spring stocking rate.

**Table 8.24:** Physical differences between the control and the zero ewe mortality system at 18 ewes/ha

Year	Lamb LWT 20/1 (kg)	Lambing %	Wool Wt (kg/ha)	Lamb LWT (kg/ha)	Ovulation Rate (eggs/ewe)
Averagett	-0.5	6.2	4.4	23.1	+0.01
Wet Autumn	-0.8	5.1	3.6	12.3	-0.01
Dry Autumn††	-0.5	4.7	3.8	19.0	+0.01
Early Spring	-1.0	3.3	2.4	- 1.6	-0.04
Late Spring	-0.4	-3.3	1.2	-23.9	-0.16

††5 fewer paddocks retired than in control system

Overall, two major conclusions emerged from the above results. Firstly, the apparent reward to increasing fleece growth potential is comparable, if not greater, than that from increasing lambing percentage and is less subject to seasonal variability. Secondly, increases to voluntary intake may provide the best means of achieving greater efficiency of feed utilisation, other animal responses being equal. A higher voluntary intake allowed higher effective stocking rates, and animal growth rates, to be achieved in times of surplus, while having relatively little effect during times of feed restriction.

### 8.3.3.2 Pasture Factors

Sensitivity of the system to changes in a range factors influencing pasture production are shown in Fig. 8.22. Mean responses range from mediocre at best, to inferior at worst. However, in many cases this probably reflected the unsuitability of the grazing decisions for capitalising on the changing feed supplies induced, especially in good years. In poor years, responses were favourable in all cases at 18 ewes/ha (Table 8.25), but not at 20 ewes/ha.

The temperature function was altered arbitrarily by shifting the entire function by  $-2^{\circ}\text{C}$  to represent a more active cool season pasture. As a result winter pasture growth rates (between 12/5 and 1/9) were higher by between 25 to 29% in the hypothetical systems. This, in conjunction with good early spring growth rates, produced much higher spring pasture covers than in the control systems, which in above average seasons severely compounded pasture control and quality problems in summer. In poor years, however, system performance was dramatically improved by increases to ewe and lamb weights in the spring (+10.2 and +2.2 kg respectively in late springs).

Not unexpectedly, dry autumn years were most favoured by increases of 5 and 10% to transpiration efficiency and by reductions in the critical soil moisture level at which pasture succumbs to drought, by increasing senescence (Table 8.25). With the former, improved soil moisture conditions in late December and January produced surplus feed at this time (+450 to +520 kg DM/ha). In dry autumns, feed transferred from this surplus, plus additional growth promoted by improved use of limited autumn rainfall produced desirable effects on both autumn consumption (+232 kg DM/ha from

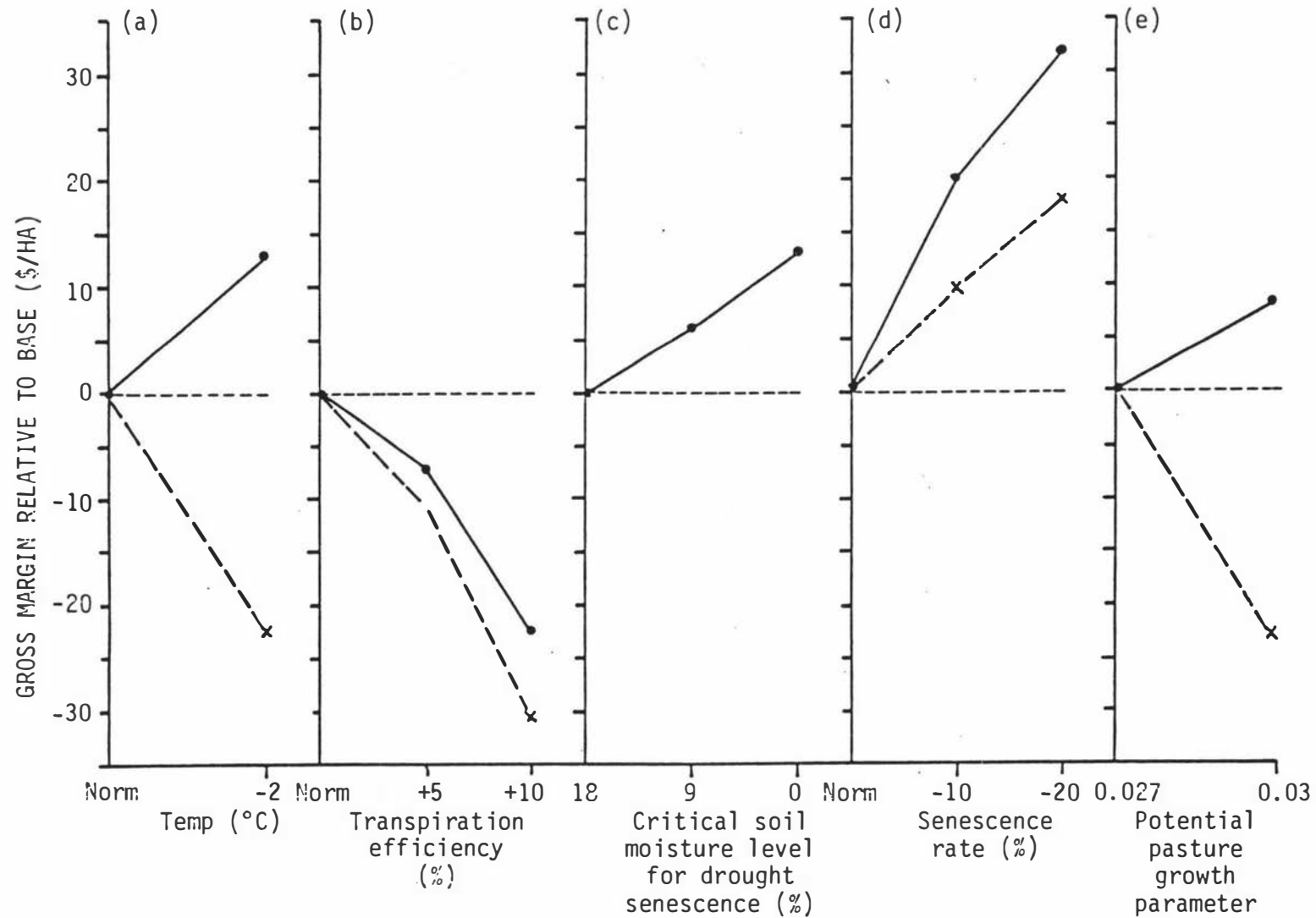


Figure 8.22 Gross margin advantage (mean over all seasons) to hypothetical pasture factor systems at stocking rate 18 (—) and 20 ewes/ha (---). Base system was 18 ewes/ha with optimal decisions.

TABLE 8.25: Seasonal differences in gross margin, relative to control systems at best stocking rate (pasture factors)

Factor	Factor Level	'Best' Stocking Rate	Year				
			Average	Wet Autumn	Dry Autumn	Early Spring	Late Spring
Temperature	- 2 °C	18	12.1	-53.0	65.1	-21.2	64.0
Transpiration Efficiency	+10%	18	-23.1	-56.2	25.3	-39.7	-19.1
Critical Soil Moisture for Drought Senescence	0	18	9.8	- 1.0	42.7	2.0	14.0
Senescence Rate	-20%	18	43.7	0.2	53.2	4.5	58.3
Potential Pasture Growth	0.03	18	4.0	-44.9	66.9	-32.7	48.2

†Base system was 18 ewes/ha with optimal decisions

January 20 to April 14), and pasture cover at the beginning of winter (+678 kg DM/ha on April 14).

Following a reduction in the critical soil moisture parameter (DRTD) from 18% to zero available soil moisture, more green DM was transferred forward to support autumn consumption in dry years. In moist years, soils seldom dried out so there was little or no effect from reducing DRTD.

As basic senescence rates were decreased, greater forward transfer of feed took place. When the transfer was towards a period of high demand (e.g. spring) from a period of less demand (e.g. winter), it encouraged future consumption, and/or growth. For instance, in a late spring year, despite a higher pasture cover on April 14 (+ 312 kg DM/ha) in the '-20%' senescence rate system, green pasture losses from the system by September 1 were similar to the control system (1136 compared to 1133 kg DM/ha). The net result was a 221 kg DM/ha advantage in cover on September 1 and additional net consumption of 88 kg DM/ha (additional consumption minus additional growth) over winter. Obviously in good seasons, where the system is less sensitive to feed transfers, or where such transfers produce pasture control problems, advantages from reduced senescence rates decline.

Additional feed produced by increasing the potential pasture growth parameter (PSlope) from 0.027 to 0.03, with the accompanying 10-day advance in reproductive growth, was either used, or transferred, to advantage in poor seasons. However in average and good seasons symptoms of under-stocking occurred. Increasing stocking rate to 20 ewes/ha in the latter seasons still left gross margins \$55/ha below the mean of these seasons in the base system. Part of

the reason for this was almost certainly due to an excessive delay in lambing day at 20 ewes/ha under these conditions, as evidenced by relatively high pasture covers in spring (1388 kg DM/ha on October 27 in an average year).

In general, the foregoing all suggest that attention will need to be paid to a number of aspects of grazing management in good years if changes to potential pasture production are to be reflected in favourable animal responses. In particular, advancing lambing day to take advantage of improved spring conditions, and maybe increasing stocking rate and level of retiring, in late spring, will need to be considered. However, only in predominantly dry summer regions is attention to drought-tolerant species likely to be profitable.

#### 8.4 SENSITIVITY TO AN EXTENDED RANGE OF PARAMETERS

All the conclusions reached in this Chapter have been based on the underlying assumption that model structure and parameter values are accurate. As previously indicated, a fair degree of confidence was gained in the model prior to experimentation. However it was decided to test, within the context of a well defined system, the sensitivity of model output to arbitrary changes to a range of parameters which had not been specifically subject to calibration. Despite objections raised to this form of sensitivity analysis in Section 3.4.4, it appeared that there was no other means of formally assessing the effects of possible incorrect specification of these parameters. The system chosen was the optimal system at 18 ewes/ha, in an average year.

The parameters tested are described in Table 8.26 and sensitivity of the major components of output to changes in these parameters is given in the same Table.

TABLE 8.26: Results of sensitivity analysis on selected parameters

Parameter Number	Description and Effect of Parameter	Perturbation	Sensitivity							
			Gross Margin (\$/ha)		Lamb Selling LWT (kg)		Lambing %		Wool Weight (kg/ha)	
			+	-	+	-	+	-	+	-
1	Maintenance factor for grazing hill country	±10%	-88.5	54.2	-3.9	2.6	-7.0	5.1	0.7	-1.4
2	Parameter reducing VI above 50 kg LWT	-20%		1.1		0		0.1		0.4
3	Water holding capacity A horizon and therefore of B	± 5 mm	0.6	- 0.8	0	0	0.1	-0.1	0	0
4	Water holding capacity B horizon and total profile	±15 mm	- 1.5	-31.6	0	-1.4	-0.6	-1.3	0.2	-1.5
5	Commencement of reproductive pasture growth	±10 days	-13.3	2.3	-0.7	0.2	-0.7	0	-0.3	-0.2
6	Substitution of milk for grass in suckling lamb	±10%	-14.8	6.6	-1.2	1	0.6	-1.1	0.6	-0.6
7	Suckling lamb VI	±10%	29.4	-85.7	3.5	-5.1	-2.9	0.3	-2.0	0.3
8	Parameter controlling intake/cover relationship under set stocking (+ = graze harder)	±10%	- 3.5	- 1.2	0	-0.1	-0.5	-0.1	-0.3	0.1
9	Parameter influencing cover restriction to intake at different allowances (+ = greater restriction)	±10%	1.2	- 1.5	0.1	-0.1	0.1	-0.1	0	0
10	Parameter influencing proportion of intake achieved at a given allowance (+ increases intake)	±10%	-11.4	8.5	-0.7	0.6	-0.6	0.2	0.2	-0.3
11	Days per paddock when use set stock function for intake rather than allowance function	4		-80.9		-3.6		-5.4		-0.1
12	Slope of VI/pasture quality function (+ = greater intake at given quality)	±10%	5.4	-79.0	-1.2	1.7	4.0	-16.6	2.9	-9.9
13	Slope of diet selection function (+ increases digestibility of diet selected relative to pasture digestibility)	±10%	5.0	-113.5	0.2	-4.1	0.3	-8.5	0.1	-4.7
14	Slope of green cover/reduction in digestibility function (+ = greater reduction/unit green cover)	±20%	-29.5	6.3	-0.5	-0.4	-4.0	2.1	-2.2	1.2
15	Maximum pasture digestibility as affected by time (providing not greater than 80%)	±10%	50.8	-154.1	1.7	-4.5	4.8	-15.6	2.2	-8.1

There was considerable sensitivity of output to changes in a number of the parameters, but equally no apparent effect of others. In some cases the latter was due to choice of system and raises the importance of this factor in determining parameter sensitivity. For instance, parameter 2 is important only beyond the upper limit of ewe liveweight attained in the present system, and pre-grazing pasture levels remained above the most responsive zone for parameter 9 in the system studied. Positive changes to parameter 14 had little affect owing to the standard of pasture control already achieved, whereas for parameter 13, relative insensitivity to positive change was due instead to the presence of upper seasonal constraints on digestibility in the model.

Other examples of relative insensitivity were due to positive effects in one part of the system being cancelled by negative effects in others. For example, increasing the slope of the pasture quality, intake function (parameter 12) caused a marked increase in autumn consumption and hence lambing percent and fleece weight, but it reduced early spring pasture cover, and consumption, which in turn reduced lamb growth rate.

The considerable sensitivity to level of maintenance requirements (parameter 1) was noteworthy but the implications of this result are clear. The only affect, other than on energy supplied for productive purposes, was on lamb intake capacity, which is related to lamb liveweight. Voluntary intake of the suckling lamb (parameter 7) also had a major influence on system performance through its affect on lamb weight and ewe liveweight (negatively correlated). The latter effect was due to more feed being available (for the ewes) as a result of less being eaten by the lambs.

Perhaps the most notable feature of these results was the sensitivity of the system to changes in the parameters determining diet quality and intake (parameters 11 to 15).

Sensitivity of output to choice of intake function (set stocked or allowance - parameter 11) was marked for grazing durations of 4 days per paddock. This served to illustrate the problem of needing to make a decision about when to use the allowance function and when to use the set stocked function. Use of the set stocked function for grazing durations of 4 days resulted in much lower grazing residuals (360 vs 100 kg GDM/ha) and hence higher consumption over winter. This penalised spring performance. The same effect, but much less drastic, was seen when intake, as a proportion of allowance, was increased (parameter 10).

The qualitative pasture relationships had a major influence throughout the system due to their double effect on intake and diet quality.

Given the degree of sensitivity displayed by the model to alterations in parameters affecting intake and pasture quality it must be concluded that further experimental justification should be obtained for the parameters used in the model.

## 8.5 SUMMARY

In earlier sections of this Chapter, effects of a range of management decisions on the performance of NIHC sheep grazing systems were investigated. This was done in order to determine those decisions which led to 'optimal' system performance.

Grazing decisions that maximised spring pasture production and 'allowed' an early lambing day to be employed, were shown to be important in this context.

These conclusions were confirmed for a range of year types and for different lamb selling dates.

In subsequent sections, use of the model to determine constraints preventing further increases to production was demonstrated. And a number of possible areas for further improving system performance were shown to have value in particular circumstances (e.g. nitrogen fertiliser, artificial increases to ovulation rate and increased wool growth potentials).

Finally a number of parameters influencing intake and pasture and diet quality were identified as possibly needing further experimental justification based on system sensitivity to changes made to these parameters.

In Chapter 9 research needs and priorities are discussed in relation to both these results, and problems identified during model development and evaluation.

## Chapter 9

### RESEARCH NEEDS AND EVALUATION OF MODELLING

#### 9.1 INTRODUCTION

Previous chapters have discussed the modelling undertaken in this study. Model construction, subsequent evaluation and experimentation has thrown up a range of research needs and possibilities. An attempt is made here to provide an integrated evaluation of these needs and to examine the implications for research. Then, to deal with the second objective, this study and modelling are evaluated with respect to their utility in research management

#### 9.2 EVALUATION OF COMPONENT DATA RELATING TO HILL COUNTRY SHEEP GRAZING SYSTEMS

One of the objectives of the study was to assemble and evaluate component data relating to NIHC sheep grazing systems. This section attempts to outline the state of component knowledge relevant to hill country at the time of model construction. Some of these data needs may have since been rectified.

Construction of the model played an important role in evaluating data needs since it provided a discipline of specific information requirements. Some of the needs will be apparent to non modellers, but without a readily defined (applicable) end use, such as to fit them into a model, the response has often been a general plea for more component research. In addition, some of the perceived data needs may have arisen because of the way data is needed for inclusion into a model, which may be different to the way the data was collected and presented in the absence of a model. In other cases the dilemma is in

selecting relevant data where quite an amount may appear to exist, but where there are conflicting conclusions which cannot be reconciled.

### 9.2.1 Pasture Growth

Environmental effects are of major importance in determining variation in the seasonal production of pasture, knowledge of which is important in synthesising improved systems. At the time the study commenced a limited amount of data suggested that environmental variability (climate and soil fertility) was an important source of variation in net pasture production on hill country. Physical features (slope and aspect) of hill country were associated with this variation. However these data, while describing important features of variation in the pattern and potential of hill country pasture production, were largely unsuitable for model construction. Differences between slopes and aspects due to temperature and radiation could only be related to differences in production in a general way, and were confounded by both known and unknown variations in soil moisture and soil fertility.

Data from flat sites were of assistance in determining relative effects of climate (e.g. temperature and radiation) on growth. However these relationships need to be derived on hill country soils of known fertility, since interactions with soil fertility and pasture composition are likely to be important in determining potential production. There is also a need to define temperature parameters (in the field) which more accurately reflect the temperature to which pasture responds than the 1.2 m screen temperatures presently available.

The major data deficiencies which were not obtainable from flat sites concerned soil water holding capacities of hill soils on different slopes and aspects and the effects of rainfall on soil water levels. In summary, specific data needs are; (1) the effect of rainfall intensity on runoff and water entry rates on soils of different slopes and degrees of dryness, (2) depth of water entry following rain, and plant growth in relation to the environmentally determined potential following rewetting after a period of moisture stress, and (3) the soil depth to which water is available to hill country pasture.

#### 9.2.2 Senescence and Grazing Effects

A number of reasons exist for needing to quantify the dynamic movement of herbage from green through the senescent stage and eventually to decay. Firstly, sheep practically neglect dead herbage. Secondly, decay may mask or influence the effects of different variables on true growth when measured by net production. And thirdly, net production may underestimate true growth met by the animal during grazing. The latter is likely to be particularly important where grazing durations are long as under set stocking.

There exists a limited amount of data (none specific to hill country) describing rates of senescence and decay at different times of the year, but there is little quantification of factors affecting these rates, such as temperature, soil moisture stress, recent grazing and in particular senescence in swards containing a lot of reproductive growth in late summer.

The apparent inadequacy of a simple LAI-growth rate function in periodically grazed swards, has been noted in Section 7.4. This was

most evident in those swards laxly grazed during the period of reproductive growth of grasses. There is clearly a need for better definition of grazing effects on total pasture growth and the dynamics of senescence and decay, particularly over the late spring-summer period. The above information is important if improved systems based on improved grazing management are to be devised in the future.

### 9.2.3 Pasture Quality and Animal Intake

The sensitivity of the model to changes in parameters determining intake was clearly shown in Chapter 8. In this model, like many others, voluntary intake was related to diet quality, since it is well established that diet quality can set limits on voluntary intake. Diet quality was related to average quality of herbage on offer. This was less elaborate than in other models but was nevertheless conceptually similar, in that it assumed a continuous movement of live herbage through different digestibility classes. However, some question arose over the extent of the sensitivity of animal performance to pasture quality, especially in the autumn (see Section 8.4). This may have been due in part to interactions between grazing pressure and diet selection ability, which were not resolved in the model. Also, the limited data available suggested that the real situation may differ from that commonly modelled. For example, Browse et al.'s (1981) data suggested that it is green stem that reduces average pasture quality, implying that green leaf is of uniformly high quality. Further, the data of Guy et al. (1981) showed sheep strongly resist all components of the sward except green leaf.

Clearly there is a need for more information on the patterns of digestibility of the different components of the sward and on the

effects of accessibility of each component on diet selection and quality. This has implications for the description of pasture dynamics, requiring partitioning between leaf and stem to be explained during reproductive growth.

Finally, a greater understanding of accessibility and competition effects on pasture (green leaf) intake needs to be developed covering a wide range of grazing pressures and durations. The difficulty with using empirical relationships confined to specific management decisions occurs when trying to decide when one set of conditions gives way to another (see Section 8.4).

#### **9.2.4 Sheep Production**

In general there was a greater, more widely accepted, information base to draw on for describing the sheep component than for previous components. Perhaps the major problem was where an amount of data was available but appeared to show conflicting conclusions. One area where this has major influence on system performance is the effect of ewe liveweight at lambing on milk production post lambing, and hence lamb weaning weight (see Fig. 9.1). Using the functions derived by White (1975) an entirely different conclusion is reached about the importance of ewe liveweight at lambing than when using the functions derived here from Peart's data. Other examples of conflicts were whether voluntary intake increases, decreases or remains unaffected in late pregnancy, and the effect of liveweight on voluntary intake in mature sheep.

There are, however, a number of areas where information is limited. The effects on energy reserves and foetal growth and milk production when ewes are in different degrees of negative energy

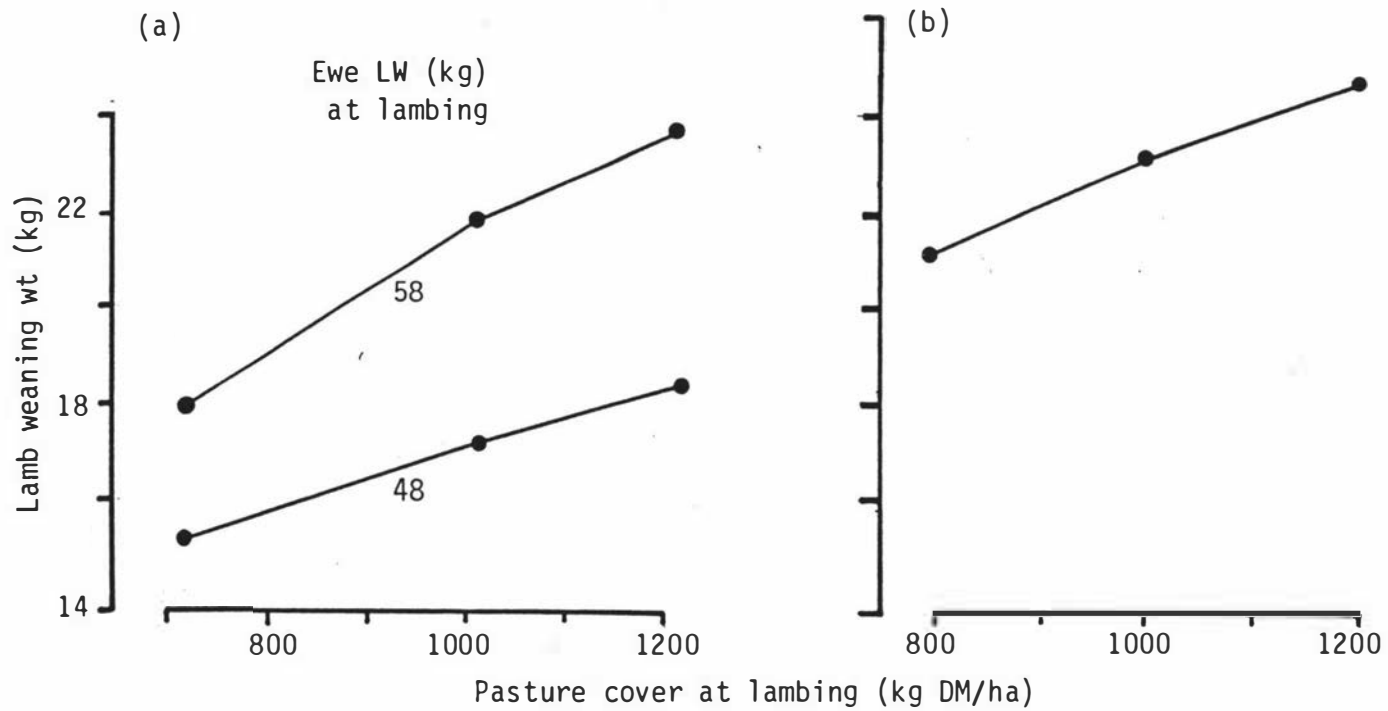


Figure 9.1 Relationships between lamb weaning weight and pasture cover at lambing (a) where ewe liveweight at lambing influences potential milk production, and (b) where ewe liveweight at lambing does not influence potential milk production. Note (a) and (b) are not strictly comparable owing to slightly different lambing days and weaning ages.

balance does not appear to be well defined. Also only limited information was available describing wool growth in relation to feeding levels, time of year and physiological state in the grazing animal, although this is now being rectified (H. Hawker pers. comm.). No information was found on maintenance requirements of sheep grazing hill country and it was not possible to correlate major climate variables to lamb mortality. The latter could be important where different lambing dates are considered.

Despite some quite definitive work describing pasture intakes by suckling lambs, and the substitution of grass for milk, this still represented an area of some concern in the model because pasture voluntary intake had to be increased above levels apparently achieved in the data, to predict satisfactory lamb growth. Finally, no data existed to describe the effects of competition between animals of different physiological states within a mob, or between ewes and lambs, on performance of individuals within the mob.

### 9.3 EVALUATION OF ALTERNATIVE GRAZING MANAGEMENT SYSTEMS

One of the requirements of hill country research which was seen as high priority by NRAC (1978) was to define grazing management decisions that 'optimise' pasture growth, utilisation and animal production under hill country conditions. Modelling played an important role in attempting to achieve the above by indicating the physical and economic effects of a range of management decisions on the performance of the ewe flock.

The importance of winter and early spring grazing management and choice of lambing day were clearly shown. Lambing early was an important means of achieving high levels of system performance at any

stocking rate. This made early spring feed supplies the most important limitation to system productivity and profitability, a result which was consistent across a range of years where pasture growth varied both above and below average in both autumn and spring. A long winter rotation, and a rotation in early spring were both required to maximise spring feed supply. Such was the importance of creating favourable early spring nutrition and conditions for pasture growth, that at high stocking rates (18 ewes/ha) attempts to flush ewes were forsaken so as not to reduce average cover on the farm at the start of winter.

The consistency of the above conclusions in all years, including dry autumns, raised the question of the importance of the weighting between productive components in the economic index, in influencing these conclusions. This question was not explored in detail. However the index used<sup>1</sup> did favour the production of heavy lambs by rewarding them with a higher price per kg. Obviously in circumstances where price per kg was the same regardless of liveweight, or where increased liveweight was not proportionately compensated, say on the store market, lambing percent would become more important relative to lamb selling liveweight. The model suggests this would favour a later lambing.

The role of modelling in deriving input/output relationships for the different management strategies has been demonstrated. It is possible, however, to see useful refinements to the decisions already chosen. Decisions about when to end the rotation in spring, when to start retiring paddocks from grazing and when to sell lambs could have been based on average pasture cover on the farm. These refinements

<sup>1</sup>See Appendix E for details.

became more obvious following the general evaluation undertaken, and if field evaluation of 'best' systems had been an aim of this study, a second set of experiments could have been performed on the model to improve decisions for field testing.

### 9.3.1 Manipulation of Pasture and Animal Components

A readily available means of manipulating animal performance is increasing ovulation rate using Fecundin. As yet though the use of Fecundin is largely in the developmental stages and it has not been used extensively in real systems.

Modelling clearly showed that artificial increases to ovulation rate could increase per head performance and overall system performance, but at a lower stocking rate than was previously 'optimal'. It played a useful role in determining those management decisions which were likely to accommodate the new technology to best effect, in this case showing that reducing stocking rate was desirable so as not to require delaying lambing.

Modelling also showed that increases to spring feed supply increased lamb liveweight, ewe fleece weight and lambing percent, to an extent that would be economically worthwhile in most years, provided these increases in feed supply could be achieved using nitrogen. The advantage of modelling over simpler marginal analyses, is that all consequences of increasing feed supply are valued, such as the cost of additional late spring surpluses. These can be extremely difficult to value in simple analyses, and are often not valued, thus false conclusions can easily be reached. For example, in some years an increase in spring feed supply led to temporary benefits to ewe and

lamb liveweight in spring but adverse effects of the generated late spring surplus reduced these benefits to uneconomic levels.

Of the other manipulations made to system components, increases to wool growth potential and removing the seasonal depression in potential wool growth both showed great promise for increasing system profitability. There was also an indication that larger breeds of sheep, or sheep with higher voluntary intakes, could be used more efficiently to utilise the seasonal supply of pasture grown.

#### 9.4 RESEARCH PRIORITIES

Despite previous claims (see Section 2.4.3), it is difficult to imagine an objective means of setting priorities using the model. Given the hypothetical situation of a completely valid model (biologically), priorities could possibly be stated objectively by ranking system benefits (e.g. Miller, 1980) from improving say, pasture yield or ovulation rate. Yet even in this case other intangibles must enter into the process such as the relative chance of success in pursuit of the various aims.

In the realistic situation where a more or less 'valid' model has been developed,<sup>2</sup> further difficulties arise in deciding between the need to improve the validity of the model, and developing improved systems from information already derived. There are obviously problems in making statements about system constraints, and the alleviation of these, when the model contains assumptions covering basic relationships. And the problem in determining the importance of incorrect basic assumptions has already been discussed in Section 3.4.3.

<sup>2</sup>That is a model which we have accepted for the moment.

There is however, a need for pragmatism in designing improved systems, since this would never be attempted if perfect knowledge of all components was a prerequisite for such activity. The choice between conducting more basic research and developing and testing improved systems in the field must be subjective. It probably should be based on whether there appears to be a need for a greater understanding of the operation of a particular component to enable improved systems to be devised.

Other problems in determining research priorities also exist. Many research possibilities may be outside the competence of one researcher, or even team of researchers. In addition, there may arise a need to study problems outside the boundary of the system modelled e.g. the integration of hoggets (McCall, 1984) or cattle, into the system. In spite of the above problems some general priorities for studying hill country sheep grazing systems can be stated, based on the modelling exercise.

#### **9.4.1 Alternative Grazing Management Systems**

There were three major implications for research from the analysis of grazing systems. First, the importance of lambing day and spring feeding on system productivity needs to be established in the field. Some work has already shown the importance of spring feeding levels on lamb weaning weights (Smeaton & Rattray, 1984). This needs to be further developed to include lambing day. Secondly the practise of rotating ewes and young lambs is not generally practised on NIHC farms and there is a need for research and development to demonstrate the feasibility of this at the farm level, as well as to test the reality of apparent benefits.

In support of the above work there is a need to further clarify (under grazing), the effects of ewe liveweight at lambing on potential milk production (as reflected in lamb growth rate) and the ability to buffer lambs through different durations and severities of undernourishment in early lactation.

Thirdly, flushing ewes to achieve increased lambing percentages has been regarded as an important means of increasing system performance (Rattray, 1981). The suggestion to the contrary in this study is therefore clearly in need of field verification at the system level.

#### **9.4.2 Intake and Pasture Production**

There is a clear need for a greater understanding, and more information, regarding factors affecting intake, quality of the diet and pasture growth and senescence rates, during and immediately following the reproductive growth phase of grasses. This information is needed to aid the definition of improved systems for handling pasture surpluses in summer. Modelling showed the sensitivity of intake and animal production to pasture quality at this time of year and the possibility of problems in the conceptualisation of pasture quality and intake must be considered. It appears that intake needs to be described in relation to availability and accessibility of green leaf.

Because the pattern of pasture growth throughout the year is central to grazing management systems, a mechanistic description of pasture growth as a function of the environment (including soil fertility) is also seen as a priority, to enable future extrapolation

to other sites. This needs to include further work on the prediction of responses to nitrogen, shown here to have potential value.

#### 9.4.3 Animal Physiology

Increases to system profitability through artificially boosting ovulation rate were clearly shown to be possible. Two priorities must be; to show these in the real system and, to improve the reliability of Fecundin, or at least gain an understanding of reasons for poor responses.

Hart (1955) showed implants of thyroxine in ewes at strategic times of the year to increase wool production in autumn and winter by masking the cyclical depression in wool growth. Resumption of this seemingly forgotten line of work warrants priority given the value of increased wool production.

### 9.5 EVALUATION OF MODELLING IN RESEARCH PLANNING

A complete evaluation of modelling in directing and coordinating NIHC research will require modelling to be used over a greater period of real time than was possible for this study. It can only be attempted following experience with modelling in conjunction with a research programme in the field. In addition, any evaluation is likely to suffer from an ill-defined base for comparison since there will be no 'control' research programme, and hence evaluations must be subjective.

This evaluation is of aspects of the modelling approach relevant to the task of planning a research programme, and is based on experience gained in this study. Some points which are mentioned in the literature, and some which are not so well developed, bear

comment in relation to the apparent advantages and limitations of the approach.

### 9.5.1 Communication and Learning Advantages

Benefits to learning associated with modelling were recognised by Wright et al. (1976), but they concluded that such benefits were difficult to illustrate. In this case modelling has played a useful role in developing an appreciation of important management decisions. Such an appreciation is not easily gained by intuitive means, although it might have been obtained from spending an equivalent amount of time gaining experience in the field. The efficiency of modelling versus gaining field experience cannot be determined here.

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Where modelling did appear to offer an advantage was in integrating knowledge relating to the components of NIHC grazing systems and in providing a tangible framework for conducting future component research. Also, with modelling, it may be possible to work towards a complete understanding of system components which can readily be tapped by successive generations of researchers.

Involvement in modelling also provided a good background for directing communications about the strengths and weaknesses of data (and available concepts), with other scientists, particularly if they had modelling experience or were presently involved in modelling. Specific relationships required to construct the model provided a precise frame of reference for a question, as did deficiencies in model prediction. Finally, results from this modelling study, when accompanied by reasons for the result being obtained, provided a precise basis for developing discussion with those experienced in operating grazing systems in the field.

### 9.5.2 Developing Priorities and Research Planning

Difficulties in establishing objective research priorities using a model have already been discussed. Despite these problems, modelling offers the chance to be more specific in describing research needs than is the case where such evaluations are attempted in the absence of modelling (e.g. Hight, 1976; NRAC, 1978). Research needs can at least be discussed in relation to a tangible background of assumptions required in the model, and the potential benefits of new systems.

Two further potential advantages of modelling that became apparent were: first, having completed the initial evaluation of different grazing systems the results stimulated ideas for future refinements to the decisions used. Time constraints precluded following these up in this study, but where a field trial was to be designed, modelling may have eliminated the need for a pilot trial investigation. The second point, which is possibly a corollary to the first, is that modelling may give researchers more confidence to design complex (real world type) experiments (e.g. involving more than one class of animal), by allowing appropriate (meaningful) grazing decision rules to be developed and by ensuring that expected contrasts between treatments have been thoroughly thought out before measurements begin. In addition such experiments could be used to test hypotheses encapsulated in the model.

However, success in devising new systems must depend on the initiative of the researcher. Modelling can only stimulate this initiative through making it easier, and quicker, to test ideas.

### 9.5.3 Problems of Time and Size

Limitations on modelling studies because of the real time involved in model development, evaluation, experimental planning and result interpretation, have been noted by (Miller, 1983).<sup>3</sup> A further limitation noted here was the size of the task of experimentation with a complex system, even using a simulation model. Despite potentially opening up a whole new range of possibilities for large and complex experiments involving more than one class of stock, in reality, the burden of size of the experiment and both the time required to interpret the results and the means of analysing and presenting the results, are still major limitations. For example the two major experiments in this study each took over 20 hours of computer process time to run on a Prime 750 computer, and they generated large volumes of output. The alternative approach to experimentation of designing and analysing treatments sequentially may be a more efficient design, but it is likely to have a greater real time requirement.

### 9.5.4 Modelling in Isolation from Field Research

The fact that the modelling was carried out in isolation from a field research programme was justified by the objective to evaluate modelling in the role of planning a field programme. These circumstances produced both an advantage and a disadvantage.

The major disadvantage was that model development and validation was hampered on a number of occasions by the lack of appropriate detailed data which a field research programme, in conjunction with modelling, may have been able to provide, making a better model. The advantage was that the above situation did not interfere with the

<sup>3</sup>The time involved in the extension of models and how to operate them should also be included in this list. It is an aspect which unfortunately in this, and in many other modelling studies appears to have suffered from constraints of time.

completion of the model and the testing of systems. A temptation when conducting model development in conjunction with a field programme is to continually postpone using the model in preference to further trying to improve it.

## 9.6 CONCLUSIONS

This study has shown that modelling can be used first, to effectively identify constraints to increased production in grazing systems, and secondly, to aid in determining research priorities. However, it also showed that modelling did not remove all subjectivity from these processes, and that there are a number of real problems, and risks, in objectively determining research priorities using an 'invalid' model. A beneficial feature of modelling is in allowing the important issues and information, as seen by the modeller, to be communicated in a way that allows other people to interact on concrete evidence. A model provides a check in the research process by providing a means to allow peers to have a look in at assumptions often made intuitively.

In other respects, the model is an efficient vehicle for integrating knowledge relating to system components and for synthesising management systems. Two benefits which are apparent but which were not able to be demonstrated are the benefits to modelling of conducting field research in parallel with model evaluation, and the assistance of modelling in designing trials both directly, as with whole system experiments and indirectly, by providing a coherent context for determining the type of information required to explain system behaviour.

The process of developing a pre-research model to evaluate research needs has been a valuable one. However to obtain all of the benefits offered, modelling now needs to be extended to operate as an integral part of the research process.

APPENDIX A: Aspect and slope factors for temperature and radiation

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Assumed Temperature Factors

Month	North Aspect	South Aspect
Jan.	1.15	1.00
Feb.	1.13	0.95
March	1.07	0.81
April	1.08	0.78
May	1.03	0.84
June	1.33	0.92
July	1.19	0.77
Aug.	1.17	0.78
Sept.	1.12	0.91
Oct.	1.09	0.90
Nov.	1.00	0.96
Dec.	1.06	1.03

Assumed Radiation Factors (adapted from McAneney & Noble, 1976)

Aspect	North			South		
	0-12°	13-25°	>25°	0-12°	13-25°	>25°
Slope						
Periods						
22/12-13/1, 29/11-21/12	1.00	0.96	0.90	1.00	0.97	0.92
14/1-3/2, 7/11-28/11	1.01	0.99	0.94	1.00	0.96	0.89
4/2-26/2, 16/10-6/11	1.02	1.04	1.01	0.98	0.90	0.79
27/2-20/3, 23/9-15/10	1.04	1.11	1.15	0.97	0.86	0.74
21/3-12/4, 31/8-22/9	1.07	1.19	1.26	0.94	0.77	0.61
13/4-5/5, 8/8-30/8	1.10	1.30	1.47	0.91	0.71	0.52
6/5-28/5, 16/7-7/8	1.13	1.39	1.60	0.89	0.61	0.39
29/5-21/6, 22/6-15/7	1.15	1.48	1.75	0.86	0.56	0.33

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APPENDIX B: Statistical Proof (R.J. Townsley personal communication)

(a) To Prove:  $\sum_q (\bar{Y}_i - \bar{X}_{ij})^2 = \sum_q (\hat{Y}_i - \bar{X}_{ij})^2 + \sum_q (\bar{Y}_i - \hat{Y}_i)^2$

$$(\bar{Y}_i - \bar{X}_{ij}) = (\bar{Y}_i - \hat{Y}_i) + (\hat{Y}_i - \bar{X}_{ij})$$

$$(\bar{Y}_i - \bar{X}_{ij})^2 = (\bar{Y}_i - \hat{Y}_i)^2 + (\hat{Y}_i - \bar{X}_{ij})^2 + 2(\bar{Y}_i - \hat{Y}_i)(\hat{Y}_i - \bar{X}_{ij})$$

Since  $\hat{Y}_i = \hat{a} + \hat{b} \bar{X}_{ij} = \bar{Y} - \hat{b} \bar{X}_j + \hat{b} \bar{X}_{ij}$

$$= \bar{Y} + \hat{b} x_{ij}$$

Where,  $x_{ij} = \bar{X}_{ij} - \bar{X}_j$

$$y_i = \bar{Y}_i - \bar{Y}$$

We have:  $\bar{Y}_i - \hat{Y}_i = \bar{Y}_i - \bar{Y} - \hat{b} x_{ij} = y_i - \hat{b} x_{ij}$

Now,  $\hat{Y}_i - \bar{X}_{ij} = \bar{Y} + \hat{b} x_{ij} - \bar{X}_{ij}$

$$= (\bar{Y} - \bar{X}_j) + \hat{b} x_{ij} - (\bar{X}_{ij} - \bar{X}_j)$$

$$= (\bar{Y} - \bar{X}_j) + \hat{b} x_{ij} - x_{ij}$$

$$= (\bar{Y} - \bar{X}_j) + (\hat{b} - 1) x_{ij}$$

Therefore:

$$(\bar{Y}_i - \hat{Y}_i)(\hat{Y}_i - \bar{X}_{ij}) = (y_i - \hat{b} x_{ij}) [(\bar{Y} - \bar{X}_j) + (\hat{b} - 1) x_{ij}]$$

$$= (\bar{Y} - \bar{X}_j) y_i - \hat{b} (\bar{Y} - \bar{X}_j) x_{ij}$$

$$+ (\hat{b} - 1) (y_i x_{ij} - \hat{b} x_{ij}^2)$$

$$\sum (\bar{Y}_i - \hat{Y}_i)(\hat{Y}_i - \bar{X}_{ij}) = (\bar{Y} - \bar{X}_j) \sum y_i - \hat{b} (\bar{Y} - \bar{X}_j) \sum x_{ij}$$

$$+ (\hat{b} - 1) \sum [y_i x_{ij} - \hat{b} x_{ij}^2]$$

$$= 0$$

Since  $\sum y_i = \sum x_{ij} = 0$ , and

$$\hat{b} = \frac{\sum y_i x_{ij}}{\sum x_{ij}^2}$$

Thus,  $\sum_q (\bar{Y}_i - \bar{X}_{ij})^2 = \sum_q (\bar{Y}_i - \hat{Y}_i)^2 + \sum_q (\hat{Y}_i - \bar{X}_{ij})^2$

(b) To Prove:  $\sum_q (\hat{Y}_i - \bar{x}_{ij})^2 = q(\bar{Y} - \bar{x}_j)^2 + (b - 1)^2 \sum x_{ij}^2$

$$\begin{aligned}\hat{Y}_i - \bar{x}_{ij} &= \bar{Y} + bx_{ij} - \bar{x}_{ij} \\ &= (\bar{Y} - \bar{x}_j) + bx_{ij} - \bar{x}_{ij} + \bar{x}_j \\ &= (\bar{Y} - \bar{x}_j) + (b - 1)x_{ij}\end{aligned}$$

$$(\hat{Y}_i - \bar{x}_{ij})^2 = (\bar{Y} - \bar{x}_j)^2 + (b - 1)^2 x_{ij}^2 + 2(b - 1)(\bar{Y} - \bar{x}_j)x_{ij}$$

$$\sum_q (\hat{Y}_i - \bar{x}_{ij})^2 = q(\bar{Y} - \bar{x}_j)^2 + (b - 1)^2 \sum x_{ij}^2$$

Since,  $2(b - 1)(\bar{Y} - \bar{x}_j) \sum x_{ij} = 0$



Reference	Pasture cover (kg DM/ha)	Percent Green Pasture	Pasture Quality (MJME/kg DM)	Pasture Allowance (kg DM/hd/d)	Pasture Intake		Liveweight Gain		Wool Growth Rate	
					Observed (kg DM/hd/d)	Simulated	Observed (g/day)	Simulated	Observed (g/day)	Simulated
	2700	70**	10.4*	1.2	0.76	1.02	45	49	9.2	9.0
				2.5	1.38	1.36	174	105	11.0	11.5
				4.2	1.44	1.50	185	127	11.6	12.6
				6.9	2.23	1.54	224	134	12.9	13.0
(Heavy Ewes)	2000**	70**	10.4*	1.1	0.84	0.88	-130	0	7.1	7.9
				2.4	1.32	1.22	36	54	10.7	10.5
				3.9	1.51	1.33	57	71	11.7	11.5
(Light Ewes)				1.1	0.95	0.88	-87	37	7.0	7.9
				2.4	1.32	1.27	67	107	8.6	10.9
				3.9	1.31	1.41	136	132	9.7	11.9
Sreaton <i>et al.</i> (1981) (Hill Country Ewes - Autumn)	2400	25	10.0*	2.4			-69	-145	7.7	4.1
				4.5			8	-69	9.5	6.2
				8.0			4	-20	9.7	7.5
				8.3			9	-18	9.9	7.5
				13.2			20	1	10.1	8.2
	2000	55	10.0*	1.3			-13	-79		
				2.0			13	0		
				3.6			56	44		
				5.1			56	61		
				7.4			51	73		
				8.1			68	74		
Jagusch <i>et al.</i> (1979) (Lambs: 10-18 Weeks of Age, assumed LW = 20 kg)	3300	80	10.6	1.8	1.0	0.88	88	111		
				3.1	1.3	1.04	121	156		
				5.5	1.4	1.11	156	177		

Continued

Reference	Pasture cover (kg DM/ha)	Percent Green Pasture	Pasture Quality (MJME/kg DM)	Pasture Allowance (kg DM/hd/d)	Pasture Intake		Liveweight Gain		Wool Growth Rate	
					Observed	Simulated	Observed	Simulated	Observed	Simulated
					(kg DM/hd/d)		(g/day)		(g/day)	
	2500	80	10.7	1.5	0.7	0.80	84	89		
				3.9	1.5	1.08	126	173		
				5.7	1.9	1.11	150	181		
Thomson et al. (1980) (Lambs 6/12-9/2, initial LWT = 19.7 kg)	3000	89	10.1	1		0.65	52	34		
				2		0.83	102	86		
				3		0.90	123	103		
				4		0.92	128	109		
				5		0.93	128	111		
				6		0.93	126	111		
(Lambs 10/2-4/4, initial LWT = 24.4 kg)	3100	86	10.2	1	0.74	0.75	55	62		
				2		0.99	93	126		
				3	1.44	1.11	124	154		
				4		1.16	148	166		
				5	2.15	1.18	157	171		
				6		1.19	164	173		
Lambs (5/4-25/5, initial LWT = 31.3 kg)	2500	93	10.0	1	0.81	0.81	- 4	48		
				2		1.11	58	113		
				3	1.44	1.23	94	138		
				4		1.29	104	149		
				5	2.50	1.31	133	154		
				6		1.32	136	156		

\* Assumed Quality of Green Pasture

\*\* Assumed Values

† Green Allowances

APPENDIX D: Design for third replicate of 3\*5 factorial  
(I.M. Gravett, personal communication)

1	1	1	1	1	2	1	1	1	3	3	1	1	1	2
		1	2	3			1	2	2			1	2	1
		1	3	2			1	3	1			1	3	3
		2	1	3			2	1	2			2	1	1
		2	2	2			2	2	1			2	2	3
		2	3	1			2	3	3			2	3	2
		3	1	2			3	1	1			3	1	3
		3	2	1			3	2	3			3	2	2
		3	3	3			3	3	2			3	3	1
2	1	1	3	2	1	1	2	2	1	1	1			
	1	2	2		1	2	1		1	2	3			
	1	3	1		1	3	3		1	3	2			
	2	1	2		2	1	1		2	1	3			
	2	2	1		2	2	3		2	2	2			
	2	3	3		2	3	2		2	3	1			
	3	1	1		3	1	3		3	1	2			
	3	2	3		3	2	2		3	2	1			
	3	3	2		3	3	1		3	3	3			
3	1	1	2	3	1	1	1	3	1	1	3			
	1	2	1		1	2	3		1	2	2			
	1	3	3		1	3	2		1	3	1			
	2	1	1		2	1	3		2	1	2			
	2	2	3		2	2	2		2	2	1			
	2	3	2		2	3	1		2	3	3			
	3	1	3		3	1	2		3	1	1			
	3	2	2		3	2	1		3	2	3			
	3	3	1		3	3	3		3	3	2			

## APPENDIX E: Economic assumptions

### Variable Costs - July 1983 (W.J. Parker, personal communication)

- Assumptions: 1 shearing, 1 crutching, 1 dagging, 1 tipcrutch = \$2.28/ewe  
 less shearing costs of 4.6% that die = \$2.20/ewe wintered.
- : Animal health \$0.90/ewe wintered.
  - : Rams \$0.50/ewe wintered.
  - : Ewe replacement costs, two tooth ewe price \$27.50.  
 Cull ewe price \$10.00, 25% replacement rate, 4.6% ewe death  
 rate = \$4.84/ewe wintered.
  - : Interest on capital. Capital value \$20/ewe, 15% interest =  
 \$3/ewe wintered.
  - : Total cost/ewe wintered = \$11.44.

### Prices Assumed

- Wool : \$3.20/kg. (MAF Costs and Prices 1983.)
- Lamb : December 1982 schedule prices (A.B. Walker personal  
 communication).  
 Carcass weight <12.5 kg, \$1.36/kg.  
 Carcass weight >12.5 kg, \$1.48/kg.  
 Assumed dressing out percentage = 50%.  
 Assumed range about average liveweight =  $\pm 4$  kg (one standard  
 deviation for lambs at weaning - D.J. Garrick (unpublished  
 data)).
- ∴ If average selling LWT <21.5 kg, Price = \$0.68/kg LWT.  
 If average selling LWT >29.5 kg, Price = \$0.74/kg LWT.  
 ELSE Price =  $\$(0.0075 \cdot \text{LWT} + 0.51875)/\text{kg LWT}$ .

APPENDIX F: Optimum lambing day and associated gross margin for each combination of grazing decision at stocking rate 14 ewes/ha

Grazing Decision	Spring Retire Flush	0			15			30		
		0	7	15	0	7	15	0	7	15
60	15	227† 370.9*	227 375.1	227 387.4	226 389.5	226 393.8	226 403.9	226 390.3	226 395.0	226 405.0
	30	227 370.3	227 375.4	227 386.9	226 388.5	226 393.6	226 402.8	226 389.4	225 395.0	226 404.1
	60	228 368.8	228 371.4	228 383.7	226 387.0	226 389.6	226 399.7	226 388.2	226 391.3	226 401.3
90	15	227 377.7	227 381.4	227 393.6	225 393.5	225 397.2	225 407.2	225 392.6	225 396.7	226 406.6
	30	227 377.1	227 381.5	227 392.9	225 392.4	225 396.9	225 406.0	225 391.7	225 396.6	225 405.7
	60	227 375.6	227 377.6	227 389.8	226 390.9	225 393.0	226 402.9	226 390.6	226 393.1	226 402.9
120	15	226 383.3	226 386.6	226 398.1	226 396.9	225 400.1	226 409.4	226 397.4	226 401.1	226 410.3
	30	226 382.8	225 386.8	226 397.5	225 395.8	225 399.9	226 408.4	225 396.5	225 401.1	226 409.5
	60	226 397.8	226 381.4	226 392.9	226 393.0	226 394.6	226 403.9	226 394.0	226 396.1	226 405.3

† optimum lambing day

\* associated optimum gross margin

Continued over

## Appendix F Continued, stocking rate 16 ewes/ha

Grazing Decision	0			15			30			
	0	6	12	0	6	12	0	6	12	
Spring Retire Flush										
Winter										
60	15	236 349.1	236 359.4	238 370.6	235 383.5	235 393.9	237 403.2	234 391.1	234 401.3	235 410.3
	30	233 351.6	233 359.5	237 368.3	234 386.4	234 394.4	236 401.5	233 394.1	233 402.0	234 408.7
	60	233 354.5	233 360.1	236 374.1	234 388.4	234 394.1	235 406.5	233 396.7	233 402.2	234 414.5
90	15	239 370.3	238 381.0	240 391.7	234 404.8	234 415.7	235 423.5	232 404.9	232 415.8	234 423.1
	30	238 370.8	237 379.1	239 387.8	233 406.4	233 415.0	235 420.5	231 406.9	231 415.3	233 420.3
	60	236 370.9	236 377.0	238 390.8	233 406.1	233 412.3	234 423.4	231 407.1	232 413.2	233 423.8
120	15	235 378.8	235 389.9	237 397.4	231 412.0	232 423.1	233 427.6	233 413.3	233 424.3	234 429.6
	30	234 381.1	234 389.8	236 395.1	230 415.5	231 424.1	232 426.4	232 416.3	232 424.8	233 428.0
	60	234 384.4	234 390.7	235 401.5	231 417.9	231 424.2	232 432.1	232 419.3	232 425.5	233 434.2

Continued over

## Appendix F Continued, stocking rate 18 ewes/ha

Grazing Decision Winter	Decision Spring Retire Flush	0			15			30		
		0	5	10	0	5	10	0	5	10
60	15	254 352.7	254 359.0	254 360.6	250 377.3	254 384.8	254 390.2	249 381.6	247 389.1	254 395.7
	30	254 351.1	254 358.3	254 362.8	250 373.9	255 383.0	254 390.9	249 381.2	247 390.0	254 399.5
	60	254 346.9	254 357.6	254 360.0	247 374.8	251 385.3	254 391.1	247 381.8	246 394.0	254 399.1
90	15	249 371.0	251 376.8	254 375.5	242 405.3	244 409.8	257 406.3	240 408.1	243 416.0	252 406.1
	30	249 368.9	252 376.1	254 377.6	241 402.1	244 407.7	258 407.5	240 408.0	242 417.0	252 409.8
	60	247 368.1	248 377.7	255 375.8	241 405.1	243 413.7	251 408.2	240 410.4	242 422.5	248 412.0
120	15	248 382.2	250 386.3	257 384.4	242 417.0	243 419.9	246 411.3	239 419.0	241 424.9	243 411.2
	30	248 384.8	250 390.2	258 391.6	242 418.3	243 422.5	246 416.5	239 423.6	241 430.6	243 419.6
	60	247 385.1	248 393.3	252 390.1	242 422.3	243 429.6	245 421.6	239 427.0	241 437.2	243 424.4

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