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APPLICATION OF LINEAR PROGRAMMING TO FARM
MANAGEMENT ANALYSIS: INTENSIVE BEEF
GRAZING SYSTEMS

A thesis presented in partial fulfilment
of the requirements for the degree of
Master of Agricultural Science in Farm
Management at Massey University.

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TABLE OF CONTENTS

	<u>Page</u>
TABLE OF CONTENTS	ii
LIST OF FIGURES	vii
ACKNOWLEDGEMENTS	ix
ABSTRACT	x
CHAPTER ONE: MOTIVATION, OBJECTIVES AND OUTLINE OF STUDY	
1.1 Introduction	1
1.1.1 Intensive Grazing Systems	1
1.2 Motivation for This Study	3
1.2.1 The Systems Research Concept	4
1.2.2 The Usefulness of Mathematical Systems Models	9
1.3 Objectives of the Study	10
1.4 Thesis Outline	10
CHAPTER TWO: THE BEEF GRAZING SYSTEM	
2.1 Introduction	12
2.2 Components of the Grazing System	12
2.2.1 Interaction of the System Components Over Time	14
2.2.2 Uncertainty Within the System	17
2.2.3 Summary of System Components	18
2.3 Research Work on the Components of a Beef Grazing System	18
2.3.1 Pasture Production and Grazing Management	19
2.3.2 Animal Production and Feed Requirements	22
2.3.3 The Use of Research Data in This Study	24
2.4 System Modelling Studies on Beef Production in New Zealand	25
2.4.1 The Profitability Studies of Lattimore (1970) and Lowe (1971)	25
2.4.2 The Simulation Study of Wright, Vallance and Nicol (1973)	27
2.5 A Dairy Farming Systems Modelling Study	29

	<u>Page</u>
2.6 The Comparison of Linear Programming with Simulation as a Technique for Studying Grazing Systems	30
2.7 The Model Used	31
2.8 Summary	32
 CHAPTER THREE: PASTURE GROWTH	
3.1 Introduction	33
3.2 Factors Affecting the Regrowth of Pasture	33
3.2.1 The Pasture Regrowth Curve	33
3.2.2 Changes in the Growth Curves Throughout the Year	34
3.2.3 The Effect of Management on Pasture Growth	34
3.2.4 The Effect of Grazing Animals on Pasture Production	39
3.2.4.1 The Number of Animals Grazed	39
3.2.4.2 The Treading Effects of Animals	40
3.2.4.3 The Effect of Faeces	41
3.3 Pasture Production Data Used in This Study	42
3.3.1 Assumptions Involved in Defining Pasture Regrowth	45
3.4 The Pasture Production Model	46
3.4.1 Pasture Production Possibilities Within the Model	46
3.4.2 The Structure of the Model	51
3.4.3 The Representation of the Grazing Process by the Model	53
3.4.3.1 The Length of Spell Between Grazings	53
3.4.3.2 The Height to Which Pasture is Grazed	54
3.4.4 Comment on the Length of Spell Options Within the Pasture Production Model	56
3.5 DM Production Associated with the Pasture Production Activities	58
3.6 Limitations in the Pasture Production Model	61
3.7 Annual DM Production from the Pasture Production Model	63

	<u>Page</u>
3.8 Summary	65
 CHAPTER FOUR: ANIMAL PRODUCTION	
4.1 Introduction	66
4.2 The Intake of Grazing Beef Animals	66
4.2.1 Factors Affecting the Potential Daily Intake of Grazing Beef Animals	69
4.2.2 Factors that Affect the Shape of the Function Relating Available Pasture to Intake	70
4.3 The Representation of Animal Intake Within the Model	75
4.4 The Conversion of Feed Intake into Animal Production	77
4.4.1 The Energy Value of Feed	77
4.4.2 Systems for Expressing Feed Requirements	80
4.4.2.1 Published Feeding Standards	82
4.5 Feeding Standards Used in this Study	86
4.5.1 Calculation of Feed Requirements	86
4.5.1.1 The Relationship Between Animal Liveweight and Maintenance Requirement	86
4.5.1.2 The Relationship Between Animal Liveweight Level of Performance (L.W.G.) and Production Requirement	87
4.5.1.3 The Effect of Pasture Quality on Feeding Standards	91
4.5.1.4 A Consideration of Compensatory Growth	92
4.5.1.5 The Significance of Intake (Liveweight Gain) Restrictions in the Feed Requirements Model	93
4.6 Summary	94

CHAPTER FIVE: MODEL EXPERIMENTATION AND RESULTS		<u>Page</u>
5.1	Introduction	96
5.2	Animals Considered in the Study	96
5.3	The Stocking Rate Decision	97
5.3.1	BEEF Production Systems	97
5.3.2	Maximization of Stocking Rates for BEEF Activities	99
5.3.3	Conditions that Prevent Further Increases in Stocking Rate for BEEF Systems	104
5.3.3.1	BEEF 1	104
5.3.3.2	BEEF 2	104
5.3.3.3	BEEF 3	105
5.3.3.4	BEEF 4	105
5.4	Discussion on Maximum Stocking Rates for BEEF Systems	105
5.5	Grazing Management Plans	108
5.5.1	Comparison of Grazing Management Plans for BEEF1 and BEEF2	120
5.5.2	Comparisons of Grazing Management Plans that Maximize Stocking Rate for BEEF2 with BEEF3 and BEEF4	121
5.6	Relating Grazing Management Plans to Farmer Practice	
5.6.1	Uses of the Model for Grazing Manage- ment Studies	125
5.7	Supplementary Feeding	126
5.7.1	Hay and Silage Making Activities	126
5.7.2	Supplementary Feeding Activities	128
5.7.3	Experimentation with Supplementary Feeding Possibilities	129
5.7.4	Discussion on the Increased Stocking Rate Due to Supplementary Feeding	131
5.7.5	Further Experimentation Possible With the Model Including Supplementary Feeding Possibilities	132
5.8	Summary	133

	<u>Page</u>
CHAPTER SIX: EVALUATION OF STUDY	
6.1 Introduction	134
6.2 Verification of the Model	135
6.2.1 Pasture Production	135
6.2.2 Animal Production as a Function of Intake	136
6.3 Analysis of Farm Management Problems Using L.P. Models	138
6.4 Evaluation of Study	141
APPENDIX ONE: THE PASTURE PRODUCTION MODEL	143
APPENDIX TWO: BEEF ACTIVITIES	148
APPENDIX THREE: SHADOW PRICES ASSOCIATED WITH THE MAXIMUM STOCKING RATE FROM BEEF2	150
APPENDIX FOUR: THE SUPPLEMENTARY FEEDING MODEL	153
BIBLIOGRAPHY	157

LIST OF FIGURES

<u>Fig.</u>		<u>Page</u>
1.1	Two Aspects of Systems Analysis in Relation to Systems Synthesis	7
2.1	Components of a Beef Production System	13
2.2	Interrelationships Between Variables that Affect Production in the t'th Period of the Year	16
2.3	The Evolutionary Development of Grazing Management Systems	
3.1	Generalized Pasture Regrowth Curve	35
3.2	Representation of Hypothetical Management Decisions	37
3.3	Pasture Regrowth and Daily Increments in DM/ha., After HIGH and LOW Defoliation	44
3.4	Pasture Production After Grazing HIGH and LOW in Period (t)	62
3.5	Grazing Pattern for Maximum Annual DM Production from the Model	64
4.1	Actual Daily Intake/Head as a Function of Available Feed/Head	68
4.2	A Relationship Between Pasture Available/Animal and Intake/Animal	72
4.3	A Generalized Representation of the Results of Reardon (1975)	74
4.4	Partitioning of Feed Energy Within the Ruminant	78
4.5	Partitioning of Available Energy	79
4.6	Comparison of the Feeding Standards of Lowe (1971), Jagusch (1973), and Those Shown in Table 4.1; for Three Levels of Liveweight Gain, and Three Liveweights	85
4.7	Maintenance Requirement as a Function of Liveweight	88

4.8	Maintenance Requirement as a Function of (Liveweight) ^{0.75}	88
4.9	Liveweight Gain as a Function of Production Intake/(Liveweight) ^{0.75}	90
5.1	Patterns of Liveweight Achieved by Animals in Beef Production Systems at Maximum Stocking Rates	101
5.2	Daily Liveweight Gain Achieved	102-103
5.3-5.6	Period Feed Requirements for BEEF 1, 2, 3 and 4, at Maximum Stocking Rates	109-112
5.7-5.10	Grazing Management Plan for BEEF 1, 2, 3 and 4	115-118
5.11	The Fate of 27 ha. Grazed LOW in Period (1)	124

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ABSTRACT

In the absence of quantitative data from the practical farm situation, Linear Programming (L.P.), was used as a framework for collecting research information on an intensive beef grazing system.

Three hundred pasture production activities were defined so that pasture was available for grazing at two grazing severities in each of 30 periods throughout the year, after a range of spelling lengths. Seventeen supplementary feedmaking activities allowed hay or silage to be made over the late spring, early summer period. Supplementary feed could be fed out in any period of the year subject to the constraint that per animal intake of supplementary feed did not exceed maintenance requirement.

Animals considered by the model are Friesian bulls purchased at three months of age, and 100 Kg. liveweight, and grazed within the system for 12 - 18 months, until they reached a liveweight of 380 Kg. Animal requirements were calculated as a function of liveweight and level of liveweight gain. These requirements were expressed in terms of pasture dry matter per animal, and were adjusted for assumed changes in the available energy (M.E.) content of pasture throughout the year.

Although the model could not be verified in relation to the real-life situation, due to lack of quantitative data, the capability of the model for solving farm management problems was investigated. An iterative procedure for solving the stocking-rate decision was developed, and results presented and analysed. The use of the model for investigation of beef farm management problems was discussed.

CHAPTER ONE

MOTIVATION, OBJECTIVES AND OUTLINE OF STUDY

1.1 Introduction

The amount of beef produced in New Zealand has increased markedly in the past decade. Table 1.1 shows that the weight of beef exported has nearly doubled in the period 1963/64 to 1972/73. The F.O.B. value of beef exports has increased over four times in that period.

While the numbers of traditional beef animals have increased over this period, much of the increase can be attributed to the retention of surplus dairy-bred calves for beef production purposes. Slaughter statistics do not differentiate between the heifers and steers of traditional beef origin (e.g. Hereford or Aberdeen Angus) and those animals bred from the dairy herd (e.g. Friesian or Friesian Crossbred). However, the numbers of bulls slaughtered, presented in Table 1.2, illustrate the trend towards dairy bred animals. In the 1967/68 killing season, practically all of the 77,000 bulls slaughtered were cull breeding bulls from the dairy industry. The increase to 258,000 bulls slaughtered in the 1972/73 season was almost entirely due to the retention of dairy bred bulls for beef production.

Many of the increased number of beef animals now grazed in New Zealand, are intensively grazed on farms that were previously dairy farms or fat-lamb farms.

1.1.1 Intensive Grazing Systems

Stocking rate, class of animals grazed and the interval between movement of animals to fresh pasture (grazing interval), are three of the control measures exerted by the manager over animal intake and pasture regrowth. These control measures can be manipulated by the grazing systems manager in an attempt to equate the amount of feed eaten with animal feed requirements and to take account of factors known to be important in affecting the regrowth of pasture, especially the height to which pasture is grazed and the interval between successive grazings.

Table 1.1

AMOUNT AND VALUE OF BEEF EXPORTS FROM NEW ZEALAND

<u>Year Ending 31 June</u>	<u>Amount (,000 cwt)</u>	<u>Value (\$,000 F.O.B.)</u>
1964	2,148	51,698
1965	2,173	51,576
1966	1,798	48,812
1967	1,946	58,725
1968	2,195	75,462
1969	2,457	101,260
1970	3,302	143,277
1971	3,376	159,663
1972	3,516	178,250
1973	3,842	229,435

(Source: Agricultural Statistics, Dept. of Statistics, 1963/64 - 1972/73)

Table 1.2

NUMBER OF BULLS SLAUGHTERED IN NEW ZEALAND

<u>Year Ending 31 October</u>	<u>Number (,000)</u>
1968	76.7
1969	94.2
1970	132.1
1971	170.3
1972	233.5
1973	257.8

(Source: Agbrief, Economics Division, Ministry of Agriculture and Fisheries, October 1972, October 1973)

1.1.1 Intensive Grazing Systems (Continued)

Although there is no commonly accepted standard by which the relative intensity of a grazing system may be measured, intensive grazing systems are characterised by high stocking rates and the frequent movement of animals to fresh pasture (rotational grazing). Intensive grazing systems are associated with a high degree of managerial control over animal intake and pasture regrowth. In comparison with less intensive grazing systems such as set-stocking, rotational grazing systems have frequently been associated with higher stocking rates and increased animal output per unit area.

1.2 Motivation For This Study

The author worked for 15 months in 1971/72 as a farm advisor in the North Taranaki area. Many farmers at that time had either wholly or partially changed over from running dairy cattle to farming systems involving the production of beef. Farmer experience with intensively grazed dairy production systems and the suitability of their land for intensive rotationally grazed systems, have contributed to the evolution of intensively grazed beef production systems.

Lattimore (1970) and Lowe (1971) investigated the reasons why farmers changed to beef production from dairying and sheep farming respectively. These studies cited a better outlook for beef prices relative to dairy prices on world markets at that time, and reduced labour requirements of beef farming compared with sheep or dairy farming as reason for changing farming systems over to beef production.

Lowe (1971) and Lattimore (1970) also investigated the profitability of beef production in relation to sheep and dairy farming systems on case study farms. Under a wide range of prices and farming conditions they concluded that beef production was an economically viable alternative to both dairying and sheep farming.

While the findings of Lowe (1971) and Lattimore (1970) may be valid, many of the production relationships involved in beef production systems based on the intensive grazing of pasture remain unknown.⁽¹⁾

(1) A detailed account of the approaches used by Lowe and Lattimore is given in Sect. 2.3.1.

Because of the lack of published information on many seemingly important relationships (e.g. the relationship between available pasture and pasture intake) the comparison of one farmer's system with others, in the hope of recognizing managerial deficiencies and being able to suggest more economically efficient systems, is at best a rather hazardous task.

To evaluate the effect of management on beef production using a farm survey would have involved collecting data from farmers who had:

1. accurately recorded management decisions they had made throughout the beef production process.
2. measured, or at least estimated, and recorded intermediary system outputs (i.e. pasture production and daily liveweight gains).

At the time this study was initiated, many beef farmers had started regular weighing of beef animals to estimate daily liveweight gain throughout the year. Very few, however, recorded accurately the management decisions they had made (areas of pasture grazed, rotation length), and virtually none measured or estimated either pasture growth rates or the amount of pasture available at each grazing.

In these circumstances the concept of "systems research" and in particular the construction of a mathematical model of the system in question, is recognized as a means of aggregating the information that is known about beef production systems and also as a means of conducting some preliminary investigations into the effect of grazing management on beef production.

1.2.1 The Systems Research Concept

Dent and Anderson (1971) state that:

"a system implies a complex of factors that are interrelated, it implies interaction between these factors, and it implies that a conceptual boundary may be erected around the complex as a limit to its organisational autonomy"

Clearly, where a farmer, or someone investigating a beef production system is concerned, the "complex of factors" referred to above will at least include animals, pasture, an area of land supporting that pasture, climatic factors and market factors, as well as all the interrelationships that may exist between these factors.

Dent and Anderson (1971) continue:

"Most situations that may be profitably looked at in this light have important dynamic elements associated with them, so that the state of the system is time-dependant. The state of the system is also frequently influenced by uncontrollable elements so that its future outcomes cannot be predicted with certainty."

Beef production systems are "dynamic" in the sense referred to above since the state of the system at any point in the production process is dependant on the outcome of decisions taken prior to that point. For example, the pasture available at any time will bear some relationship to the area of pasture grazed and the pasture residue at previous grazings. Also the liveweight of the animals at any time depends on the level of liveweight gain achieved earlier in the production process. The "uncontrollable elements" within a beef production system are the climatic and market factors which affect the amount of produce to be sold and the value of that produce.

Wright (1971) has used the term systems research to:

"encompass all activities involving the study of large and complex systems".

To overcome problems with terminology Wright defined attempts to modify systems by either manipulating relationships within existing systems (control) or designing completely new systems (design) as Systems Synthesis. In order to carry out either the design or control aspects of systems synthesis, it is necessary to study in detail relationships involved in that system. This study has been referred to by Wright (1971) as Systems Analysis.

Analysis and Synthesis were viewed by Wright (1971) as distinct but interdependent components of systems research since the demand for analysis was created by synthesis and the results from analysis to be of use, had to be subjected to some form of synthesis.

While the design and control are clearly aspects of systems synthesis, the analysis phase of systems research can also be divided into two distinct aspects; aspects that are distinct in their timing with regard to systems synthesis. This division of systems analysis is shown in Fig. 1.1. Any research project will logically begin with a study of the components involved in the system being studied and relationships between these components (referred to in Fig. 1.1 as Components Analysis). Given this information, some attempt can be made to modify the system by either:

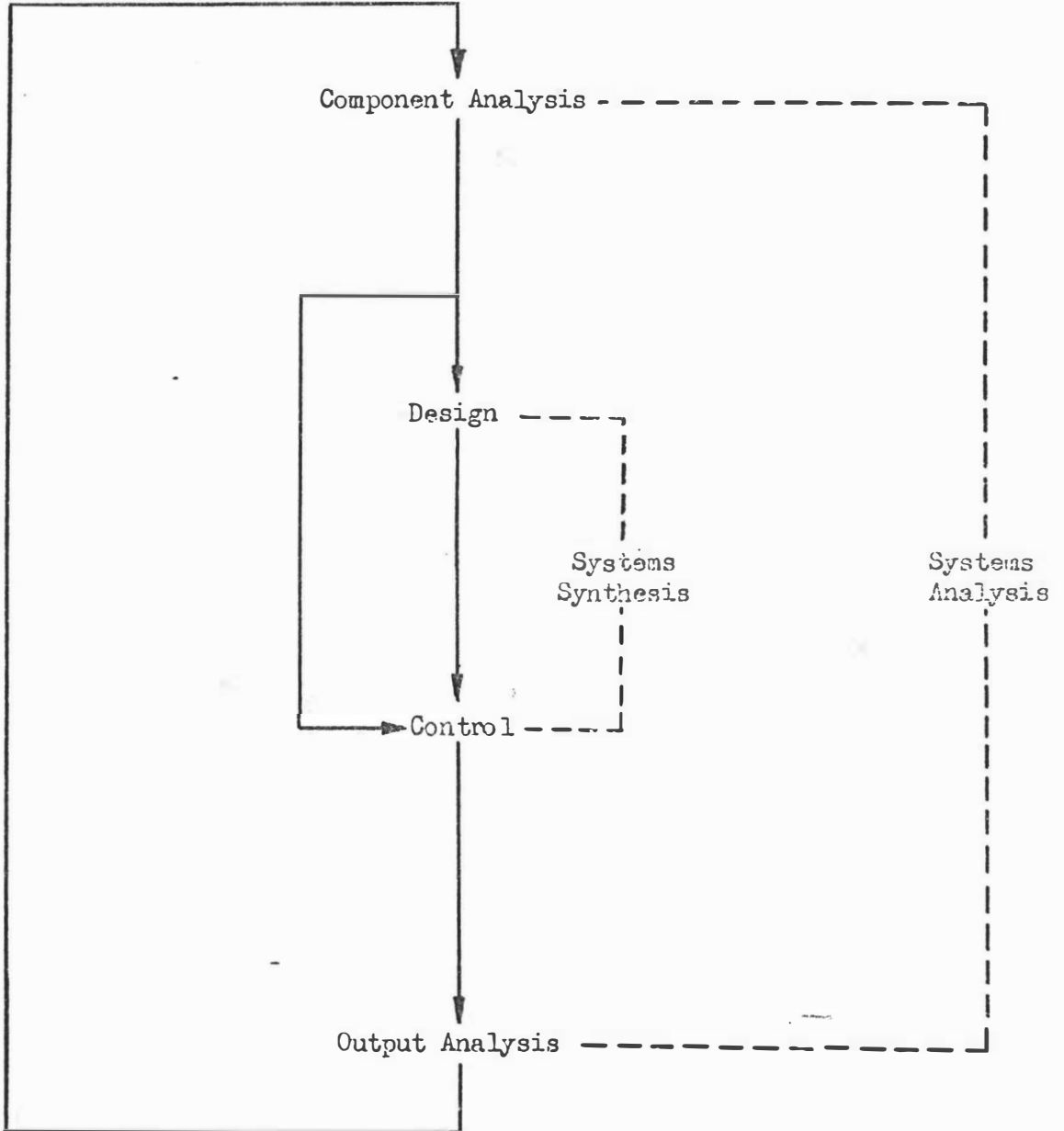
1. introducing new components into the system.
That is, design, as defined by Wright (1971)
e.g. the introduction of a summer green-feed
crop into a grass-based production system.
or
2. manipulating relationships between components
in the system. That is, control, in Wright's
(1971) definition, e.g. altering the length of
spell between grazings.
or
3. some combination of 1. and 2.

Having made such modifications the researcher will then be interested in studying output from the system and relating this output to the system as he has "synthesized" it, (referred to as Output Analysis in Fig. 1.1). The researcher might then be interested in further analysing the components and relationships within the system to see how output may be further improved. The research process of Components Analysis, Synthesis and Output Analysis, then becomes iterative and continues for as long as further understanding and improvement of the system is required.

This expansion of systems analysis into component and output analysis is presented so that analytical aspects of research may be discussed in this study in a more specific manner. The term Systems

Fig. 1.1

Two Aspects Of Systems Analysis In Relation
To Systems Synthesis



1.2.1 The Systems Research Concept (Continued)

Analysis will be used only with reference to both component and output analysis.

In practice, Wright (1971) states systems research is characterised by a systems orientation, an interdisciplinary approach and the use of systems models.

That problems should be studied in relation to the whole system (systems orientation) is generally well accepted. For example, stall-feeding experiments involving beef animals may be necessary in determining the feed requirements of beef animals. However, unless some attempt is made to relate these results to the grazing situation, they may be of little use to the majority of New Zealand beef producers.

Because of the complex nature of agricultural grazing systems, research into the various components of systems has become rather specialised. For example, a dairy scientist tends to be trained in and works on, matters pertaining to animals and in particular dairy animals.

While this specialisation may be necessary for the analysis aspect of research, synthesis, as discussed above, relies heavily on an interdisciplinary approach i.e. a cooperative effort between animal scientists and plant scientists may come closer to defining factors that affect the utilisation of pasture by grazing animals, than one or other of the two viewing the subject as a purely "plant" or "animal" problem.

Both a systems orientation and interdisciplinary research are accepted by research workers as necessary, and to an increasing extent are part of the current agricultural research effort in New Zealand. Hutton (1973a) while discussing his approach to experimentation on grazing systems stated:

"It is a matter of establishing what the really important things are and measuring them. Things such as feed growth and distribution, system of conservation, when to feed back, animal requirements, when they can be varied etc....."

The third characteristic of systems research mentioned on the previous page, systems modelling, is however, neither widely accepted nor proven to be of value to New Zealand agricultural research.

1.2.2 The Usefulness Of Mathematical System Models

Wright (1971) distinguishes between the descriptive and normative use of models in systems research. In its descriptive application a model may be useful as a means of reducing the real-world system to manageable proportions and focusing attention on aspects where knowledge is limited, and to generally gain a better understanding of the system under study. Models are used in a normative fashion to solve problems. In this application, models are characterised by some objective function which allows the analyst to evaluate different decision rules for an existing or new system.

Joblin (1970) while reviewing the nutrition and management of beef cattle under New Zealand conditions, suggested that detailed research work is needed on the feed requirements of the various types and classes of beef cattle for maintenance and production. He also suggested that more research is needed on the feeding value of pasture fodders and crops. Mathematical modelling of feed requirements and feed production data could be used to describe a range of promising management systems which could then be tested by large farmlet-type experiments. Data collected from these "expensive" management trials on the production parameters involved would recognise variation from the original models and be used to correct future modelling exercises.

The establishment of a research plan as suggested by Joblin (1970) (involving the complementary use of physical and model research) may prove beneficial to the gathering of information on beef production systems. However, until such a research programme is attempted, the actual advantages of modelling in determining management systems to be investigated by physical research can only be subjectively assessed.

In this study the author realised at an early stage that the unavailability of suitable data would limit the degree of reality and usefulness that the model could achieve, particularly with relation to

Joblin's (1970) suggestion of defining "promising management systems". The modelling exercise however, does provide a framework within which knowledge about beef production can be discussed, and areas in which further knowledge is required, can be outlined. Data limitations in the context of a model building exercise are no more of a problem than they are at the farm level where management decisions have to be, and are, made every day.

Furthermore, the construction of a mathematical model⁽¹⁾ based on available information, will allow some experimentation to be carried out to investigate the effect of management on beef production. In particular, the effect of length of spell between grazing and the height to which pasture is grazed are investigated in this study. While the results of this experimentation are not "real" in that they are obtained from a model of the real situation, they can be discussed with regard to the information on which the model is based, and comment can be made on how the model may be used if more information was available.

1.3 Objectives Of The Study

The prime objective of this study is to investigate the components within a beef production system. The lack of quantitative data available from farmers involved with beef production has prompted the use of a mathematical model as a means of meeting this objective.

A secondary objective is to consider the usefulness of mathematical models, and in particular linear programming models, as a framework for collecting the information known about grazing management systems, (descriptive) and for deriving improved management systems from the results of experimentation with the model (normative).

1.4 Thesis Outline

Chapter Two outlines the particular system studied, and the

(1) The actual model used, and alternatives that may have been used, are discussed in Sections 2.5 and 2.6.

components of that system. Research work (both physical and in the "Systems" context) on the components is examined. The type of model used in the study is presented and discussed in relation to other types of models that may have been used.

Chapter Three discusses the pasture production component of the system and outlines how the available knowledge is incorporated into the model.

Two particular aspects of animal production are discussed in Chapter Four, and the method by which they are included in the model is outlined. These two aspects are the utilisation of available pasture by grazing animals, and the conversion of pasture intake to animal production.

Chapter Five presents the results obtained from experimentation with the model and discusses the type of experiments that may be run on the model.

An evaluation of the study with regard to its goals and the limitations of the approach used are presented in Chapter Six.

CHAPTER TWO

THE BEEF GRAZING SYSTEM

2.1 Introduction

The components and interaction between components involved in beef production are discussed. New Zealand research work on pasture production and the feed requirements of beef animals are examined.

Mathematical modelling exercises are discussed in relation to grazing management research, and the usefulness of Linear Programming as a means of assisting this research is outlined.

Finally, the model used in this study is briefly described.

2.2 Components Of The Grazing System

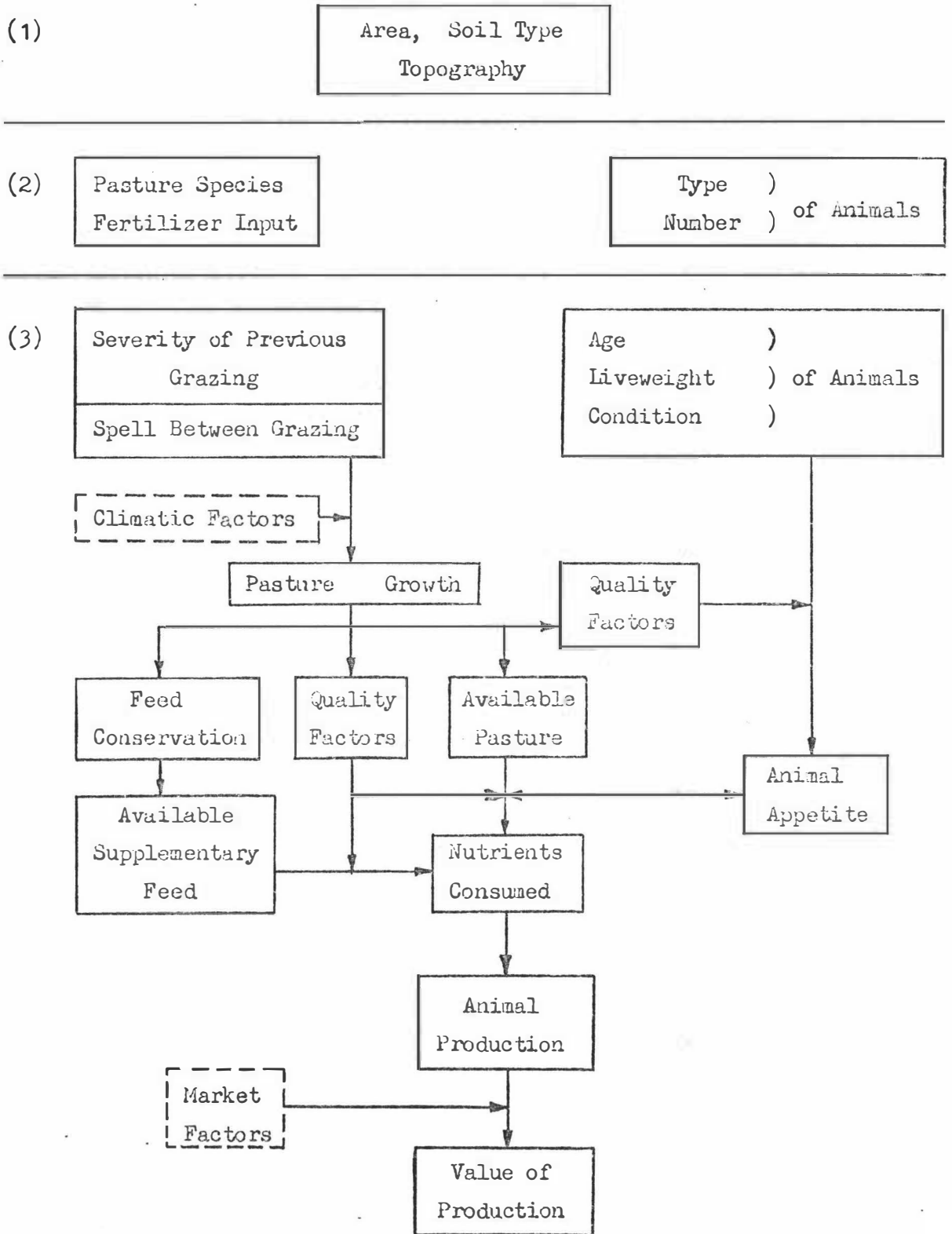
As in other animal grazing systems, the basic management problem in the production of beef from pasture is one of matching the feed supplied with animal requirements so that the farmer's goals are met. While maximising net profit from a fixed area of land is often stated as being the farmer's goal, this need not always be so. The extent to which any particular farmer attempts to maximise profit will be dependant on his aversion to risk, the extent to which he is prepared to adopt new technology, and the amount of time he is prepared to put into the farming enterprise.

It is possible, at least conceptually, to use modelling to devise a management system that meets any particular farmer's goal. This study is concerned with investigating all the components of beef grazing systems in order that the effects of pasture management on beef production may be evaluated; in particular the number of animals that can be run under different systems of pasture management is studied.

The components of production within a simplified dry land, all grass, beef production system are shown in Fig. 2.1. The components

Fig. 2.1

COMPONENTS OF A BEEF PRODUCTION SYSTEM



(1) Long Term

(2) Medium Term

(3) Short Term

Components over which the manager has some control.

Components over which the manager has little or no control.

2.2 Component Of The Grazing System (Continued)

are classified into three time-horizons with respect to the time period over which the grazing system manager may alter them.

In the long-term the manager may alter the system boundaries of an area of land and hence the topography and soil-type on which the system is based. Between production years (medium-term) the manager makes some decisions on the pasture species present, the amount of fertiliser to be applied, and the number and type of animals to be grazed. Within production years (short-term), at intervals as short as one day in many cases, the manager attempts to control the amount and quality of pasture made available to the animals, which in conjunction with the amount of feed actually eaten, will determine the animal production achieved.

Exactly how the manager should manipulate these components to achieve his goal is complicated by two characteristics of intensive grazing systems. Firstly the interaction over time of the components of both animal and pasture production, and secondly the uncertainty introduced into the system by climatic and market factors which are largely outside managerial control.

2.2.1 Interaction Of The System Components Over Time

The dynamic nature of an intensive beef grazing system is discussed below, assuming that the long and medium-term system components outlined in Section 2.1 are fixed and no supplementary feed (e.g. silage) is made.

Fig. 2.2 presents the interrelationships between variables that determine animal production in some short period "t", of the year. These interrelationships may be described by the following system of equations:

$$AV_t = A_t \times D_t \quad (2.1)$$

$$Y_t = f_1 \left(\frac{AV_t}{n_t}, D_t, Q_t, A_n t \right) \quad (2.2)$$
$$= \frac{C_t}{n_t}$$

$$C_t = Y_t \times n_t \quad (2.3)$$

$$P_t = f_2 (Y_t, Q_t, A_t) \quad (2.4)$$

$$TP_t = P_t \times n_t \quad (2.5)$$

where for period "t"

Av_t = Total pasture D.M. available

A_t = Area grazed

D_t = D.M. / Unit area

Y_t = D.M. Intake / Animal

n_t = Number of animals

Q_t = Pasture quality

An_t = Animal factors

C_t = Total D.M. consumed

P_t = Production / Animal

TP_t = Total animal production

The variables An_t , Q_t , and D_t are "state variables" in that they are determined by management decisions in previous periods. The variable A_t is a "decision variable" in that the manager must decide the area to be grazed in period "t". The number of animals within the system (n_t) is considered to be fixed.

Now in some subsequent period of the year "t + k" where:

"k" = number of periods before pasture grazed in period "t" is grazed again

T = the climatic factors that affect pasture growth over those "k" periods

$$D_{t+k} = g_1(R_t, k, T) \quad (2.6)$$

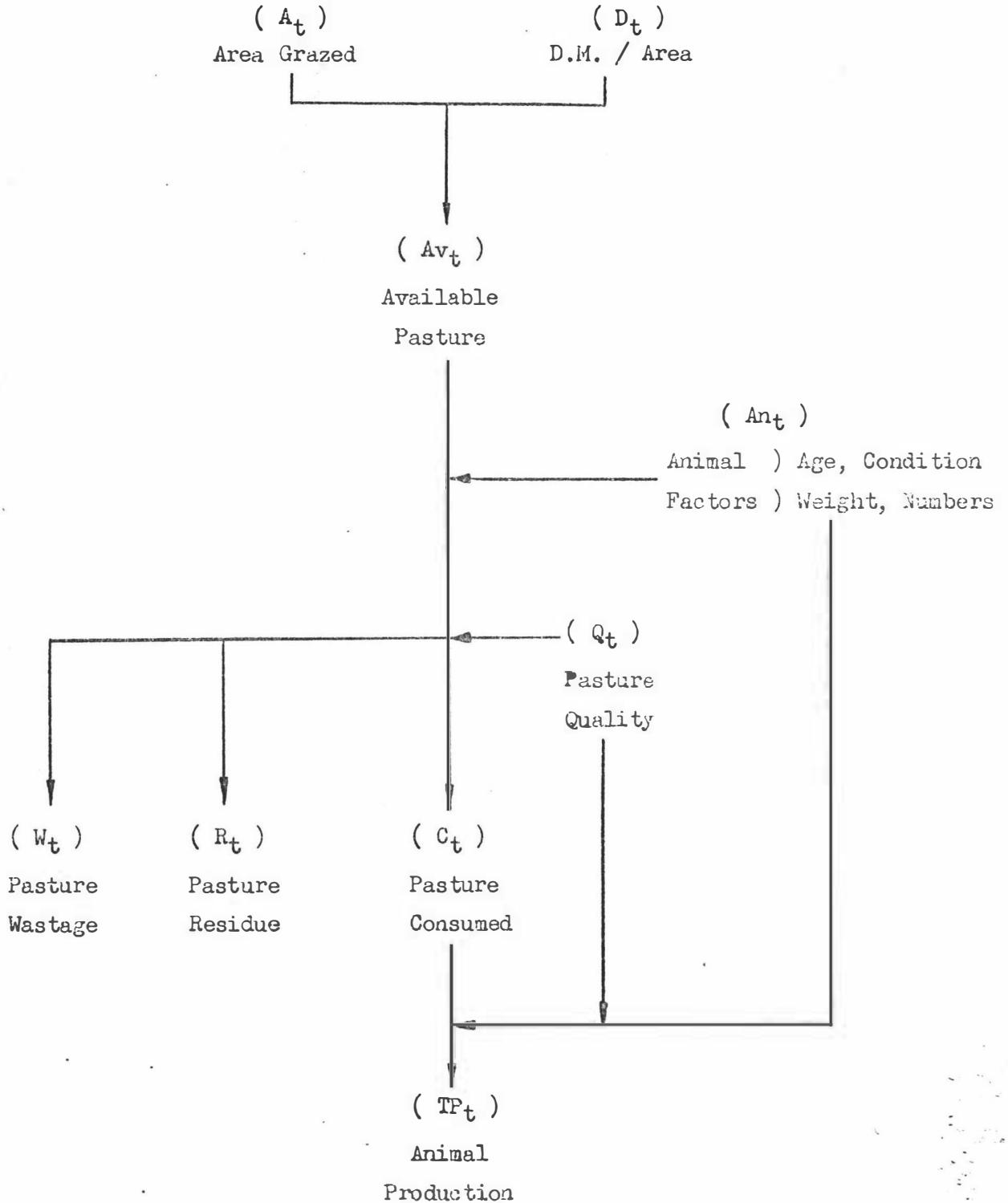
$$Q_{t+k} = g_2(R_t, W_t, k, T) \quad (2.7)$$

$$An_{t+k} = t + k \sum_{i=t}^{t+k} P_i \quad (2.8)$$

then the management decision made in period "t" on the area of pasture grazed (A_t) clearly affects animal production in period, "t + k", since the "state variables" of the system in period "t + k" are determined in part by R_t , W_t , P_t (from Equation 2.6 - 2.8). From Fig. 2.2 it can be

Fig. 2.2

INTERRELATIONSHIPS BETWEEN VARIABLES THAT AFFECT
PRODUCTION IN THE "t" TH PERIOD OF THE YEAR



2.2.1 Interaction Of The System Components Over Time (Continued)

seen that R_t and W_t , are determined by the "state variables" in period "t" and the area of pasture grazed (A_t) in that period. From equations 2.1 - 2.4 P_t is also determined by the decision on the area grazed (A_t).

2.2.2 Uncertainty Within The System

As mentioned in Sect. 2.1 uncertainty is introduced into the system by climatic and market factors.

It has been illustrated in Sect. 2.2.1 that the decision to graze a certain area in any period is based on knowledge of the system's state variables in that period and the likely outcome of that decision on state variables in subsequent periods. The climatic factors represented by T in equations 2.4 - 2.6 are not known with certainty when the planning exercise is undertaken. The extent to which the manager "hedges" against unknown future climatic conditions, particularly those which may result in reduced pasture growth, will depend on his knowledge of how the system is likely to react, and his aversion to risk. The decisions on the area of pasture to be grazed in any period, and hence the amount of pasture available for future grazings, and the number of animals grazed within the system, will vary depending on the particular manager's state of knowledge and aversion to risk.

As shown in Fig. 2.1 the value of production from the system is determined by the level of production that has been achieved up until the time of sale and the market factors that exist when the sale is made. Hence, in some periods of the year, the manager must make a decision on either selling animals under the current known market factors, or grazing them within the system for further periods when their value will be determined by unknown future market factors. The selling decision will depend on farmer goals, aversion to risk and knowledge of how the market is likely to react.

While the analysis of the dynamic nature of the grazing system discussed in Sect. 2.2.1 assumed that animal numbers remained constant the selling decision in any one period will affect animal production in future periods, since the amount of pasture consumed will be affected

by the numbers of animals present in the system. The effect of pasture consumed (C_t) on the state variables of the system in subsequent periods has been discussed in Sect. 2.2.1.

2.2.3 Summary Of System Components

The intensive beef grazing system has been shown to be complex in the number of components and interrelationships between components it contains. The manipulation of system components by the manager in an attempt to meet his goals is complicated by the interrelationships between components over time and the uncertainty introduced by climatic and market factors.

2.3 Research Work On The Components Of A Beef Grazing System

Because of the relative insignificance of intensive beef production as a form of farming in New Zealand in the past, research relating specifically to beef production is minimal when compared to other forms of livestock farming.

Wright (1973a) has presented schematically (shown in Fig. 2.3) how grazing systems evolve in practice.

The left-hand loop in Fig. 2.3 represents the process by which the farmer makes changes to his farming system; the right-hand loop, and the internal loop represent the research process. Thus, improvement in system performance, in either technical⁽¹⁾ or economic⁽²⁾ terms is brought about by the results and observations of both farmers and research workers.

The basic aim of research work should logically be to allow a better understanding of systems being used (Systems Analysis as in Sect. 1.2.1) to improve the control of these existing systems or allow

-
- (1) Technical system performance is measured by physical output e.g. amount of beef carcass produced/unit area.
 - (2) Economic system performance is measured by some financial output e.g. net profit/unit area.

more efficient systems to be designed. (Design and control are the two aspects of Systems Synthesis discussed in Sect. 1.2.1). However, as Campbell (1961) points out, the ad hoc nature of some research has often lead to confusion about grazing systems rather than to a clearer understanding of the system.

The components and relationships presented in Fig's 2.1 and 2.2 are used as a basis for the following discussion on some of the New Zealand research work on beef grazing systems.

2.3.1 Pasture Production And Grazing Management

Much of the available information on the growth of pasture in New Zealand can be attributed to Brougham's classical trials of the mid-fifties (e.g. Brougham 1955, 56, 59). Brougham's research involved the use of cutting treatments to simulate the grazing process. Factors such as light interception and its relationship with pasture residue, radiation, moisture and pasture species, were recognised as key factors in determining not only the amount of pasture that was produced over time, but also in the changes in rate of growth over time.

While cutting trials may not necessarily represent the pasture that is available to grazing animals, or the pasture residue that remains following grazing by animals, they should provide some valuable information on the growth (regrowth) of pasture if:

1. length of spell between cuttings is varied so that the shape of the pasture regrowth curve (the changes in rates of growth) can be defined from the results.
2. the height down to which pasture is cut is measured so that the effect of grazing severity on pasture regrowth can be determined.
3. some record is kept of the climatic factors that occurred during the period of the cutting experiment so that at least some hypothesis can be made about the effect of climate on pasture production.
4. Some estimation of pasture quality (e.g. digestible energy content) is attempted so that the value of

the pasture produced under different cutting treatments can be assessed in terms of the animal production it may support.

Pasture production that is useful in the sense that it takes into account points 1, 2, 3 and 4, will be difficult to collect under actual grazing situations because of:

1. the amount of research resources (e.g. land, animals) necessary to include sufficient treatments so that the effects of spelling length and grazing height can be investigated
2. the difficulty involved in imposing grazing height treatments using animals, and in measuring the height of grazing in an unevenly grazed sward.

Brougham (1970) has overcome these difficulties to a certain extent by imposing pasture managements (length of spell and grazing height) in combinations, and at times of the year, that he considered critical on the basis of his earlier cutting trial work. Brougham has shown in this work the beneficial effect on total D.M. production of hard-grazing a ryegrass-white clover sward in the winter and the detrimental effects of hard-grazing in the summer.

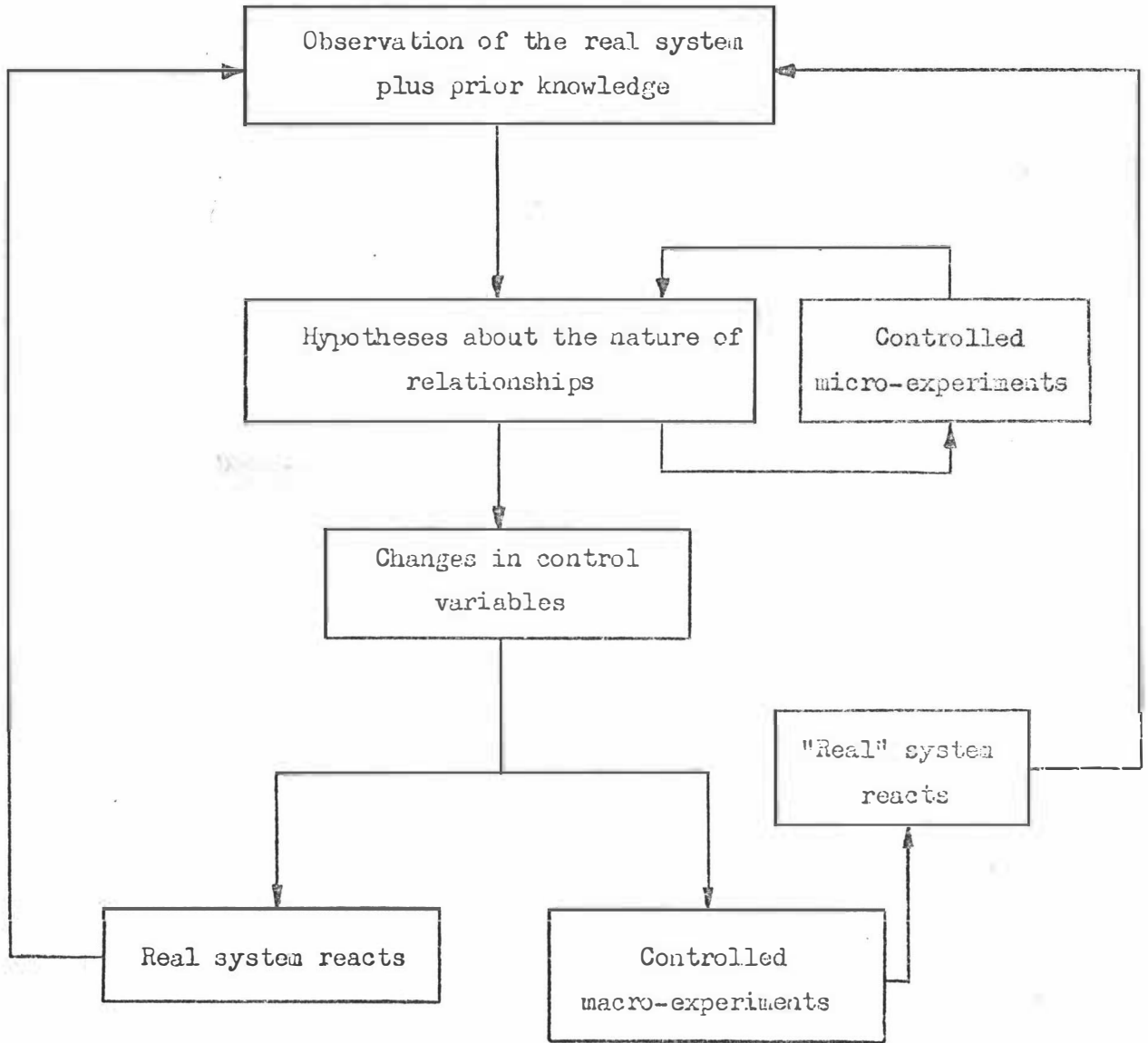
Apart from Brougham's research, very few other detailed studies are reported in the literature. The primary sources of pasture growth data throughout New Zealand are the fertilizer and rate of growth trials carried out by the Research Division (Field Research Section) of the Ministry of Agriculture (as reported in the Annual Reports of that Division). Such data do give some idea of pasture growth rates in areas geographically removed from the main research areas. However, the length of spell between cuttings and the height to which pasture is cut are seldom varied or reported on. Pasture quality is also seldom reported on in these trials.

Stocking rates trials often measure pasture production as well as animal production (e.g. MacLean et al 1970). However, the pasture production in such trials is a result of the grazing management applied

Fig. 2.3

THE EVOLUTIONARY DEVELOPMENT OF GRAZING MANAGEMENT SYSTEMS

(Source: Wright (1973))



2.3.1 Pasture Production And Grazing Management (Continued)

in the trial, and while the pasture production achieved can be discussed objectively in relation to the management practices used, it does not necessarily provide information useful in constructing management systems that are removed from the actual trial in time, location, or management variables involved.

Similarly pasture production data obtained from fixed interval grazing trials (i.e. where a 13 day rotation is compared with a 26 day rotation throughout lactation, as in the dairy system trial conducted at Waimate West, see Millar (1971)) are only applicable to the particular stocking rates, and hence grazing intensities that were present in the trial. Furthermore, it seems unlikely that one particular rotation length will necessarily outyield some other rotation length throughout all seasons of the year. Hence the 13 v's 26 days comparison, while it may be important in one particular season of the year, may have little application to commercial farming systems in other seasons of the year.

Fig. 2.3 implies that grazing systems are "evolved" through a process of considering what is known, making some hypothesis and testing that hypothesis through either "micro" or "macro" experiments; and then repeating the process after evaluating these experiments.

That a more formal framework for evaluating the results of these experiments may have led to a more efficient use of research resources in relation to pasture production studies is supported by two factors:

1. the large number of "stocking-rate", "fixed interval" type experiments as opposed to detailed pasture production studies published in the literature.
2. the lack of quantitative data available in the literature on the relationships between pasture management and pasture production.

2.3.2 Animal Production And Feed Requirements

It is of interest to note that in a symposium on the nutritional

requirements of livestock reported in the Proceedings of the New Zealand Society of Animal Production in 1961, while dairy cattle, sheep and swine were discussed, no mention was made of beef cattle.

The Annual Report of the Research Division of the Ministry of Agriculture (1965/66) reviews trials on beef production in progress at that time. These included comparisons of the growth rates of calves born in either the spring or the autumn; feeding trials where rising one-year and rising two-year cattle were fed a range of conserved feeds plus autumn saved pasture at two stocking rates; digestibility trials using sheep and cattle being fed a range of those conserved feeds and pasture and a study of beef production from various breeds and crosses of traditional beef and dairy-bred stock.

The Research Division Report (1966/67) stated:

"In the past beef cattle..... feeding and management programmes were not designed to produce high outputs of beef meat per acre. To achieve these efficiently and competitively with other systems of livestock farming, data are required on systems of grass production, management, and utilisation appropriate to beef production and yields from these must be assessed relative to those from alternative and competitive types of livestock farming."

A trial started at that time (reported by Joyce (1970)) compared dairy beef as a production alternative to wethers and breeding ewes at a range of stocking rates. Many other beef production trials have been initiated since 1966/67 (e.g. MacLean et al (1970)). However the emphasis tends to have been placed on ascertaining production possibilities under some predetermined management system, comparing beef production in different environments or comparing differences in performance between breeds or sexes, rather than an analytical research looking at the components and interrelationships discussed in Section 2.2.1.

An exception to this trend is the work reported by Heardon (1975) in which the responses in liveweight gain to supplementary feeding have been studied. A range of pasture availabilities and supplementary feeds were supplied to the animals. As well as measuring

animal intakes under the different treatments, the relationships between available pasture and animal intake were studied. Some information was also recorded on the effect of pasture residue on pasture regrowth.

In 1971 when reviewing the feed requirements of beef animals for maintenance and production in New Zealand, Joyce (1971) stated:

"any recommendation other than the maintenance requirements of cattle lie between 90 and 270 M.Cal. of metabolizable energy (M.E.) per kilogram of metabolic liveweight..... would be a gross oversimplification of the problem."

Discussing the requirement above maintenance for beef production Joyce (1971) concluded:

- "(1) Results from grazing experiments in New Zealand, while agreeing in general with the utilisation of M.E. fed above maintenance as laid down in feeding standards, indicate that the total feed requirements are considerably in excess of these standards.
- (2) The type of experimentation carried out over past years in New Zealand has not led to any marked advance in defining feed requirements of grazing beef cattle in New Zealand. When cattle feeding experiments are laid down they should be designed so that intakes can be interpreted in terms of:
 - (a) Liveweight
 - (b) Rate of gain
 - (c) Type of diet

Until this is done it is doubtful if any worthwhile progress will be made in defining the optimum feeding levels for cattle under New Zealand grazing conditions."

2.3.3 The Use Of Research Data In This Study

This study is an attempt to use systems modelling as a means of

aggregating the information known about beef production systems in a form that can be experimented with, so that some conclusions can be drawn on the effect of grazing management on beef production.

Whether or not a modelling study such as this can contribute to the efficiency of the evolutionary nature of the research process described in Fig. 2.3 will only be determined when similar studies are run in conjunction with physical research projects and some (subjective) attempt is made to evaluate the contribution of the modelling exercise.

As this study was carried out in isolation from any physical research work on beef production, the modelling exercise provides only a framework for collecting available information and a chance to evaluate the suitability of Linear Programming as a modelling technique for studying grazing system problems.

2.4 Systems Modelling Studies On Beef Production In New Zealand

2.4.1 The Profitability Studies Of Lattimore (1970) And Lowe (1971)

The objective of Lattimore's study was:

"to examine in detail the economics of beef production from retained (or purchased) calves on the dairy farms where these calves are available at present."

A survey of mixed beef-dairy farms was carried out to obtain the ideas, and experience of a large number of farmers, on the various facets of beef production. Given this information and the technical data available, a Linear Programming model was then constructed to evaluate the profitability of beef production on three selected case-study farms.

The optimisation routine of the Linear Programming technique allowed the resource (land, feed supply, labour) structure of each farm to be allocated simultaneously to various production possibilities (dairy and beef) so that profit from the use of those resources could be maximised. Optimal farm plans were obtained under a range of dairy

and beef prices.

Lattimore pointed out that the major limitation of the study was application of the results to other farms that have varying resource structures. In particular, he referred to the working capital requirements between farms, the variation in land type between farms, the availability of labour, and the organisational skills that different farmers possess.

However, the validity of Lattimore's study also depends on the accuracy with which he has defined the relationship between available feed and animal production. The approach used was to define available feed in each month of the year by multiplying the case-study farms' actual stock carried by the animal feed requirements of those stock for each month of the year. The amount of feed available was then assumed not to vary whether the farm was running dairy cattle, beef cattle, or any combination of the two. Hence the effect of grazing management was not included in the study. Lattimore recognises this fact and states that within the scope of his study:

"the analysis of the case farms was concerned with the feasibility and profitability of substituting beef cattle for dairy cows at a similar stocking rate to that operating on the farm at present."

Lattimore was interested in how some predetermined beef production activities may be substituted for the dairy farming activities being run on the farm. Devising more efficient beef grazing systems was outside the scope of his study.

Lowe (1971) stated that the objectives of his study were:

"(1) to investigate the various aspects of beef producing systems and find which system is likely to return most net profit to the farmer.

and

(2) to compare beef production systems with sheep farming systems on a profitability basis."

Again relevant information was collected from a large number of farmers who had some experience with the system being studied; and feed supply, calculated from estimates of the requirements of stock already being run on the farm, was allocated to various stock alternatives so as to maximise profits. A Linear Programming model was used for the calculation of optimal stocking policies over a range of product (sheep and beef) prices.

As in Lattimore's study, the effect of management on output from the system is only considered to the extent that the model could choose between various stock policies, the feed requirements of which had been predetermined. The possibility of altering feed supply by pasture management other than that needed to meet the requirements of the production possibilities outlined is not considered.

Despite the rather restrictive management possibilities inherent in Lowe's and Lattimore's studies, they do provide information on grazing systems that is complementary to that information produced by physical research.

They allow available research information to be assembled, they allow production possibilities defined by that research information and by farmers' experience to be outlined, and they investigate how those production possibilities may be most economically combined within the resource structure of commercial farms.

The studies of Lowe and Lattimore do not however, and nor were they intended to, provide information on how beef production systems may be run more efficiently by altering the relationships between available pasture, pasture consumed and future pasture growth. Rather their approach is one of maximising returns from a given amount of available pasture by investigating how various types of animals might use that pasture.

2.4.2 The Simulation Study Of Wright Vallance And Nicol (1973)

This study was designed to investigate the possibility of fattening beef cattle on irrigated lucerne and Tama ryegrass in the Canterbury

environment.

Lucerne and Tama production data that were available from field trials were included in a simulation model so that for a given pattern of defoliation, feed supply throughout the year could be described.

Animal production response functions were defined for the animals (Friesian crossbred animals purchased at 6 months of age and 400 - 500 lb liveweight and finished at 18 - 20 months of age yielding carcasses of 500 - 600 lb) to be grazed in the system.

The simulation model was run on a computer to:

1. establish a base system. This was primarily a problem of scheduling stock numbers in relation to a specified pattern of feed availability;
2. test the sensitivity of the output from the base system to changes in what were considered to be key variables - feed quantity, feed quality, utilisation of available feed by the animals, and prices paid for the animals.

The model did not include any optimisation procedure. However, the fact that a whole year's data could be generated quickly by the computer model for a given set of assumptions, allowed a trial and error method of defining better systems to be employed.

This simulation study allowed the known information to be collected and used to define possible production systems. The aim of the study was to provide information to research workers who were interested in setting up field trials on the systems studied.

Nicol (1973) reported on the setting up of a field trial on this lucerne-tama-beef system. He concluded that the systems modelling exercise prior to the setting up of the field trial had:

- "(a) Brought personnel from a number of disciplines together in a formal way to their mutual benefit.

- (b) Identified areas where historical data was lacking and indicated areas for research.
- (c) Been a useful tool for teaching basic husbandries (the study was carried out at Lincoln College).
- (d) Acted as a basis for the request for grants to establish a field trial.
- (e) Contributed relatively little towards the running of the trial since its initiation.
- (f) The potential to be used, once data becomes available from the field trial, in making recommendations for improvements in the field trial."

From the basis of these observations, the modelling exercise could be judged as having been useful. The continued usefulness of modelling in the study outlined, and the useful application of modelling in other fields of grazing management research seems to be dependant on whether or not the potential mentioned in point (f) above, actually adds to the efficiency of the evolutionary nature of research as discussed in Sect. 2.3.

2.5 A Dairy Farming Systems Modelling Study

To investigate the economics of the use of nitrogen fertilizer on factory supply dairy farms Pollard (1972) constructed a Linear Programming model of a dairy grazing system.

The model was designed so that it could determine the grazing management system (area grazed in each period and length of spell between grazing) that would maximise net profit for a range of stocking rates.

Pasture production data was specified throughout the year for a range of spelling dates and predetermined grazing heights which were assumed to be optimal (based on Brougham's (1970) recommendations).

Butterfat production functions for each stage of lactation were specified (within limits) in relation to feed requirements.

While the objectives of the study were:

"..... to examine in detail both technical and economic factors associated with fertilizer N use....."

the limitations expected to be imposed by the lack of experimental data meant that the scope of the study included:

"..... a consideration of the major problems to overcome in developing a realistic grazing model."

As the size of the model used approached the limit that could be handled on the available computing facilities, the time involved in each run of the model was 3 - 4 hours. Analysis of each solution also took several hours. These two factors meant that little experimentation could be carried out. Recommendations on grazing systems based on the modelling exercise were thus quite limited.

Lack of knowledge about relationships within the grazing system also detracted from the degree of reality achieved in Pollard's study (e.g. the utilisation of available pasture by grazing animals).

2.6 The Comparison Of Linear Programming With Simulation As A Technique For Studying Grazing Systems

As mentioned by Pollard (1972) the rigid framework of Linear Programming (L.P.) causes some problems in handling non-linear functions and stochastic variables. As well as these, in the case of beef production there are difficulties in including some decision rules within the L.P. framework. In particular, the model is unable to make a decision on the level of liveweight gain that animals may achieve in any period of the year since, liveweight gain is determined by the amount of feed available, and the liveweight of the animals in that period. The liveweight of animals during any period is determined by the liveweight gain that has been achieved in previous periods.

Other modelling techniques, and in particular, simulation can

handle non-linear functions, stochastic variables and any decisions rules the operator may wish to include. Simulation does not however include an optimisation routine like L.P. and since optimisation is almost invariably sought in the study of grazing systems, an experimental procedure is usually developed so that the simulation is first run under some set of decisions. The output is then examined with regard to the decisions that were included in the model, the decisions are changed, and the model is re-run, hopefully with output becoming more nearly optimal.

In any particular situation, application of Linear Programming leads to optimal decision rules. Although these decision rules (stock numbers, grazing management) are based on perfect foresight, they can be tested under any other situation. Under different pasture growth conditions, for example, a given set of decision rules will result in different levels of livestock output. However, we can also use the Linear Programming model to determine the optimum decision rules, and associated level of system performance, for each situation. In this way then we can use Linear Programming to estimate the opportunity cost of a given set of decision rules under different situations.

While simulation can handle stochastic variables these are rarely included in simulation studies. The approach more usually is to conduct some experimentation under a predetermined set of system inputs (e.g. climatic factors). The inputs are changed and the experimental procedure is then repeated. A similar approach can be used with L.P. and the optimisation routine is again an added advantage, in that system output is optimal for the given conditions.

2.7 The Model Used

Initially pasture was included as the only feeding opportunity in the L.P. model. A pattern of animal production was defined, and the animal feed requirements calculated. These requirements were then included on a per animal basis within the L.P. model. The model was then used to derive a grazing management pattern so that the number of animals grazed in the system was maximised. Associated with output of the model was information on the periods of the year where pasture supply was limiting increases in the number of animals grazed and

conversely those periods of the year when feed supply was surplus to animal requirements. Based on this information the pattern of animal production was changed and the model re-run.

The factors affecting pasture production and animal performance and the way they are included in the modelling exercise are discussed in Chapters 3 and 4 respectively. A detailed description of the experimentation is given along with results in Chapter 5. Sect. 6. discusses more fully the limitations found to exist with L.P. as a method for studying grazing management systems.

2.8 Summary

The beef grazing system has been shown to be complex both in the number of components involved, and the interaction of these components over time. Uncertainty about future system output is introduced by climatic and market factors over which the farmer has little or no control.

Some doubt is raised as to whether or not current forms of pasture production research leads to a better understanding of grazing management systems. Research on animal production has in the past, tended to concentrate on the differences in the level of output from various animal production systems, while the factors affecting production within these systems have, in many cases, remained unknown. Mathematical modelling has been used as a framework for gathering together information that is known about grazing management systems. Whether or not modelling exercises improve the evolutionary process by which management systems are devised remains unclear.

That Linear Programming is a rigid framework with some apparent disadvantages for the study of grazing management systems has been noted. The disadvantages, in many cases, however, may be no greater than in other modelling techniques; and the optimisation routine inherent in Linear Programming is an advantage often sought by those other techniques.

The L.P. model used allocates available pasture so that the maximum number of animals can meet a predetermined pattern of liveweight gain.

CHAPTER THREE

PASTURE GROWTH

3.1 Introduction

Factors that have been shown to affect the production of pasture are discussed in this chapter. Pasture production data for the Palmerston North region are considered and a family of production functions relating dry matter (D.M.) regrowth to grazing severity (height and length of spell) are described.

The incorporation of these functions into a Linear Programming (L.P.) model is outlined and the management decisions the model can make are discussed in relation to the real-life situation.

Finally, the maximum annual D.M. production from the model is determined.

3.2 Factors Affecting The Regrowth Of Pasture

3.2.1 The Pasture Regrowth Curve

Brougham (1955) has described the regrowth of pasture in terms of a sigmoid curve. The three distinct phases of regrowth as described by Brougham are shown on a generalised curve in Fig. 3.1.

Daily increments of pasture D.M. increase (phase I) following severe defoliation until constant and maximum increments are attained (phase II). Depending on the pasture species present, competition between the species present for light, moisture, and soil nutrients, and the presence of destructive organisms, daily increments finally begin to decline (phase III).

Brougham (1956) demonstrated that the duration of phase I was largely dependant on the percentage of incident light that the sward residue was able to intercept following defoliation. Where pasture was cut to either 1", 3" or 5" in mid-September the maximum daily

increment in D.M. occurred on the 24th, 16th and 4th day respectively.

Brougham also showed that the beginning of phase II coincided approximately with the attainment of a Leaf Area Index (L.A.I.)⁽¹⁾ of 5. The pasture yield at this point was 1,450 lb D.M./acre regardless of the initial cutting height.

3.2.2 Changes In Growth Curves Throughout The Year

From the results of cutting trials on an irrigated short rotation ryegrass/white clover pasture, Brougham (1959) was able to construct a set of potential pasture regrowth curves which related D.M. present in the sward to the number of days following defoliation at different times of the year.

Daily growth rates for total D.M. and for the ryegrass and clover components of the pasture changed gradually throughout the year with seasonal changes in light and temperature after the effects of temporary "weather"⁽²⁾ fluctuations were removed from the analysis.

Average daily total D.M. increments ranged from 10 lb/acre in winter to 120 lb/acre in early summer. The yield of the ryegrass component was comparatively more important than clover over the winter and spring periods, while the contribution to total yield by the clover component increased with the onset of summer until the late autumn.

Brougham explained these differences in growth rate and pasture composition in terms of species temperature tolerance, inter-species competition for light and seasonal growth patterns of the species and tissue decomposition.

3.2.3 The Effect Of Management On Pasture Growth

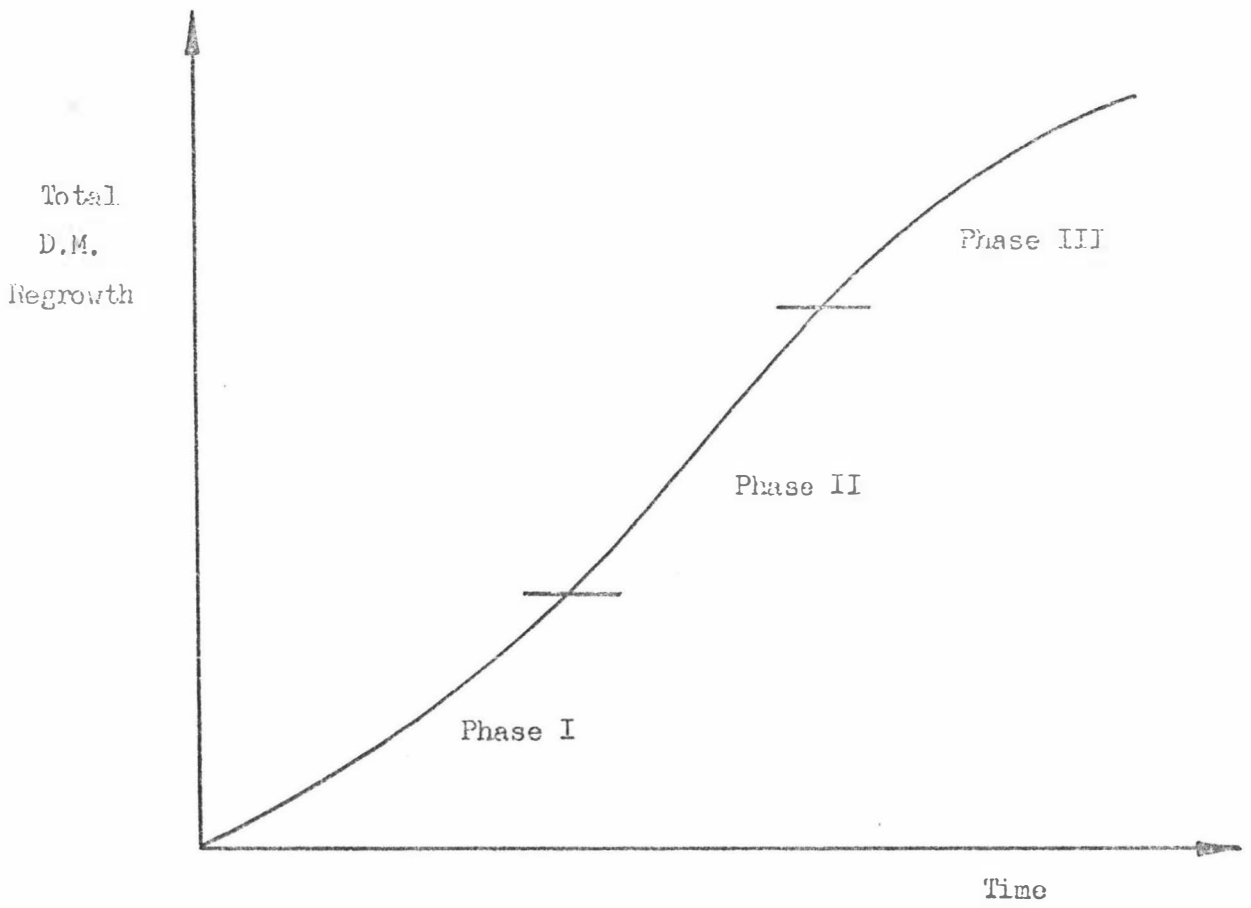
As discussed in Sections 3.2.1 and 3.2.2, pasture regrowth depends

(1) L.A.I. is defined by Brougham (1961) as the area of leaf per unit area of ground.

(2) Weather fluctuations were changes of weather that occurred within the week that D.M. yield was measured, and accounted for as much as \pm 50% of the growth rate in that week.

Fig. 3.1

Generalised Pasture Regrowth Curve



3.2.3 The Effect Of Management On Pasture Growth (Continued)

on the height to which pasture is grazed, the time since grazing, and the climatic conditions that prevail during regrowth. For any given set of climatic factors then, the decisions made by the manager of the grazing system, on the height to which pasture is grazed and the length of spell between grazings will determine the amount of pasture available for grazing. The effect that these grazing management decisions may have on available pasture are discussed below in a simple example and illustrated by Fig. 3.2.

Consider a 50 ha. beef unit running 200 fattening animals. An area of pasture has been grazed at some time "k" days before day "t". The D.M. present since that grazing on day "t - k" is represented by the function a. On day "t" 2000 Kg D.M./ha are present on the pasture. Given sufficient available pasture it is assumed that the animals within the system will eat 10 Kg D.M./head/day.

In case I the manager decides to feed $2\frac{1}{2}$ ha of pasture on day "t" (i.e. it will take 20 days of feeding $2\frac{1}{2}$ ha of pasture/day before the pasture grazed on day "t" will be grazed again).

Case I

Feed available/day	=	(2000 Kg D.M./ha x $2\frac{1}{2}$ ha)	=	5000 Kg D.M.
Appetite requirement	=	(200 animals x 10 Kg D.M./hd)	=	<u>2000</u> Kg D.M.
Uneaten pasture			=	3000 Kg D.M.
Pasture residue/ha	=	(3000 Kg D.M./ $2\frac{1}{2}$ ha)	=	1200 Kg D.M./ha

In case II the decision is to feed only 2 ha. of pasture on day "t" (i.e. a 25 day rotation).

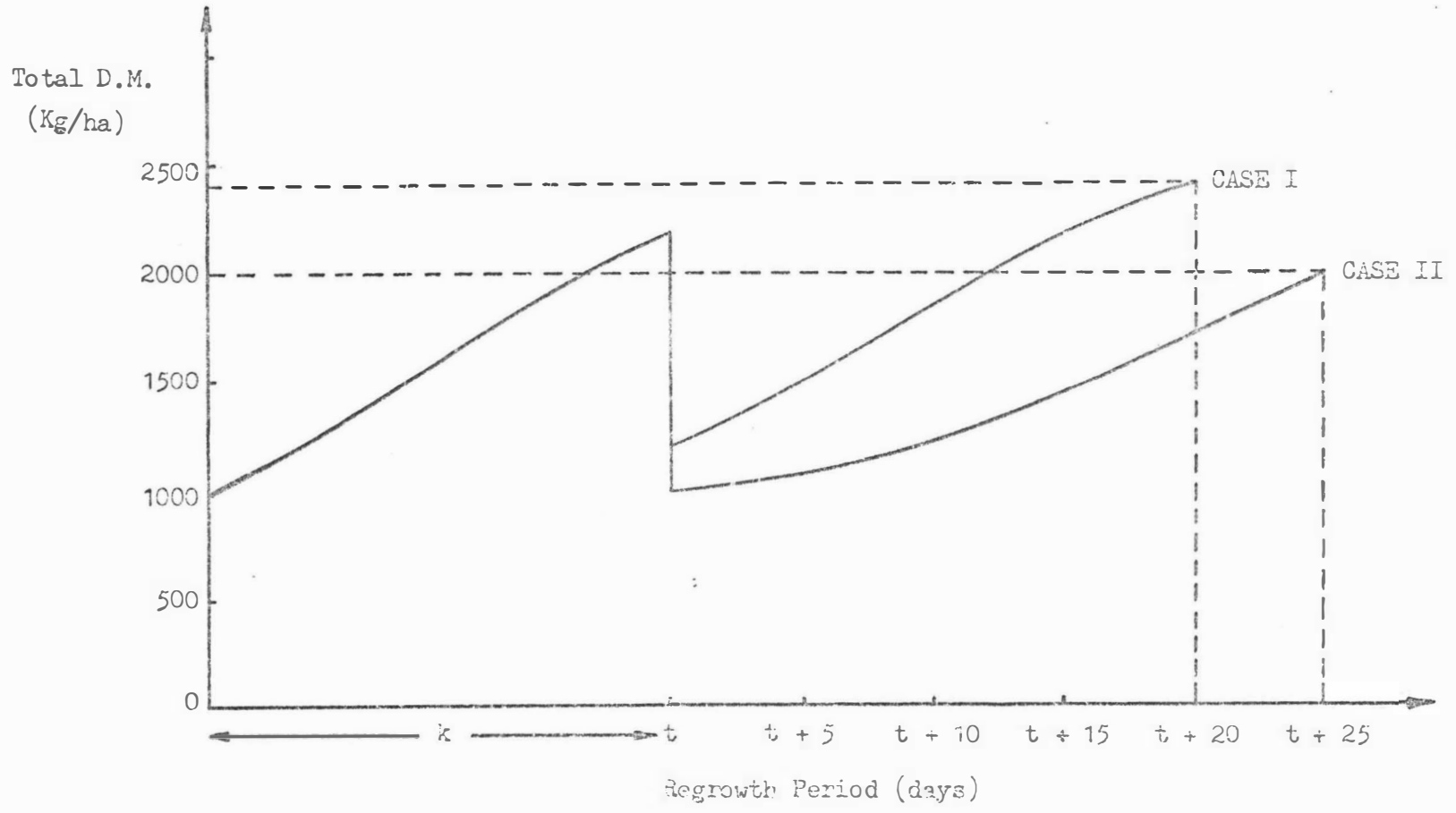
Case II

Feed available/day	=	(2000 Kg D.M./ha x 2 ha)	=	4000 Kg D.M.
Appetite requirement	=	(200 animals x 10 Kg D.M./hd)	=	<u>2000</u> Kg D.M.
Uneaten pasture			=	2000 Kg D.M.
Pasture residue/ha	=	(2000 Kg D.M./2 ha)	=	1000 Kg D.M.

Assuming the pasture regrowth curves in Fig. 3.2 the feed available after a 20 day rotation (Case I) will be 2400 Kg D.M./ha, while the outcome

Fig. 3.2

Representation Of Hypothetical Management Decisions



3.2.3 The Effect Of Management On Pasture Growth (Continued)

of the decision in Case II is that only 2000 Kg D.M./ha are available at the next grazing.

In this example then, the grazing management in Case I tends to build up feed, while the grazing management in Case II tends to maintain available pasture D.M. Although this example is an oversimplification of the real-world situation, it does illustrate the way in which grazing management can affect pasture production.

Brougham (1970) has shown the importance of grazing height and length of spell between grazing at two times of the year. In late autumn a mixed ryegrass/clover pasture was defoliated. The three treatments imposed following that grazing on April 3rd were:

- i) Graze again in 18 weeks
- ii) Two grazings at 9 week intervals
- iii) Three grazings at 6 week intervals

The D.M. yields over that eighteen week winter period were 2120, 3290, and 3620 lb D.M./acre respectively. While this represented a 70% increase in D.M. production for the three-grazing treatment over the one-grazing treatment, the pasture grazed three times over the winter also had a higher clover content in the spring, due to increased illumination at the base of the sward, and higher spring D.M. production.

Brougham (1970) found that grazing height was particularly critical over the summer period in the Palmerston North environment. In early summer a pasture that had been uniformly grazed for the previous 18 months was subjected to three grazings at three weekly intervals. Half the pasture was grazed hard while the other half was grazed only to 3". Following these treatments the whole pasture was grazed uniformly. The grazing heights following the period of treatment, although not specified, were considered by Brougham to be such that pasture production was maximised over the rest of the year. The advantage in daily D.M. increments to the lax grazed pasture was in the order of 50 - 100% over the rest of the summer and the autumn period. Brougham attributed this effect to increased soil moisture levels due to the increased pasture

cover over the summer period, and to increased survival of grass tillers under the lax grazing treatment.

Because of the interaction between grazing management, pasture species present and climate, and the need to meet animal requirements, definition of an optimum grazing system is a complex task.

From the results of his trial work, Brougham (1970) has suggested grazing management recommendations for mixed ryegrass/white clover pastures in the Palmerston North region. These recommendations are presented in Table 3.1 and are stated by Brougham to frequently produce 16-17000 lb D.M. per acre.

Table 3.1

Management System For A Mixed Sward In The Palmerston North

	<u>Area</u>			
	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>
Grazing Interval (weeks)	6 - 8	3 - 4	4 - 5	Hardgraze 4 - 6
Grazing Height (inches)	1 - 2	1 - 3	3 - 4	1 1 - 2

3.2.4 The Effect Of Grazing Animals On Pasture Production

3.2.4.1 The Number Of Animals Grazed

Many experiments are reported in the literature as having measured pasture production under different stocking rates (animals/unit area) and different types of stock.

Campbell (1969) measured the annual D.M. production of pastures grazed by sheep at 10 and 15 ewes/acre. In both treatments the spell between grazings was seven days. The lower stocking rate treatment outyielded the high stocking rate treatments, in terms of D.M. produced, by 25% over 2 years. Hull et al. (1961) who grazed beef cattle at 5 stocking rates (1.3 to 4.7 animals/acre) on irrigated pastures, also found that pasture production declined with increased stocking rate. The spell between grazing in this case was 35 days for all treatment.

Campbell's experiment however, included a further treatment in which pasture grazed by the higher stocking rate (15 ewes/acre) was spelled for 28 days between grazings. Pasture production in this case was 50% higher than that obtained under the same stocking rate and a seven day rotation.

Gordon et al (1966) considered that the neglect of grazing pressure measurements⁽¹⁾ could be a major reason for the large errors and poor repeatability of pasture experimentation. In view of Brougham's results (discussed in Section 3.2.3) regarding the effects of defoliation height and the interactions between this, length of spell and the season, it seems logical that some measure of grazing pressure and the resultant grazing height are necessary before the results from stocking rate and length of spell experiments can be very meaningful.

Hull et al (1961) also showed that while pasture regrowth from hard grazed pastures (those grazed by higher stocking rates) was higher in protein content, lower in lignin content, and hence higher in energy value, the actual pasture consumed by animals at the higher stocking rates was lower in energy value than pasture consumed by animals at lower stocking rates. This result was explained by the reduced opportunity for selective grazing at the higher stocking rates.

Campbell (1966a) has shown that higher grazing pressure allows less dead forage to accumulate in the pasture. The results of Hull et al however, suggest that differences in pasture quality (energy value) between pastures grazed at various grazing pressures may not be a true representation of the differences in the quality of pasture actually consumed at those grazing pressures.

3.2.4.2 The Treading Effect Of Animals

The presence of grazing animals also affects pasture production by mechanical damage caused by treading.

Hull et al (1961) found that D.M. yield from a treatment cut

(1) Grazing pressure here means the relationship between feed available, and the number of animals present.

for silage in their experiment, and hence not subjected to the damage caused by animal hooves, was about 35% higher than the treatment subjected to the highest grazing pressure. Some of this effect however, could have been attributed to differences in the defoliation height between the cutting and grazing treatments.

Edmond (1974) has shown that treading by sheep (at 49.4 equivalents/ha)⁽¹⁾ does reduce pasture yield by up to 30%. Clover plants were more susceptible than ryegrass in a mixed sward, and treading effects were greatest when the soil was at or above field capacity.

Campbell (1966b) has examined the effect of treading by dairy cows on autumn-saved pasture grazed in late winter. Two stocking rates were used, 60 cows/acre/day and 120 cows/acre/day, and pasture was mown as a control. The pastures were close to field capacity at the time of grazing and mowing. After treatment, pasture yield was measured as the difference between post-grazing residue and the amount of pasture present before the next grazing. Difference measurements continued for the remainder of the winter and the following spring and summer, during which time all treatments were subjected to the same grazing treatment. Three years data were collected.

Little variation in pasture yield was measured between the treatments, although large variations in pasture yield were measured between years. Campbell concluded that the small losses associated with treading would not affect animal production.

3.2.4.3 The Effect Of Faeces

The faeces dropped by animals during grazing will also affect pasture production.

Greenhalgh and Reid (1968) conducted an experiment where dairy

(1) Edmond (1958) has estimated that a grazing sheep walks 1.7 miles/day. Since a race one mile long x 4' 10" wide equals one acre, Edmond expresses the treading effect of 10 sheep walking through a 4' 10" wide race daily as equal to 10 sheep equivalents/acre. Similarly 300 sheep walking through the race once every 30 days represents $300/30 = 10$ sheep equivalents/acre. The figure 49.4 equivalents/ha described by Edmond (1974) equals 20 sheep/acre/day.

cows were grazed at two levels of grazing pressure on pasture that had previously been either mown or grazed. The previously grazed pasture had 2.8% of its area covered by faeces. By measuring the amount of pasture rejected in subsequent grazing they concluded that the presence of faeces affected animal intake over an area 8 - 12 times the size of the actual area covered.

3.3 Pasture Production Data Used In This Study

It has been shown that pasture production varies with the length of spell between grazings and the severity (height) of grazing. The interaction of these two factors with seasonal, climatic and animal factors can lead to changes in pasture composition and pasture production throughout the year.

Pollard (1972) derived a set of regrowth curves for a mixed sward (ryegrass/clover) growing in the Palmerston North locality in an average year. The data from which these curves were derived were provided by D.S.I.R. Grasslands Division staff based on their knowledge of how pasture was likely to produce under grazing conditions.

Throughout the year defoliation height was assumed to coincide with those figures suggested by Broughan (1970) (presented in table 3.1). Associated with this pattern of defoliation height would be a pattern of pasture compositional change - a pattern that according to Broughan should provide consistently high D.M. yields.

Wright (1973b) using the data from Pollard's study and other unpublished data simulated a series of relationships between D.M. present and pasture growth rate for all weeks of the year.

From these data it was possible to construct a series of pasture regrowth curves with the daily D.M. increments as a function of time after defoliation and defoliation height. Individual curves were constructed for regrowth after defoliation in each week of the year.

While the data generated by Wright referred to potential growth rather than the actual growth that may be expected in any particular

year, they did give some idea of the effect that grazing height may have on pasture regrowth.

As well as plotting D.M. present above defoliation height as a function of time after defoliation for a range of grazing severities (heights), the actual daily increments in D.M. present were also plotted. Generalised curves are shown in Fig. 3.3.

As would be expected from the work of Brougham (1956)⁽¹⁾ the maximum daily growth rates achieved after defoliation at a range of grazing severities varied little. The time taken for the pasture to achieve maximum daily growth rate did vary with defoliation height. In Fig. 3.3 the maximum daily growth rates achieved after grazing at either a HIGH or LOW grazing height are similar (c). The time taken to achieve this maximum daily growth rate however, is (d) days following a HIGH defoliation, and (e) days following a LOW defoliation.

The differences in pasture regrowth⁽²⁾ due to grazing severity were greatest over the late spring and summer periods. This result would be expected since the levels of incident light at that time of the year are at their maximum, and Brougham (1956) has shown the initial regrowth of pasture is dependant on the percentage of incident light intercepted by the pasture residue (discussed in Section 3.2.1).

The figures simulated by Wright, and the regrowth functions derived from them, take no account of changes in pasture composition, and hence future changes in pasture production due to compositional changes induced by hard or lax grazing. Due to a lack of other quantitative data on this interaction, the data made available by Wright's simulation was used to construct a family of pasture growth curves for this study.

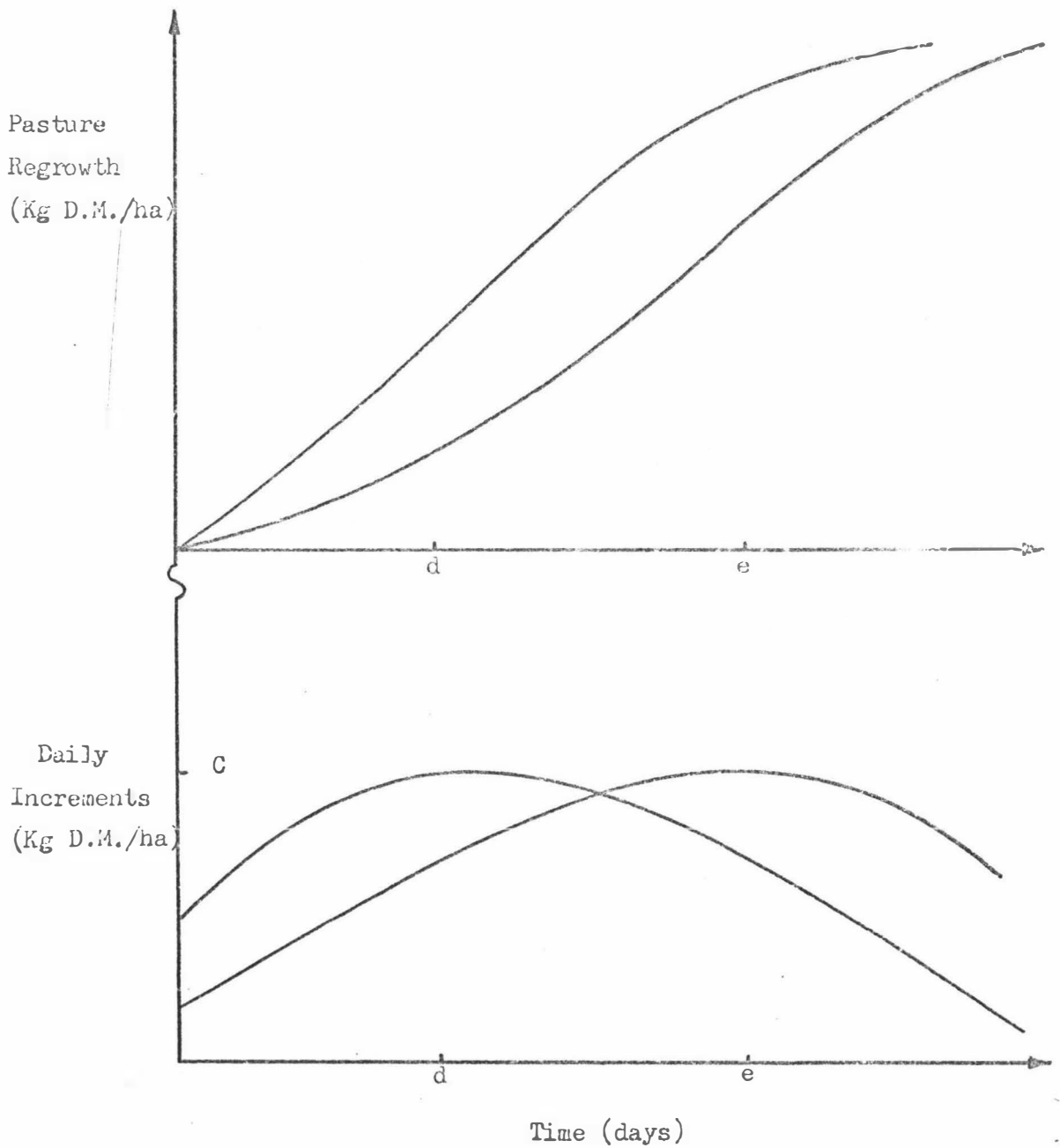
In order to devise this family of regrowth curves it was assumed that grazing could occur at either one of two grazing heights in each period of the year. The HIGH grazing height for any period was assumed

(1) Discussed in Section 3.2.

(2) The differences in pasture regrowth may be measured as the absolute difference between the regrowth curves at some point in time i.e. the horizontal distance between the HIGH and LOW curve after d days in Fig. 3.3.

Fig. 3.3

Pasture Regrowth And Daily Increments In D.M./ha
After HIGH And LOW Defoliation



to be 200 Kg D.M./ha above the grazing height used by Pollard (1972).⁽¹⁾ The LOW grazing height was assumed to be 200 Kg D.M./ha below the height specified in Pollard's study.

Then based on the differences in pasture regrowth shown to exist between pastures grazed to different heights in Wright's simulation of pasture production, a HIGH and a LOW regrowth curve were drawn about Pollard's regrowth curves for each season of the year. In this way a family of regrowth curves for each of two defoliation heights was constructed.

3.3.1 Assumptions Involved In Defining Pasture Regrowth

Inherent in this method of defining pasture regrowth functions is the assumption that the difference between the grazing heights used in this study and those used in Pollard's study (\pm 200 Kg D.M./ha) did not markedly affect pasture composition. Hence the relationships between pasture composition and D.M. production over the whole year remain essentially the same as in Pollard's study. Furthermore, absolute levels of D.M. present before or after grazing, as in Pollard's study, cannot be specified. Only the pasture regrowth available for grazing above a HIGH or a LOW grazing height can be specified. The relationships between D.M. available for grazing and time after grazing HIGH or LOW in each month of the year are presented in Tables 3.2 and 3.3 respectively.

The pasture available for grazing is defined in terms of Kg D.M./ha. Pasture quality (energy value) is assumed not to vary with height of grazing or the length of spell between grazings, at least for the range specified within the model.⁽²⁾

-
- (1) While the grazing severity (height) assumed in Pollard's study was based on Brougham's recommendations (Table 3.1) the absolute amount of pasture residue after grazing in each period was not specified in terms of D.M./ha.
 - (2) Differences in pasture quality throughout the year are considered in the calculation of animal feed requirements (Section 4.5.1.3).

The effects of grazing animals on pasture production due to trampling and defaecation are assumed to be incorporated implicitly in the defined pasture regrowth functions.

3.4 The Pasture Production Model

In real-life grazing systems the manager makes some decision on the area of pasture to be grazed in any period of the year, and hence the amount of pasture D.M. the animals are offered, after considering the amount of feed on hand, the amount of feed likely to grow, and the level of production he wishes the animals to attain.

The frequency with which he makes this decision depends on how often he decides to shift the animals to fresh pasture; a decision which is dependant on the amount of control he wishes to exercise over the problem of matching feed supplies and feed demand.

3.4.1 Pasture Production Possibilities Within The Model

The grazing year has been divided into 30 grazing periods. These are presented in Table 3.4. Grazing periods 5 - 27 inclusive are of 14 days, while periods 1 - 4 and 27 - 30, (the periods in which maximum rates of pasture growth occur) are of 7 days each.

In each period of the year the model can vary the amount of pasture available for grazing by choosing:

1. the area of pasture to be grazed
2. the height to which pasture is grazed (either HIGH or LOW)

The decision to graze a certain area of pasture in any period determines the length of spell between grazings since, in all periods, the total area of pasture must be accounted for as being either grazed or spelled. This decision (length of spell) plus the height to which pasture is grazed in any one period determines the amount of pasture

Table 3.2

Relationship Between D.M. Regrowth (Kg/ha) And Time
(Weeks) Since Grazing High

<u>Month</u>	<u>Length of spell (weeks)</u>									
	1	2	3	4	5	6	7	8	9	10
Jan	200	500	890	1220	1550	1790	1870	1900		
Feb	-	380	700	1050	1310	1510	1670	1700		
Mar	-	300	500	800	1100	1380	1600	1680		
Apr	-	320	620	900	1170	1390	1500	1570		
May	-	170	340	500	670	900	1060	1120	1150	1175
Jun	-	160	280	390	560	730	900	1060	1230	1430
Jul	-	220	330	500	730	950	1230	1510	1850	2130
Aug	-	220	500	900	1350	1780	2250	2550		
Sep	210	550	1000	1500	2120	2670	3220	3550		
Oct	310	780	1405	2020	2680	3350	4000	4400		
Nov	260	750	1400	2000	2550	3000	3300	3500		
Dec	275	600	975	1390	1775	2060	2200	2210		

Table 3.3

Relationship Between D.M. Regrowth (Kg/ha) And Time
(Weeks) Since Grazing Low

<u>Month</u>	<u>Length of spell (weeks)</u>									
	1	2	3	4	5	6	7	8	9	10
Jan	150	380	700	1050	1400	1620	1850	1830		
Feb	-	200	500	800	1110	1400	1620	1700		
Mar	-	200	380	600	890	1220	1500	1680		
Apr	-	250	480	770	1070	1350	1500	1600		
May	-	170	340	500	670	900	1060	1120	1150	1175
Jun	-	160	280	390	560	730	900	1060	1230	1430
Jul	-	220	330	500	730	950	1230	1510	1850	2130
Aug	-	180	400	780	1200	1700	2200	2550		
Sep	-	400	820	1300	1900	2520	3150	3600		
Oct	-	560	1060	1600	2400	3160	3850	4300		
Nov	200	520	1000	1600	2230	2800	3220	3480		
Dec	160	410	750	1120	1500	1875	2100	2250		

Table 3.4

Periods Within The Grazing Year

<u>Period</u>	<u>Includes Days</u>
1	1 - 7 November
2	8 - 14 "
3	15 - 21 "
4	22 - 28 "
5	29 - 12 December
6	13 - 26 "
7	27 - 9 January
8	10 - 23 "
9	24 - 6 February
10	7 - 20 "
11	21 - 6 March
12	7 - 20 "
13	21 - 3 April
14	4 - 17 "
15	18 - 1 May
16	2 - 16 "
17	17 - 30 "
18	31 - 13 June
19	14 - 27 "
20	28 - 11 July
21	12 - 25 "
22	26 - 8 August
23	9 - 22 "
24	23 - 5 September
25	6 - 19 "
26	20 - 3 October
27	4 - 10 "
28	11 - 17 "
29	18 - 24 "
30	25 - 31 "

Table 3.5

Maximum And Minimum Spells And Spelling Options After
Pasture Is Grazed For Each Period Of The Year

<u>Period</u>	<u>Length of Spell Options (days)</u>		
1	14	21	31
2	14	24	38
3	17	-	31
4	10	24	38
5	14	28	42
6	14	28	42
7	14	28	42
8	28	-	42
9	28	-	42
10	28	-	42
11	28	-	42
12	28	-	42
13	28	-	42
14	28	42	56
15	28	42	56
16	42	56	70
17	56	-	70
18	56	-	70
19	56	-	70
20	42	-	56
21	42	-	56
22	42	-	56
23	28	-	42
24	28	-	38
25	14	24	31
26	17	24	31
27	14	21	35
28	14	21	35
29	14	21	35
30	14	21	38

3.4.1 Pasture Production Possibilities Within The Model (Continued)

available for grazing in subsequent periods.

The length of spell for which pasture may be spelled after grazing is constrained:

- firstly within a minimum and maximum spell which varies with the time of the year at which grazing takes place;
- and secondly in the number of spelling alternatives within that range.

Maximum and minimum spells are defined in Table 3.5 along with the spelling options for pasture grazed in each period.⁽¹⁾ The range of spelling dates are common to pasture grazed HIGH and LOW and coincide approximately with the beginning and end of that period of regrowth when maximum daily increments of D.M. occur. These ranges also coincide approximately with the spelling times suggested by Brougham (1970) which are presented in Table 3.1. A comparison between Brougham's recommendations and the range of spelling options specified in the model is presented in Table 3.6.

3.4.2 The Structure Of The Model⁽²⁾

Each of the 300 pasture activities (P_j 's) included in the model, represents one hectare of land spelled from the mid-point of one period and making pasture available for grazing in some later period.

75 of the pasture production activities represent pasture grazed

(1) The reasons for limiting the number of spelling options are discussed in Section 3.4.4 along with reasons for the apparently unsymmetrical nature of Table 3.5. The limitations of defining spelling length within the model are discussed in Section 3.4.2 and more fully in Section 6;

(2) The mathematical structure of the pasture production matrix is described in detail in Appendix 1.

HIGH in one period, spelled for a specified time, and then grazed HIGH again in a subsequent period.

The actual lengths of spell between grazing are those defined in Table 3.5. For example, the first pasture production activity, P₁, spells pasture grazed HIGH in period 1 for 14 days (i.e. until period 3) when the pasture can again be grazed HIGH.

P₂ spells pasture grazed HIGH in period 1 for 21 days (until period 4).

P₃ spells pasture grazed HIGH in period 1 for 31 days.....
through to.....

P₇₄ spells pasture grazed HIGH in period 30 for 21 days (i.e. into period 3)

P₇₅ spells pasture grazed HIGH in period 30 for 38 days (into period 5).

Similarly 75 activities (P₇₆ - P₁₅₀) are defined for pasture grazed LOW, spelled, and then available for grazing LOW again.

Activities P₁₅₁ - P₂₂₅ allow pasture grazed HIGH to be spelled, and then grazed LOW, and activities P₂₂₆ - P₃₀₀ allow pasture grazed LOW to be spelled and then grazed HIGH.

Table 3.6 Comparison Of Spelling Lengths Allowed In The Model
With The Recommendations Of Brougham (1970)

	Length of Spell (in weeks)			
	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>
Brougham's (1970) Recommendations	6 - 8	3 - 4	4 - 5	4 - 6
Constraints on spelling length used in the model (see Table 3.5)	6 - 10	2 - 5	2 - 7	3 - 8

3.4.3 The Representation Of The Grazing Process By The Model

3.4.3.1 The Length Of Spell Between Grazings

Animal feed requirements (discussed in Section 4.5.1) are specified on a per head basis for each period of the year so that a predetermined level of animal performance (liveweight gain) is achieved. The pasture production model is required to define a grazing management plan (area of pasture grazed and height to which pasture is grazed in each period) so that the maximum number of animals may be grazed within the system; subject to the restriction that the feed supplied in each period of the year (determined by the area of pasture and the height to which pasture is grazed) is greater than or equal to the feed required in each period of the year (which is the predetermined per head feed requirement times the number of animals run in the system).

Hence the area of pasture grazed in each period of the year, as chosen by the pasture production model, is actually grazed over a 14 or 7 day period depending on the period of the year it refers to. This may be related to the real-life situation by the example below.

Example (Refer to P_1 in Table 3.7)

Assume the model decides to make feed available in period 3 by including 10 ha of activity P_1 in the grazing management plan. P_1 takes pasture grazed HIGH in period 1 (a 7 day period), spells it for 2 x 7 day periods and makes pasture available down to the HIGH grazing height in period 3 (a 7 day period from November 15 - 21).

Where the animals in the real-life situation are shifted to fresh pasture every day then the model assumes that $\frac{1}{7}$ of 10 ha is fed on each day of period 3 so that the daily feed requirements for that period (per head requirements times the number of animals in the system : divided by 7 days) are met each day. Furthermore, the model assumes that the pasture fed on the 1st day of period 3 (Nov. 15) was last grazed on the 1st day of period 1 (Nov. 1), 14 days previously.

In fact the model actually assumes that pasture is grazed instantaneously at the mid-point of each period. That is the feed requirements of the animals in period 3 are met by grazing the 10 ha of pasture supplied by activity P_1 on the 18th of November. This pasture was previously grazed at the mid-point of period 1 (Nov. 4). This is a slightly more accurate interpretation of how the model represents the grazing process since the explanation in the example on page 53 assumes that the regrowth of pasture grazed on the 1st November is the same as that grazed on the 7th November.

3.4.3.2 The Height To Which Pasture Is Grazed

It has already been stated that a basic restriction within the model is that pasture supplied in each period (or each day within a period) must be greater than or equal to the feed required in that period (or day within that period).

Where the feed requirement specified for a period (day) is less than the amount the animals within the system would eat in a period (day),⁽¹⁾ it is assumed that the system manager shifts the animals off the grazing area after they have achieved the intake specified for that period (day).

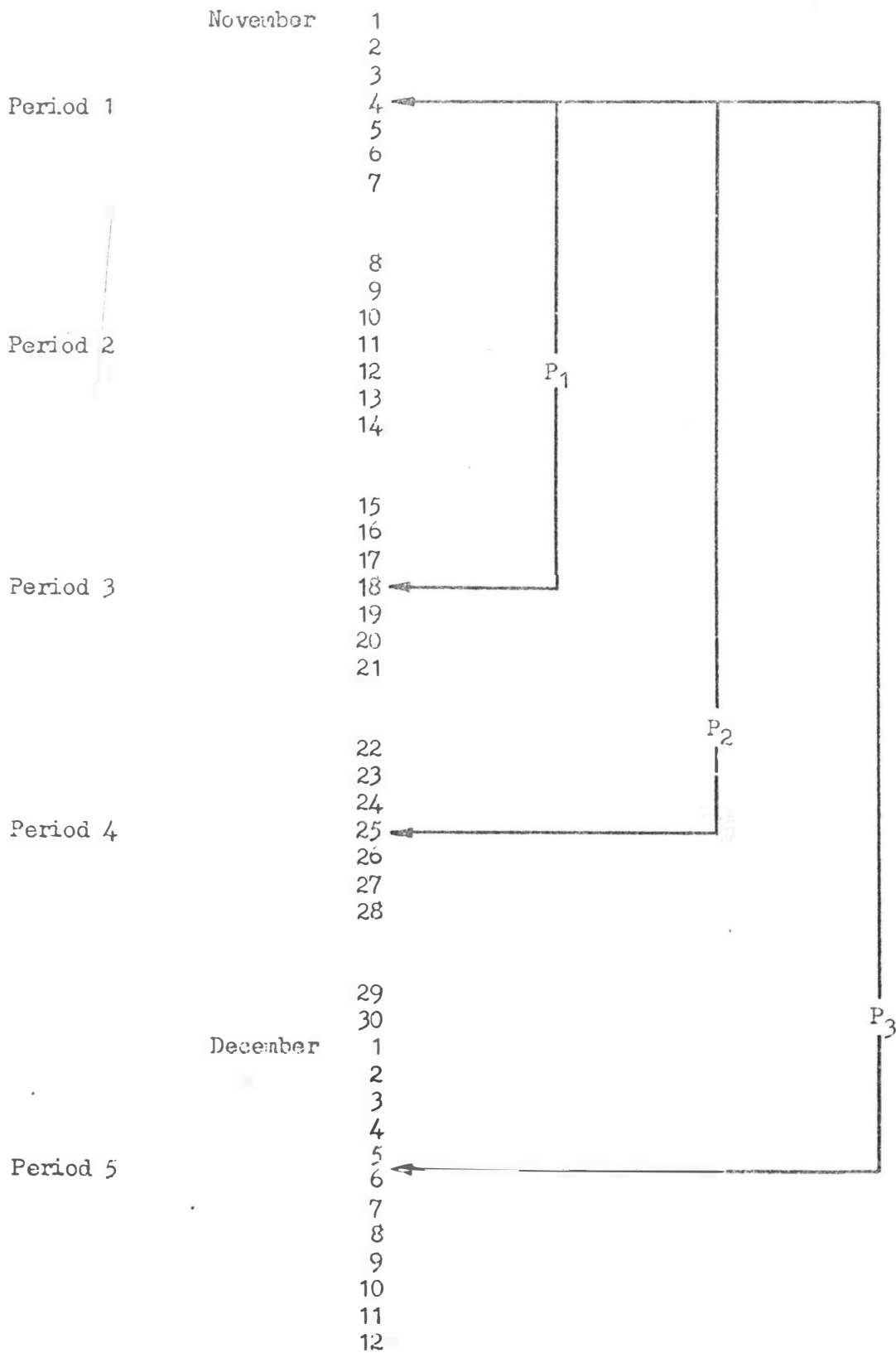
If the pasture production model makes available only enough pasture to meet the period (day) feed requirement, the time at which the animals are shifted from the grazing area coincides with them reaching the grazing height specified by the pasture production activity supplying feed in that period. Where the model makes available more pasture than the period feed requirement then the animals are shifted off the grazing area after they have attained the specified intake which means that pasture above the grazing height will remain. Since all pasture regrowth functions within the model are specified from a one of two pasture residues (HIGH or LOW) this excess pasture is assumed

(1) i.e. the predetermined feed requirement is less than the potential daily per head intake of the animals. The concept of potential daily intake is discussed in Section 4.2.1.

Table 3.7

Representations Of The Pasture Production Activities

P₁ P₂ And P₃



3.4.3.2 The Height To Which Pasture Is Grazed (Continued)

to either senesce or be removed mechanically and pasture regrowth begins from the specified residue.⁽¹⁾

3.4.4 Comment On The Length Of Spell Options Within The Pasture Production Model

As discussed earlier the grazing year is divided into 30 periods. Length of spell options are in multiples of seven days where pasture is spelled from the mid-point of one seven day period until the mid-point of another seven day period (e.g. P₂ in Table 3.7). Where pasture is spelled between the mid-points of two fourteen day periods the length of spell options are in multiples of fourteen days.

Lengths of spells which are not in multiples of seven or fourteen days (e.g. in Table 3.5 the 31 day maximum spell for pasture grazed in period 3) are necessary when pasture is spelled from the mid-point of a seven day period until the mid-point of a fourteen day period or vice-versa. The representation of P₃ (which spells pasture from Period 1 to Period 5) in Table 3.7 illustrates this. The mid-point of period 1 is mid-day on the 4th November, 31½ days previous to the mid-point of period 5 which occurs between the 5th and 6th December. The half-day was neglected when calculating D.M. production associated with this and similar activities.

To approach reality, each day of the grazing year could have been considered as a grazing period. Length of spell could have then been defined in multiples of one day. However, allowing the same number of spelling options as specified in this model (i.e. 75 options for 30 grazing dates) and allowing the treatment of grazing height as allowed in this model (i.e. HIGH to HIGH, HIGH to LOW, LOW to LOW and LOW to HIGH) would have involved the specification of $(365 \times \frac{75}{30} \times 4) = 3650$ activities.

(1) In fact this assumption is not critical, since as shown in Section 5.3.2, the experimentation is an iterative procedure. The predetermined pattern of L.W.G. (and period feed requirements) are changed in the light of information of "slack" and "tight" feed periods until a grazing management plan is devised such that no more animals can be run within the system. At this point surplus feed above the grazing heights is minimal.

While the Mathematical Programming System, Tempo, on Massey University's B6700 computer reputedly would have handled this number of activities, the interpretation of output data generated by the model would have been a difficult task.⁽¹⁾

The inclusion of seven day periods over the spring period allowed the model to become more sensitive to grazing management at that time of the year when pasture growth was fastest.

By allowing three length of spell options for the spring - early summer periods of the year, when pasture growth rates are at their highest, and two spelling options for the rest of the year, the number of activities within the pasture-production model was reduced from 360 to 300.

The benefits from handling this reduced number of activities, particularly in terms of output analysis, were subjectively assumed to outweigh any disadvantage caused by the lack of management options that could be examined within the model.

Only two length of spell options (17 and 31 days) are included for pasture grazed in period 3 (see Table 3.5). Table 3.8 shows that the other option that may have been included was a length of spell of 7 days (shown by activity P_x in Table 3.8). Such a spell was considered too short to include in the management options to be investigated by the model.

The other seemingly inconsistent constraint shown in Table 3.5 is the maximum length of spell of 31 days for pasture grazed in periods 1 and 3, while the maximum spell for pasture grazed in periods 2 and 4 is 38 days. The reason for this apparent inconsistency is illustrated in Table 3.9. Analysis of the pasture production data used in the model showed that a spell of about 5 weeks was required if the period of maximum daily increments of D.M. was to be covered by the management decisions the model could make. As shown in Table 3.9 spelling pasture

(1) The cyclical nature of experimentation with the model, discussed in Sections 2.7 and 5.3.2, depended on each run of the model being analysed quickly, input information changed and the model re-run.

from period 1 to period 5 (P_3) allowed a spell of 31 days. Extending the spell until period 6 would allow a maximum spell of 45 days. In view of the pasture production data on which the model was based this length of spell was considered unwarranted. Similarly with pasture spelled from period 2 until period 6 (P_6), a maximum spell of 38 days is included in the model. Constraining the length of spell from period 2 to period 5 would result in a maximum spell of only 24 days. Hence the compromise of a maximum spell for pasture grazed in periods 1 and 2 of about five weeks (P_3 is four days under and P_6 is three days over) was included in the model.

A similar analysis explains the maximum spells of 31 and 38 days for pasture grazed in periods 3 and 4.

3.5 D.M. Production Associated With The Pasture Production Activities

Pasture regrowth data have been defined for each month of the year after defoliation at a HIGH and LOW defoliation height (Tables 3.2 and 3.3). From these data a pasture production curve was extrapolated for regrowth after defoliation to the HIGH and LOW grazing heights at the mid-point of each of the grazing periods defined in Table 3.4.

For example, assume that the generalised regrowth curves shown in Fig. 3.4 represent pasture regrowth after grazing HIGH or LOW at the mid-point of period t .

Then the D.M. available for grazing in period $(t + x)$ after pasture had been grazed HIGH in period (t) , spelled for (x) days and grazed HIGH again in period $(t + x)$ would be:

(a - c) Kg D.M./ha grazed

Similarly the D.M. available for grazing after pasture had been grazed LOW in period (t) spelled for (x) days and then grazed LOW in period $(t + x)$ would be:

(b - d) Kg D.M./ha grazed

Table 3.8

Length Of Spell Options For Pasture Grazed In Period 3

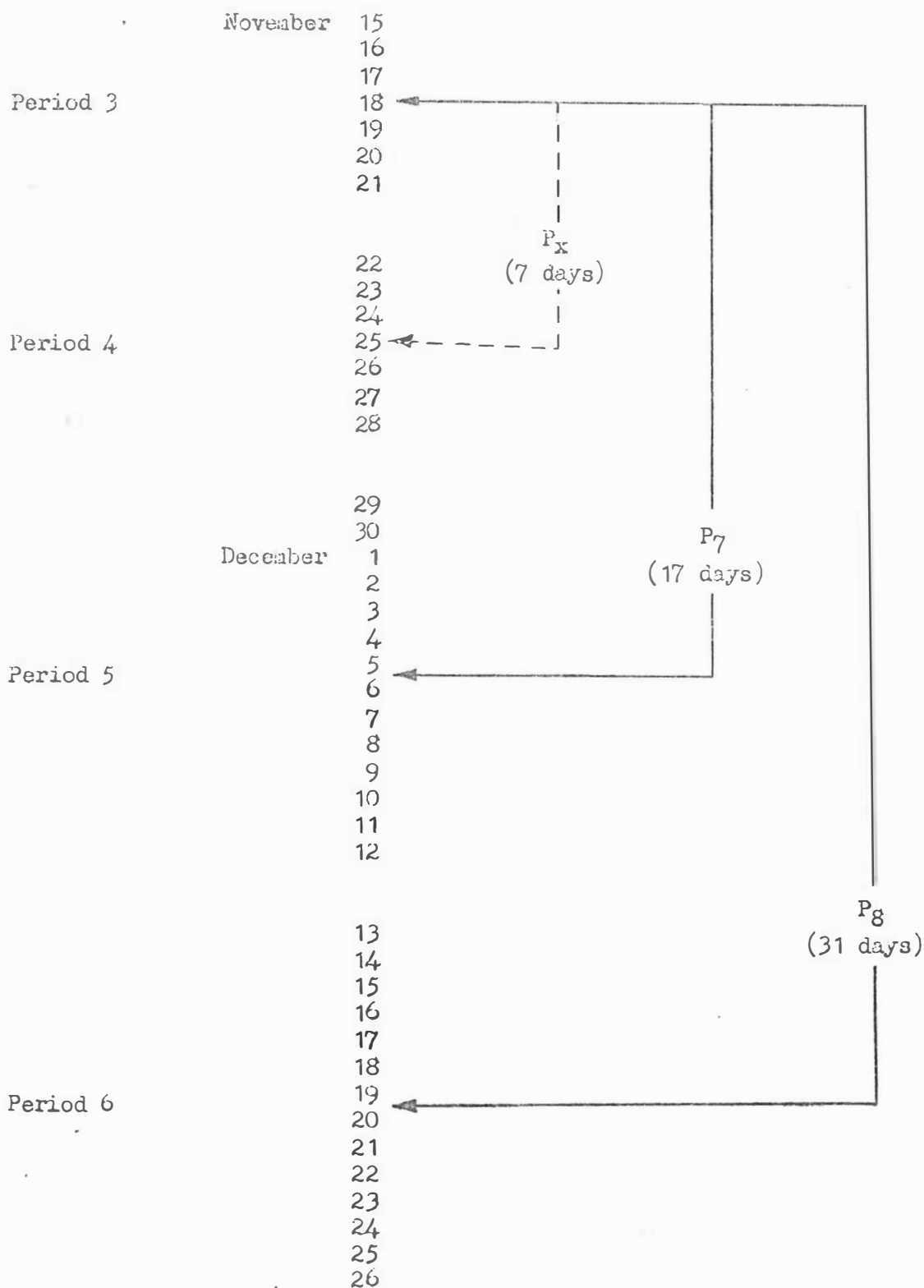
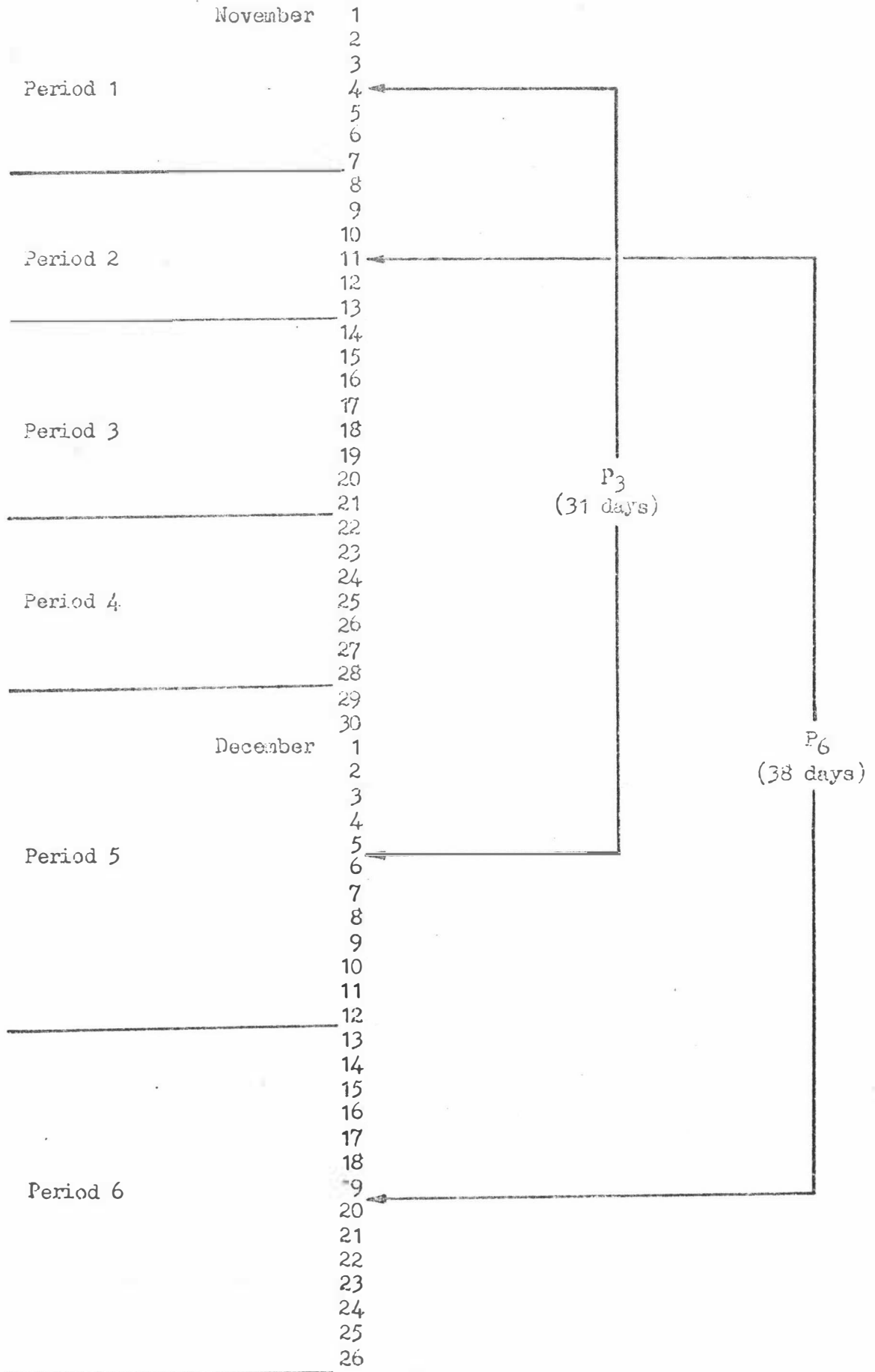


Table 3.9 Length Of Spell Options For Pasture Grazed In Periods 1 & 2



3.5 D.M. Production Associated With The Pasture Production Activities (Continued)

Now where pasture is grazed HIGH in period (t), spelled and then grazed LOW in period (t + x), the D.M. available for grazing in period (t + x) is:

Pasture available from HIGH regrowth curve Plus
the difference in grazing height in period (t + x)

$$\text{i.e. } (a - c) + (c - d) = (a - d)$$

Similarly pasture grazed LOW, spelled, and then grazed HIGH will yield:

The D.M. available from the LOW regrowth curve
Less the difference in grazing height

For the generalised example shown in Fig. 3.4 LOW to HIGH grazing yields in period (t + x)

$$(b - d) - (c - d) = (b - c) \text{ Kg D.M./ha grazed.}$$

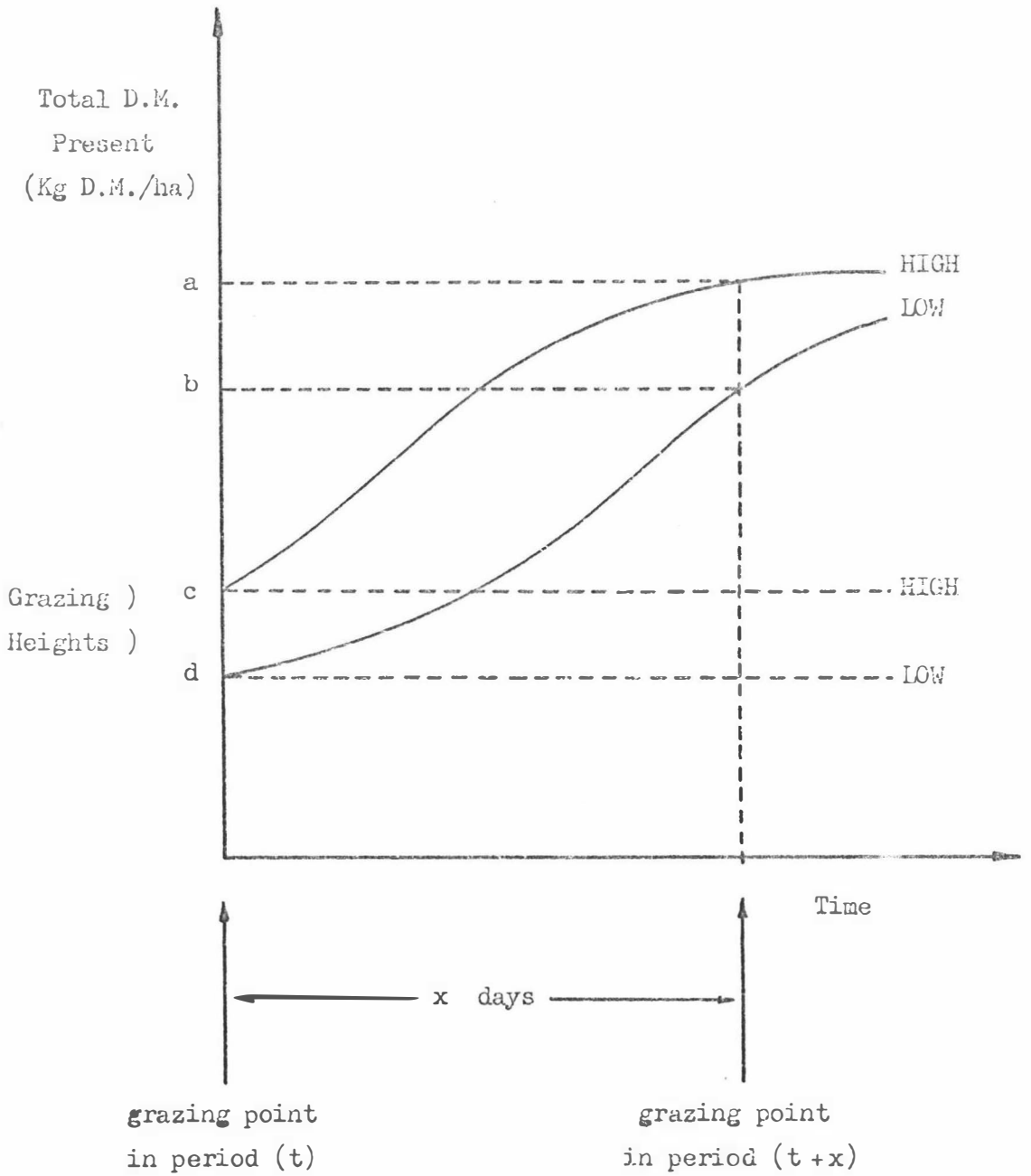
Similar calculations were made for each of the 300 grazing activities incorporated in the pasture production model.

3.6 Limitations In The Pasture Production Model

The range of spelling lengths that may be chosen by the model after grazing in any particular period is limited to those that have been outlined. The number of spelling length options could easily be increased, should this prove necessary, by considering more grazing periods within the year. The basic restriction to increasing the number of grazing periods considered in the year was the increased time that would be involved in analysing system output. While the Mathematical Programming System, Tempo, on which the model was run does include an output analysis routine, it was not in use at the time that the model was set-up. The time that would have been involved in

Fig. 3.4

Pasture Production After Grazing HIGH and LOW
In Period (t)



3.6 Limitations In The Pasture Production Model (Continued)

setting up the output analysis routine was not considered justified in view of the objectives of this study (See Section 1.3).

Although the grazing process is represented in a rather simplified way (see Section 3.4.3) it was considered sufficiently realistic to meet the objectives of this study. The advantages to be gained from expanding the pasture production model are discussed more fully in Section 0.2.1.

3.7 Annual D.M. Production From The Pasture Production Model

Some initial experimentation was carried out to find out the pasture production that could be "grown" by the model under the assumptions of grazing height and length of spell that are discussed above.

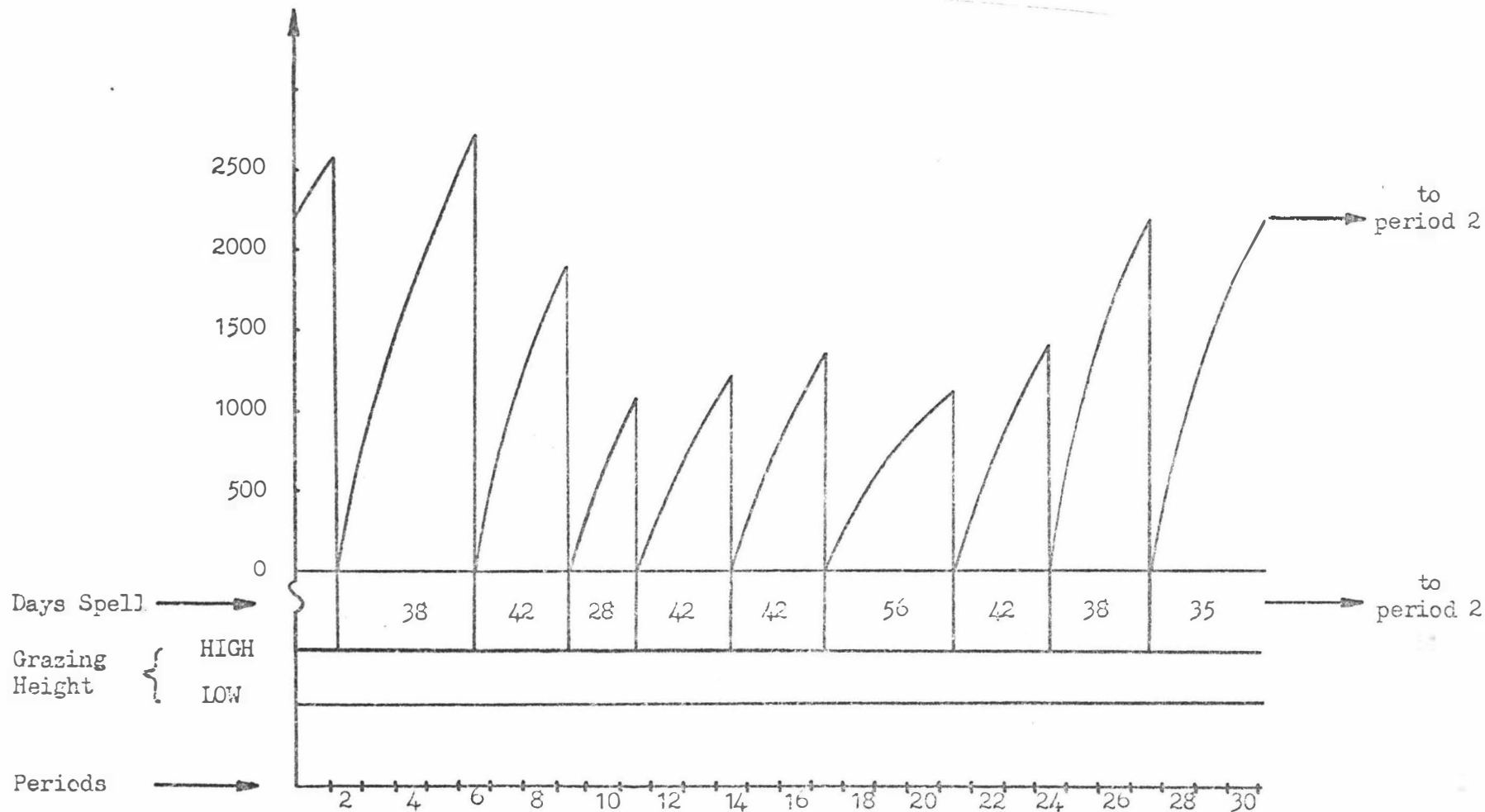
The area to be considered was constrained to one hectare and the model was used to maximise the total annual D.M. made available for grazing. The maximum produced was 15,915 Kg D.M. p.a.

The grazing pattern associated with this annual pasture production is shown in Fig. 3.5. Pasture D.M. available for grazing is shown on the vertical axis from 0 to 3000 Kg D.M./ha. Grazing periods and the months of the year in which they fall are shown on the horizontal axis. The vertical lines show the period of the year in which defoliation took place. The top of the peaks represent the amount of pasture that was available in that period and the vertical lines below the level 0 Kg D.M./ha show that pasture grazed in all periods was grazed at the HIGH grazing height.

The length of spell between grazings is quantified in days between the vertical lines that represent each grazing. Pasture, under the management system chosen by the model to maximise annual D.M. production, is grazed 10 times during the year. The length of spell between grazings is the maximum allowable for all periods of the year except those in periods 9, 17, 21.

Fig. 3.5

Grazing Pattern For Maximum Annual D.M. Production From The Model



3.7 Annual D.M. Production From The Pasture Production Model (Continued)

The pattern of feed supply made available by the grazing plan presented in Fig. 3.5 will not necessarily be obtainable in a real-life grazing situation since animals must be fed in each period of the year. However, the concurrence of the maximum D.M. production (15,915 Kg/ha) with the figure (16 - 17000 16 D.M./acre) that Brougham suggests is obtainable in the Palmerston North region under good management (Section 3.2.3) is considered sufficient validation of the pasture production model for the purposes of this study. The effect of varying the pasture production relationships is considered in Section 6.2.1.

3.8 Summary

Pasture regrowth, over time, following a severe defoliation is described by a sigmoid curve. The daily rate of regrowth at some time following defoliation depends on a variety of factors including the severity of grazing.

Pasture production functions that represent the regrowth of pasture from two grazing severities are defined for an average year in the Palmerston North region. This information is included in a Linear Programming model in such a way that pasture can be made available for grazing in each of 30 periods throughout the year.

Grazing height in each period is restricted to either the HIGH or LOW level defined in the model, and lengths of spell between grazings are also restricted.

The grazing height and length of spell restrictions limit the degree of reality that the model represents. The maximum annual D.M. production from the model of approximately 16,000 Kg D.M./ha is considered realistic in light of the available research data.

CHAPTER FOUR

ANIMAL PRODUCTION

4.1 Introduction

Blaxter (1962) has stated that minerals, vitamins, amino acids, and a source of energy are necessary for the maintenance and growth of animals. Grazed pasture normally provides adequate amounts of minerals. It also provides the necessary amino acids and vitamins, or at least substances from which the ruminant animal can synthesize them. Where the diet of the grazing animal did not include sufficient minerals, vitamins or amino acids, a clearly recognised clinical syndrome would develop.

Shortages of feed energy, Blaxter claimed, were a more important source of reduced animal production, and as well, they lead only to a gradual falling off in animal performance.

Within this study, animal performance is assumed to vary only with changing levels of feed energy made available to, and eaten by, grazing beef animals. The conversion of pasture to beef is considered in two stages:

1. the intake of the grazing animal
2. the conversion of that intake into animal product (i.e. liveweight gain)

4.2 The Intake Of Grazing Beef Animals

A model of a beef production system needs to consider pasture intake per animal as some function of the pasture available in any time period so that as well as being able to predict the animal production that will result from making a certain amount of pasture available, the model can also calculate the pasture residue remaining after grazing. (The importance of pasture residue in determining pasture regrowth has been discussed in Section 3.2.1).

A hypothetical relationship between intake per head per day and pasture D.M. available per head per day is presented in Fig. 4.1 as function (I). The lines $oa - ab$ bound the area within which this function may logically lie. The line ab specifies the potential daily intake that the animals may achieve, while the line oa represents the situation where all available pasture is eaten.

The calculation of pasture residues from function (I) for some given class of livestock, may be accomplished as follows:

Let X = available D.M./ha
Let N = total number of animals fed
Let Z = area of pasture fed (ha)

Thus $\frac{N}{Z}$ = k is stocking rate/ha., and

D.M. available per head, $x = \frac{X}{k} = \frac{X \cdot Z}{N}$

From function (I), intake/head, $y = f(x)$

Thus, residue/head is given by:

$$(x - y) \text{ Kg. D.M.}$$

and, residue/ha is given by:

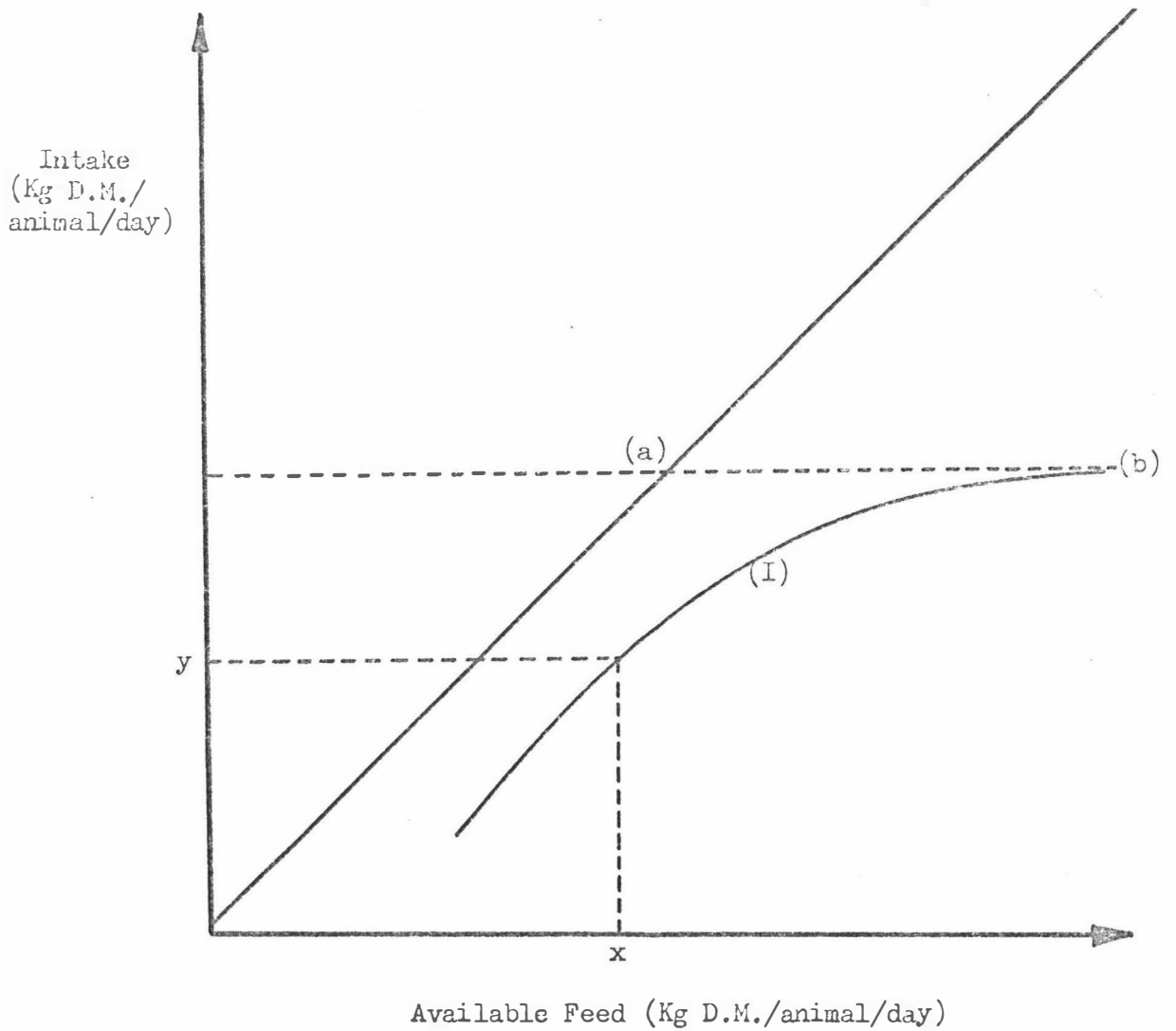
$$k(x - y) = \frac{N}{Z} (x - y)$$

Pasture residue/ha is thus a function of number (of a given class) of stock (N), area of pasture fed (Z), feed available per hectare and hence feed available per head (x). For a given number of animals pasture residue per ha is inversely proportional to the area of pasture needed to achieve any given level of pasture availability per head.

In order to apply this model for pasture residue after grazing we need estimates of the potential intake, and the intake function, $y = f(x)$, for different classes of grazing animals. Since the intake function has been assumed to apply over a range of values for pasture

Fig. 4.1

Actual Daily Intake/Head As A Function Of Available
Feed/Head



4.2 The Intake Of Grazing Beef Animals (Continued)

D.M. available/ha., experiments designed to provide data for estimating this function should include a corresponding range in pasture D.M. levels as well as different levels of available pasture D.M. per head.

4.2.1 Factors Affecting The Potential Daily Intake Of Grazing Beef Animals

A review of literature indicates that the potential daily intake of grazing beef animals is a rather complex and poorly understood facet of beef production.

Bines (1970) concluded that where roughages are fed, intake is constrained by the speed with which food passes through the rumen. Hence size of the rumen, which is related to animal liveweight (Bines 1970) would limit daily intake. Bines also considered that the faster passage of a concentrate diet through the rumen meant that rumen size would have little limiting effect on potential intake of concentrates. In this case the amount of food eaten per unit time would be related to the animal's physiological state and genetic make-up.

Raymond (1969) suggested that feed quality and in particular, digestibility, was a major determinant of the voluntary intake of grazing animals. However, Hutton (1963) working with dry dairy cattle, and Ulyatt (1970) working with sheep, found no clear relationship between the digestibility of feed and animal intake where digestibility was above 70%.

Crompton (1962) suggested that the maximum daily intake of feed D.M. for both dairy and beef cattle would be equivalent to about 3% of animal liveweight. Hutton (1963) showed that this "3% standard" could considerably underestimate the intake of lactating dairy cows, and overestimate the intake of dry dairy cows. In Hutton's work the degree of fatness the dry stock had attained appeared to affect the level of voluntary intake.

The 3% of bodyweight standard, however, seems to have been generally accepted by research workers⁽¹⁾ as a guide to the potential intake of

(1) From Wright (1975).

young growing beef animals on pasture.

In the absence of quantitative data from New Zealand beef grazing trials relating potential intake to pasture and animal parameters, a simplified indirect approach has been used to define the potential intake of the grazing animals in this study. The daily liveweight gains allowable within the model are limited to the highest gains that are consistently achieved on commercial farms. If the relationships within the model between daily intake and daily liveweight gain are correct, then the potential levels of intake implicit in the model will only be as high as those levels of intake achieved on commercial farms.

The potential daily liveweight gains (intakes) used are presented in Table 4.5 and the implications of this restriction are discussed more fully in Section 4.5.1.5.

4.2.2 Factors That Affect The Shape Of The Function Relating Available Pasture To Intake

Several overseas research workers have shown that the relationship between pasture intake/head/day and feed available/head/day is curvilinear.

Hull et al (1961) grazed beef animals at 5 stocking rates with pasture being spelled for 35 days between grazings. Over the 120 days of the experiment (which was repeated over 3 years) the animals in each stocking rate treatment were exposed to a wide range of pasture availabilities. Hull et al found a high correlation between the pasture available/head before grazing and the intake/head measured as digestible energy intake. This relationship was described by the function:

$$y = 0.16 - 0.29 \frac{1}{x}$$

where y = daily intake per animal $\left(\frac{\text{M.Cals.D.E.}}{(\text{liveweight})^{.75}} \right)$

and x = available pasture per animal per day

$$\left(\frac{\text{lbs D.M.}}{(\text{liveweight})^{.75}} \times \frac{100}{1} \right)$$

A graphical representation of this relationship is presented in

Fig. 4.2, assuming that the animals being fed were 600 lb liveweight, and the feed consumed contained 126 M. Cals of D.E. per 100 lb of D.M.

The line oa in Fig. 4.2 represents a situation where all available feed is eaten. It can be seen from Fig. 4.2 that below a daily pasture allowance of 12.5 lb/head/day the relationship of Hull et al (1961) no longer holds, since the amount eaten exceeds the amount offered. This may be partly due to the fact that Hull et al sampled the pasture available at a 2" defoliation height. Where pasture availability was low the animals may have in fact grazed below this 2" height.

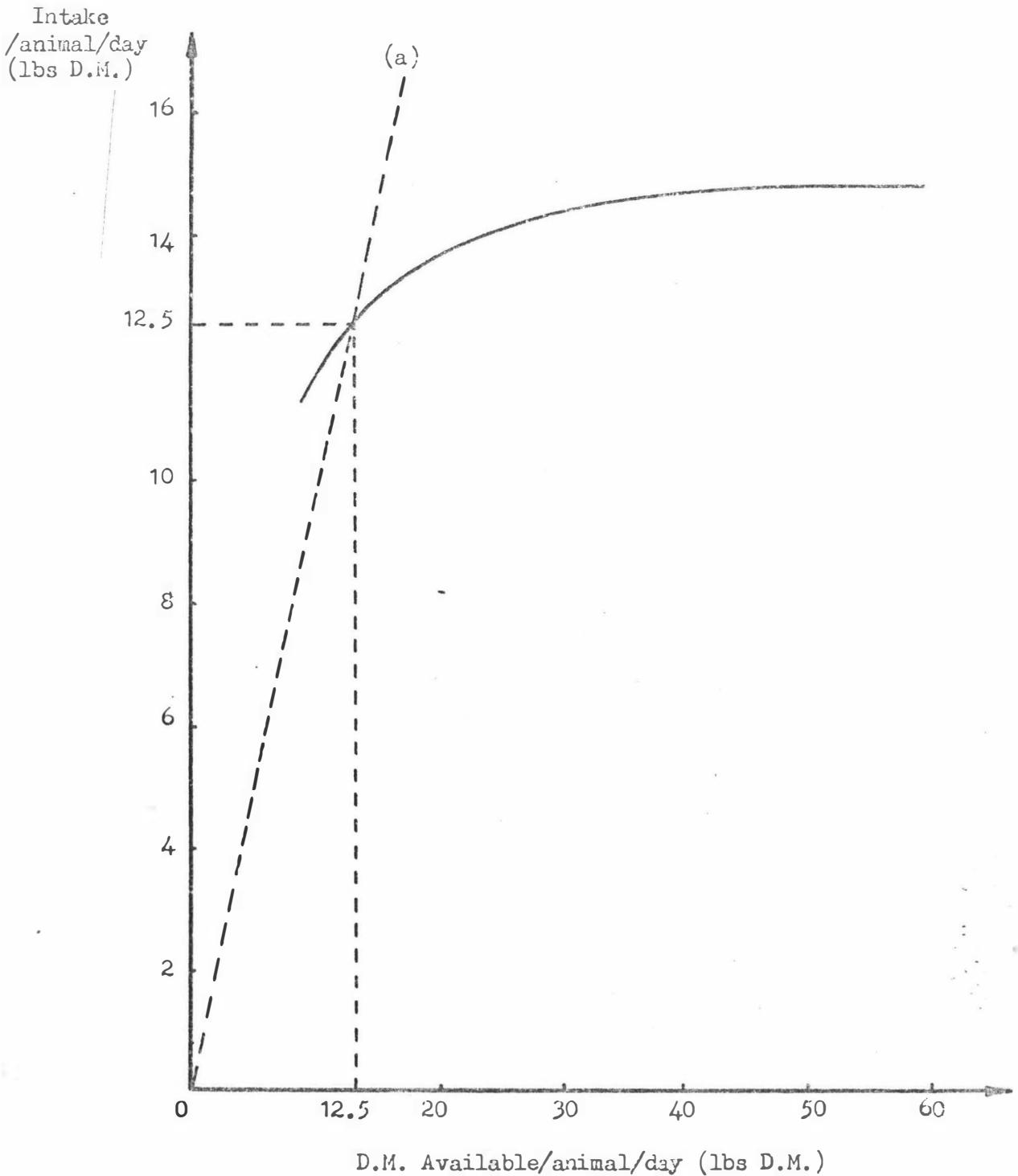
Greenhalgh et al (1966) found a curvilinear relationship between daily intake by dairy cows and daily pasture available. Animal intake and available pasture were measured in six periods of the year. Available pasture was the amount of D.M. present above a 1 - 2" sampling height. Where 25 lb D.M./cow/day was offered nearly all the available pasture was eaten. Increments in available pasture of 10 lb D.M./cow/day resulted in reduced increments in the amount of pasture eaten per head. Increasing pasture available from 45 to 55 lb D.M./head resulted in no further increase in intake/head. While the pasture fed in each of the six sampling periods of the experiment varied considerably in terms of pasture density (2000 - 4000 lb D.M./acre) and pasture species (ryegrass vs cocksfoot) the relationship between per head intake and pasture available/head was curvilinear for all periods. However, the absolute amounts of intake relative to pasture available did vary between periods. The results of Hutton's (1963) work suggest that this may have been due to changes in the physiological state of the lactating animals as well as to changes in the pasture factors (density and type). No attempt, however, was made by Greenhalgh et al (1966) to apportion the intake differences between periods to animal or pasture factors.

Reardon (1975), after some preliminary investigations into the effect of supplementary feed on the intakes of grazing beef animals during summer, recognised the complex nature of responses in pasture intake where grazing animals were offered various amounts of available pasture D.M. The density of pasture offered in Reardon's experiments ranged from 1700 to 3900 Kg D.M./ha. Where extra pasture was made available in the form of pasture with more D.M./unit area on it, an

Fig. 4.2

A Relationship Between Pasture Available/Animal
And Intake/Animal

(Adapted from Hull et al (1961))



4.2.2 Factors That Affect The Shape Of The Function Relating
Available Pasture To Intake (Continued)

extra kilogram of D.M. available per head resulted in an increase in intake/head of about 0.3 Kg.

Where extra D.M./head was made available by increasing the area to be grazed, intake/head remained practically unchanged where the pastures had only 1700 - 2200 Kg D.M./ha present. On pastures with a higher density of D.M. present (i.e. > 2200 Kg D.M./ha) increasing the D.M. available/head by increasing the area grazed did result in increased per head intakes. While warning that these results must be regarded as provisional, Reardon stated that:

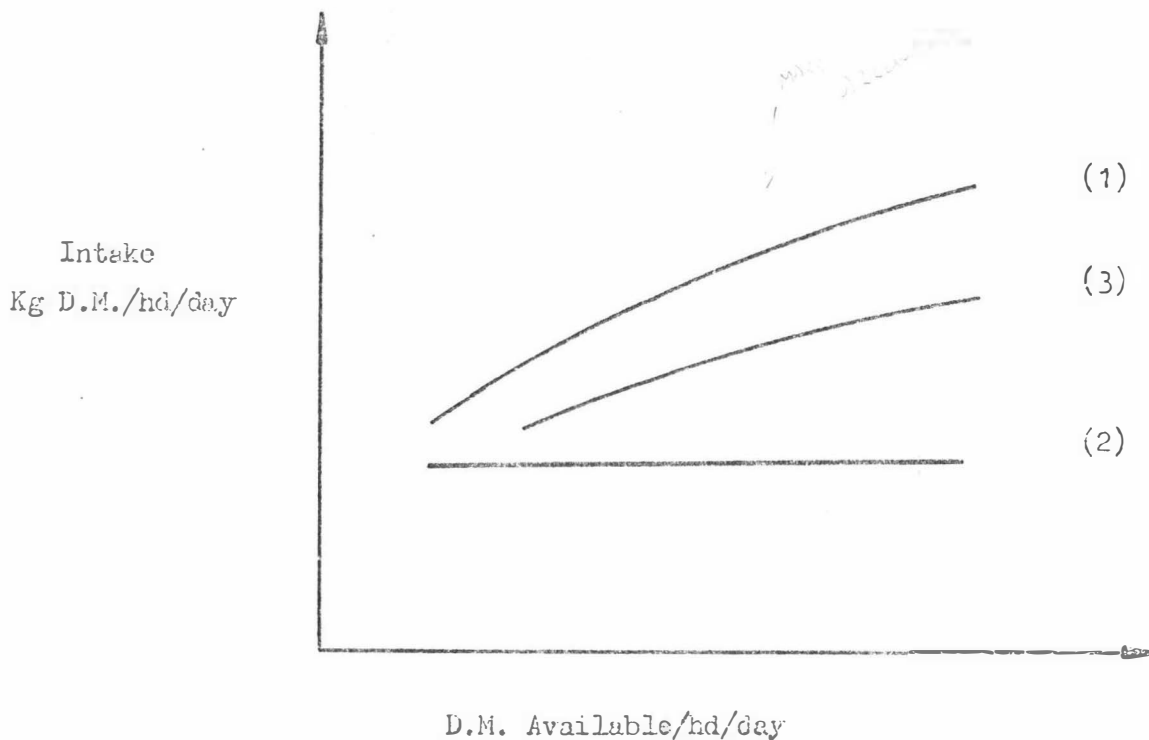
"they indicate that extra pasture D.M. offered as longer or denser pasture has more effect on intake than extra D.M. offered in the form of larger areas of pasture."

If these preliminary findings of Reardon (1975) are found to be true, then the validity of function (1) in Fig. 4.1 is called into question. A generalised representation of the results discussed by Reardon is presented in Fig. 4.3. Function (1) represents the situation where increased pasture is offered in the form of denser or longer pasture. Function (2) shows the likely response to increased pasture D.M./head in the form of increased area where pasture density is low (< 2200 Kg D.M./ha) and function (3) represents the situation where an increased area of pasture with more than 2200 Kg D.M./ha present is offered.

Taylor (1966) investigated the effect of grazing management on beef production, using carcass energy gain and weight gain as measures of animal production. The number of animals unit area/day were varied so that grazing treatments included, hard and lax grazing of long pasture and, hard and lax grazing of short pasture. Taylor was unable to find any relationship between intake (as measured by carcass energy gain or carcass weight gain) and the amount of pasture available/head/day. He did however, find a positive straight line relationship between animal performance (intake) and the height to which pasture was grazed. The animals used by Taylor were subjected to a wide range of values for grazing area/animal, $\left(\frac{Z}{N}\right)$, and pasture D.M./area, (X) . For any given value

Fig. 4.3

A Generalised Representation Of The Results Of
Reardon (1975)



Function (1): Increments in D.M. made available by offering more D.M./ha.

Function (2): Increments in D.M. made available by offering a larger area of pasture to be grazed (where D.M./ha is 1700 - 2200 Kg D.M./ha).

Function (3): Increments in D.M. made available by offering a larger area of pasture which has more than 2200 Kg-D.M./ha on it.

4.2.2 Factors That Affect The Shape Of The Function Relating Available Pasture To Intake (Continued)

of Z, N or X Tayler found that intake/head, (y) was some function (g), of pasture residue/ha.

$$\text{i.e. } y = g (\text{pasture residue/ha})$$

However, as discussed in Section 4.2, residue/ha can be expressed as:

$$\frac{N}{Z} (x - y)$$

where x = available feed/head.

Hence, the relationship observed by Tayler may be expressed as:

$$y = g \left(\frac{N}{Z} (x - y) \right)$$

Since in this relationship, intake/head, (y), is dependant on the intake/head, (y), achieved, it appears to be of little use in the planning of a management system where the objective is to make pasture available so that a predetermined level of intake is achieved. Furthermore, the relationship above could be arranged so that intake/head, (y), is some function of feed available/head, (x). That Tayler could not find such a relationship would appear to be due to the experimental technique used rather than the hypothesis that such a relationship does not exist.

Hence experimental evidence on the shape of the function relating intake/head to pasture available/head is in conflict. Hull et al (1961) suggest that one function will describe the relationship for a range of pasture conditions, while, Greenhalgh et al (1966) and Reardon suggest that the function does vary with pasture conditions (particularly density). The work of Tayler (1966) appears to be inconclusive.

4.3 The Representation Of Animal Intake Within The Model

The heights to which pasture may be grazed, and the pasture available above those heights, have been defined within the pasture

production model. Animal feed requirements are specified⁽¹⁾ on a per head basis for each period of the year so that a predetermined pattern of liveweight gain will be achieved. The model then determines the area of pasture and height (severity) of grazing so that the maximum number of animals can achieve the predetermined pattern of liveweight gain.

Thus, if in the "t"th period of the year, per animal requirements are y_t Kg D.M./animal, and if N_t animals are grazed, then total pasture D.M. requirement is $y_t N_t$. If the amount of pasture D.M. available per ha is X_t Kg and residue per ha is either R_t^L or R_t^S , for the lax and severe grazings respectively, then the area, A_t required for grazing in period t is either:

$$\frac{y_t N_t}{(X_t - R_t^L)} = A_t^L \quad \text{or} \quad \frac{y_t N_t}{(X_t - R_t^S)} = A_t^S$$

Since $R_t^L > R_t^S$, then $A_t^L > A_t^S$

Stocking rate, S_t , is either:

$$\frac{(X_t - R_t^L)}{y_t} = S_t^L \quad \text{or} \quad \frac{(X_t - R_t^S)}{y_t} = S_t^S$$

and $S_t^L < S_t^S$

Pasture D.M. available per head is either:

$$\frac{X_t y_t}{(X_t - R_t^L)} = x_t^L \quad \text{or} \quad \frac{X_t y_t}{(X_t - R_t^S)} = x_t^S$$

and $x_t^L > x_t^S$

But within the model it is assumed that intake per head, y_t , is the same in both cases. Also, since pasture residue is different in each case, the model of animal intake corresponds neither to that described by Fig. 4.1 nor to the relationship hypothesised by Tayler (1966).

(1) The specification of animal requirements is discussed in Section 4.5.1.

The model assumes that where pasture available per head is x_t^S Kg D.M. an intake of y_t Kg D.M./head/day will be achieved, thus leaving a residue of R_t^S Kg D.M./ha. Since $x_t^L > x_t^S$ we would expect $y_t^L > y_t^S$ and hence actual residue per ha to be less than the stated residue (R_t^L), where y_t is less than ad libitum intake. In this situation animal intake could be controlled at level y_t by on-off grazing. If animals cannot meet requirements (y_t) under the severe grazing assumption, then the model would not represent reality. However, insufficient quantitative data on livestock intakes under grazing conditions prevented validation of the assumptions made. The implications of these assumptions are discussed more fully in Section 6.2.3.

4.4 The Conversion Of Feed Intake Into Animal Production

Bryant (1971) has discussed the partitioning of feed energy within the ruminant animal. A diagrammatic representation of this process is presented in Fig. 4.4. Metabolizable energy (M.E.) is a measure of the energy available for use by the animal; that is, gross energy (G.E.) less the energy wasted in faeces, urine, and the gases (mainly methane) associated with digestion. Net energy ($N.E._t$) is a measure of the productive energy of a feed. It is the energy used by the animal to sustain production ($N.E._g$) and to maintain essential body functions ($N.E._m$). Heat increment (H.I.), (the difference between available and productive energy) is the heat associated with fermentation and metabolism.

4.4.1 The Energy Value Of Feed

While the M.E. content of any particular feed does vary with the level of feeding, and the animals to which it is fed, the Great Britain Agricultural Research Council (A.R.C. (1965)) has shown that M.E. equals approximately 82% of D.E. for a wide range of feeds and feeding conditions. The A.R.C. (1965) has also shown that M.E. is utilised more efficiently for maintenance than for liveweight gain (production). The $N.E._t$ content of a feed will therefore depend on the amount of M.E. that is used for maintenance ($N.E._m$) and the amount used for liveweight gain ($N.E._g$). This is illustrated in Fig. 4.5.

Fig. 4.4

Partitioning Of Feed Energy Within The Ruminant

(Source: Bryant (1971))

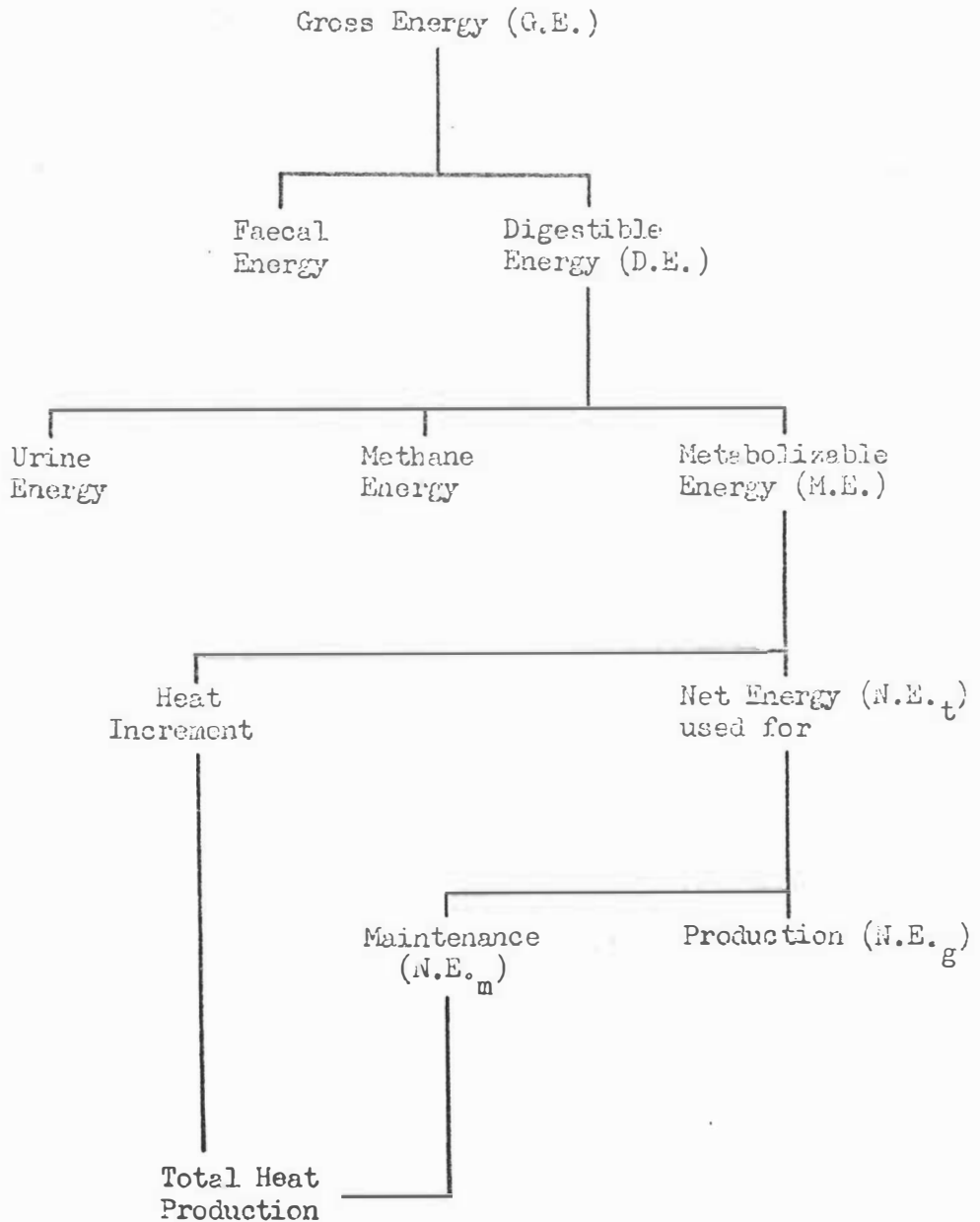
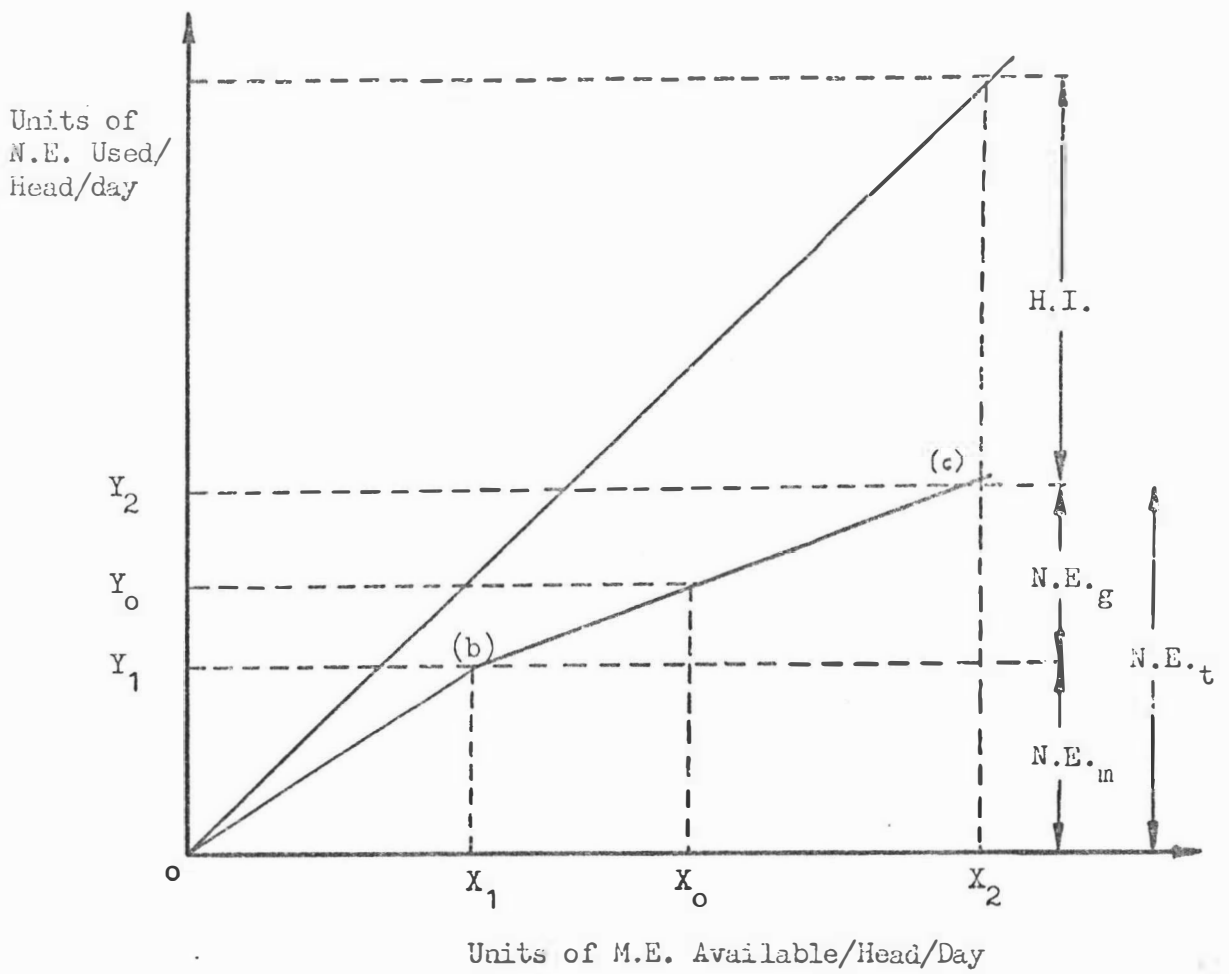


Fig. 4.5

Partitioning Of Available Energy (M.E.)



4.4.1 The Energy Value Of Feed (Continued)

The line oa in Fig. 4.5 represents the situation where all M.E. is used as N.E._t. The line obc shows the relationship between M.E. and N.E._t. Thus, where up to X₁ units of M.E. are fed the N.E._t value of the feed/Kg D.M. equals:

$$\left(\frac{Y_1}{X_1} \right) \times (\text{M.E./Kg D.M.})$$

Up to this point (b) N.E._t = N.E._m. Where X₂ units of M.E. are fed the N.E._t value of feed equals:

$$\left(\frac{Y_2}{X_2} \right) \times (\text{M.E./Kg D.M.})$$

Levels of feeding between X₁ and X₂ units of M.E. result in different N.E._t values for the feed e.g. at X₀, N.E._t value equals:

$$\left(\frac{Y_0}{X_0} \right) \times (\text{M.E./Kg D.M.})$$

The efficiency with which M.E. is used for maintenance ($\frac{Y_1}{X_1}$, the slope of the line ob) is relatively constant regardless of the feed used. (The A.R.C. (1965) use a figure of about 0.7, while the N.R.C. (1970) use between 0.6 - 0.7). However, the efficiency with which M.E. is used for liveweight gain ($\frac{Y_2 - Y_1}{X_2 - X_1}$, the slope of the line bc) does vary markedly between feeds, (The N.R.C. quote figures between 0.30-0.50), and in particular it varies with amount of M.E. per unit weight of feed.

4.4.2 Systems For Expressing Feed Requirements

In the planning (study) of animal production systems it is necessary to devise a set of feeding standards that express animal requirements and the feeding value of various feeds in the same units, so that animal

production may be specified for a given level of feed supply, or conversely so that the feed required to sustain some level of animal production may be determined.

Joyce (1971) has reviewed the feed requirements of beef animals for maintenance and production. While published N.Z. work and overseas work did vary in absolute terms, all the work cited by Joyce showed that the feed requirement/animal for maintenance increased with increasing liveweight.

Similarly, the two major overseas sources of feed requirement data (N.R.C. (1970), A.R.C. (1965)) varied in the specification of the feed required, above maintenance, for liveweight gain. In general however, the feed requirement per unit of liveweight gain increased as animals became heavier, and for animals of a similar liveweight increments in daily liveweight gain required increasing increments of feed.

Since N.E. is a measure of the actual energy used by the animal, animal requirements expressed as N.E._m and N.E._g will not vary, regardless of the feed used. The N.R.C. (1970) have expressed the feed requirements of beef animals for maintenance and liveweight gain in terms of N.E._m and N.E._g. Common feeds are also defined in terms of N.E._g and N.E._m per unit weight of feed. Under the assumption that the animal requirement for N.E._m are met before N.E._g, animal performance can be determined for any given level of feeding. Similarly the weight of feed needed to sustain some level of animal performance can be calculated from the N.R.C. (1970) tables. The method of calculation is illustrated in the following example.

Example: From the N.R.C. tables a 300 Kg steer requires 5.5 mega-calories (M.Cal) of N.E._m per day for maintenance. To achieve 1.2 Kg of L.W.G./day the same animal requires 5.27 M.Cal of N.E._g.

Where a feed contains 1.9 M.Cal. N.E._m/Kg D.M. and 1.19 M.Cal N.E._g/Kg D.M., then the animal must be fed 7.3 Kg D.M. to achieve the gain specified above since:

$$\begin{array}{rcll} \frac{5.5}{1.90} & = & 2.90 & \text{Kg D.M. - maintenance ration} \\ \frac{5.27}{1.19} & = & \underline{4.40} & \text{Kg D.M. - production ration} \\ & & 7.3 & \text{Kg D.M. - total ration} \end{array}$$

The experimental determination of feed values and animal requirements in terms of N.E. is a difficult and time consuming task (see Iofgreen and Garrett (1968)). Many of the feed values in the N.R.C. tables are estimates of N.E. content rather than experimentally derived values. The application of the N.R.C. feeding tables to New Zealand grazing conditions is discussed more fully in Section 4.4.2.1.

The A.R.C. (1965) use available energy (M.E.) as the basis for their feeding standards. Since it has been shown by the A.R.C. (and others) that the utilisation of M.E. by animals for liveweight gain varies with the amount of M.E./unit weight of feed, M.E. requirements must be expressed for a range of feed qualities (concentrations of M.E.). This is done in a tabular form with the A.R.C. feeding tables. Then for any given feed quality, animal liveweight, (L.W.), and level of liveweight gain (L.W.G.), the feed requirement can be read from the tables.

Little work has been done in New Zealand defining the energy requirements of beef cattle for a range of L.W. and L.W.G. under grazing condition. The approach adopted has been one of measuring animal intake and animal performance in New Zealand and then comparing the results with overseas feeding standards, using conversion factors to put the overseas standards and the New Zealand work on the same basis e.g. Joyce (1971).

4.4.2.1 Published Feeding Standards

A set of feeding standards have been published in the booklet "Feed Budgeting", (prepared by the Animal Husbandry Section of the Ministry of Agriculture and Fisheries). Scott (1973) reports that these standards (Table 4.1) were extrapolated from N.R.C. (1970) N.E. figures by a group of scientists at Ruakura and in the opinion of these scientists they equate reasonably well with unpublished work that has been carried out in New Zealand. The standards as presented in Table 4.1 are based on the following assumptions:

1. 1 Kg pasture D.M. provides 2.47 M.Cal M.E.

Table 4.1

Feed Requirements Of Growing Beef Animals (Kg D.M./Head/Day)

<u>Weight</u> <u>Gain/Day</u> <u>Kg</u>	<u>Liveweight (Kg)</u>								
	<u>100</u>	<u>150</u>	<u>200</u>	<u>250</u>	<u>300</u>	<u>350</u>	<u>400</u>	<u>450</u>	<u>500</u>
.0	1.61	2.19	2.72	3.21	3.68	4.14	4.57	4.99	5.40
0.25	2.08	2.83	3.51	4.15	4.76	5.36	5.91	6.46	6.98
0.50	2.59	3.50	4.35	5.15	5.89	6.63	7.32	7.99	8.65
0.75	3.11	4.23	5.14	6.20	7.11	7.99	8.83	9.63	10.41
1.00	3.67	4.98	6.18	7.32	8.38	9.42	10.41	11.36	12.28
1.25	4.26	5.78	7.17	8.49	9.72	10.94	12.08	13.18	14.26
1.50	4.88	6.62	8.21	9.72	11.13	12.51	13.83	15.09	16.32

4.4.2.1 Published Feeding Standards (Continued)

2. M.E. made available by pasture is utilised with a 61% efficiency for maintenance and 37% efficiency for liveweight gain

$$\text{i.e. M.E.} = \frac{\text{N.E.}_m}{0.61} + \frac{\text{N.E.}_g}{0.37}$$

Lowe (1971) produced a similar table of feeding standards based on the N.R.C. (1970) N.E. requirements. The maintenance requirement was raised by an arbitrary 30% to allow for energy expended in the grazing process. The conversion of N.E. requirements to D.M. is not discussed except to say that it was done in collaboration with Massey University staff.

Jagusch (1973) has presented a table of feeding standards based on the A.R.C. (1965) recommendations. Requirements are expressed as M.E./head/day and are increased by 30% above the A.R.C. figures to allow for extra energy spent in the grazing process. As well as being specified for a range of L.W. (200 - 400 Kg) and L.W.G. (0 - 1.5 Kg/head/day) the requirements are also specified for a range of feed quality (1.8 - 3.0 M. Cal. M.E./Kg D.M.)

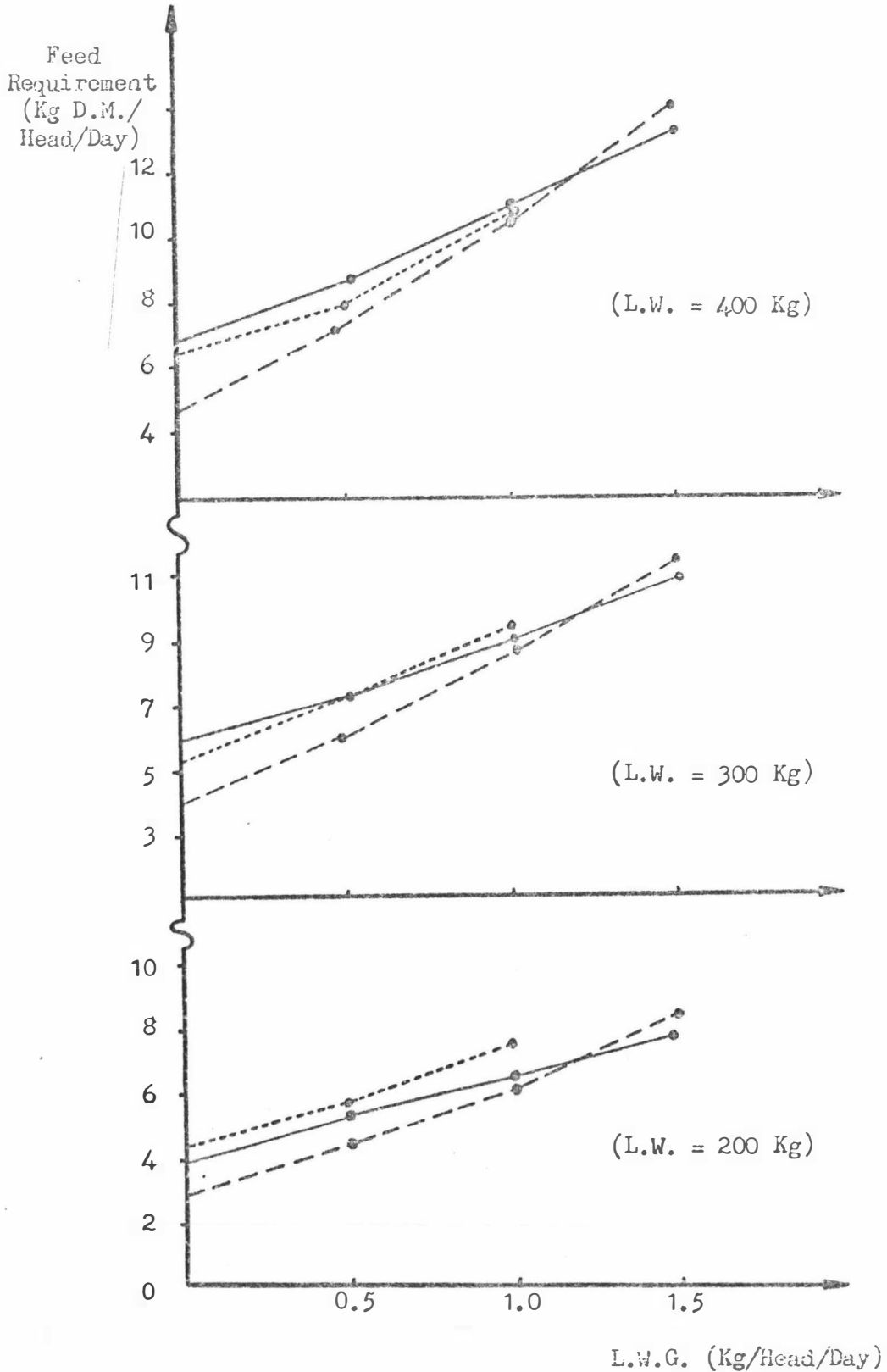
Fig. 4.6 compares the feeding requirements published by Lowe and Jagusch with those presented in Table 4.1. Jagusch's M.E. requirements for a feed containing 2.6 M. Cal. M.E./Kg D.M. were converted to D.M. by dividing by 2.47 (the pasture quality 2.47 M. Cal. M.E./Kg D.M. is assumed in Table 4.1).

Three L.W.'s (200, 300, 400 Kg) and four levels of L.W.G. (0, 0.5, 1.0, 1.5 Kg/head/day) are considered in Fig. 4.6. The feed requirements as expressed by Lowe and Jagusch (derived from N.R.C. and A.R.C. respectively) are similar for the L.W.'s and L.W.G.'s considered. (Jagusch does not quote a requirement for 1.5 Kg L.W.G./head/day where a feed quality of 2.6 M. Cal. M.E./Kg D.M. is used). Comparing Lowe's figures with those from Table 4.1 illustrates the divergence that may exist when the same original standards (N.R.C.) are converted to terms of D.M. In particular the maintenance requirements are lower for Table 4.1 and the increments in requirement for increments in L.W.G. are higher for Table 4.1.

Fig. 4.6

Comparison Of The Feeding Standards Of Lowe (1971), Jagusch (1973)
And Those Shown In Table 4.1, For Three Levels Of Liveweight Gain
(L.W.G.) And Three Liveweights (L.W.)

- - - - • from Jagusch (1973)
- - - - • from Lowe (1971)
- - - - • from Table 4.1



4.5 Feeding Standards Used In This Study

Because there is no conclusive evidence to prove that any one set of feeding standards more accurately represent the feed requirements of grazing animals under New Zealand conditions than any other; and because the standards presented in Table 4.1 are in wide use throughout New Zealand because of their inclusion in the booklet "Feed Budgeting", they were considered to be sufficiently accurate for the purposes of this study.

4.5.1 Calculation Of Feed Requirements

Experimentation with the model is an iterative process, in which the feed requirements to meet a predetermined pattern of L.W.G. are calculated on a per head basis for each period of the year, and then recalculated several times to meet changed patterns of L.W.G. Thus, some method was needed so that animal requirements could be calculated quickly for a range of L.W.'s and L.W.G.'s rather than extrapolating them from Table 4.1.

To achieve this, the relationships inherent in the data presented in Table 4.1 between:

1. maintenance requirement (0 L.W.G.) and L.W.
and
2. production requirement, and L.W. and L.W.G.

were specified and incorporated in a simulation programme which was run on Massey University's I.B.M. 1130 computer.

Given information on the animals initial L.W. and the L.W. to be achieved by the beginning of each period, the animal requirements model can calculate the L.W.G. to be achieved in each period, and the amount of feed required/animal/period to achieve that level of L.W.G.

4.5.1.1 The Relationship Between Animal Liveweight And Maintenance Requirement

The maintenance requirements (0 L.W.G.) outlined in Table 4.1 are

presented as a function of L.W. (Kg) in Fig. 4.7. Where requirements are expressed as a function of $L.W.^{.75}$, the relationship as shown in Fig. 4.8 is linear and can be described by the function:

$$MINT = 0.05 L.W.^{.75} \quad (4.1)$$

where

$$MINT = \text{Intake required/head/day for maintenance (Kg D.M.)}$$

Equation (4.1) is included in the animal requirements model. $L.W.^{.75}$ is calculated as the (liveweight) $^{.75}$ on the middle day of each period, (MED $L.W.^{.75}$). Average daily MINT is then calculated as $0.05 \text{ MED } L.W.^{.75}$ for each period. MINT times the number of days in the period (7 or 14) gives the maintenance requirement/head/period.

4.5.1.2 The Relationship Between Animal Liveweight, Level Of Performance (L.W.G.) And Production Requirement

The production requirement is defined as the amount of feed required/animal above maintenance to sustain some level of L.W.G. From the data presented in Table 4.1 production requirements can be calculated for animals ranging from 100 to 500 Kg L.W. achieving from 0.25 to 1.5 Kg L.W.G. These figures are presented in Table 4.2.

When production requirement is expressed as a proportion of $L.W.^{.75}$ (Table 4.3) then for each level of L.W.G. the production requirement/ $L.W.^{.75}$ is the same over the range of L.W. considered. (e.g. for a daily L.W.G. of 0.25 Kg, the production requirement is 0.015 Kg D.M./Kg $L.W.^{.75}$, regardless of animal L.W.). Furthermore, the relationship between L.W.G. and production requirement/Kg $L.W.^{.75}$ can be approximated by a linear function (Fig. 4.9) described by equation (4.2)

$$L.W.G. = 0.075 + 0.14 \left(\frac{PINT}{L.W.^{.75}} \right) (100) \quad (4.2)$$

where

$$PINT = \text{Intake requirement/animal/day above maintenance (Kg D.M.)}$$

Rearranging Equation (4.2) results in

$$PINT = \frac{(L.W.G. - 0.075)}{0.14} L.W.^{.75} \quad (4.3)$$

Fig. 4.7

Maintenance Requirement As A Function Of Liveweight

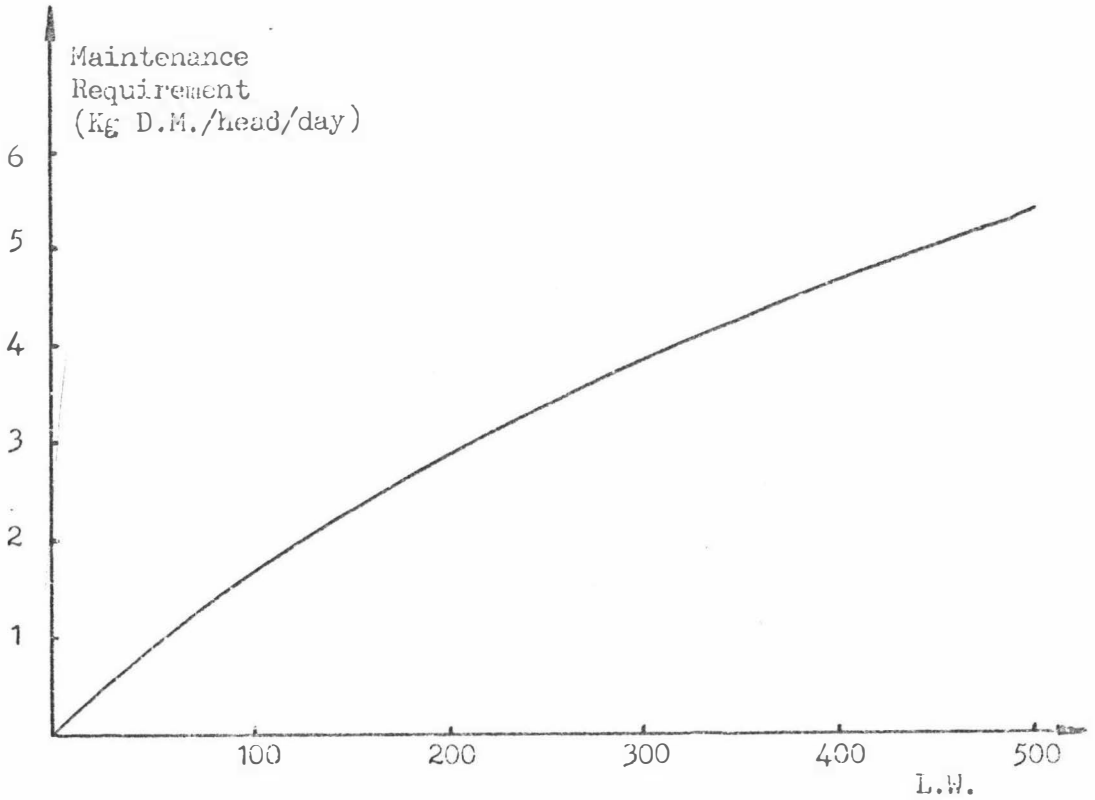


Fig. 4.8

Maintenance Requirement As A Function Of (Liveweight)^{.75}

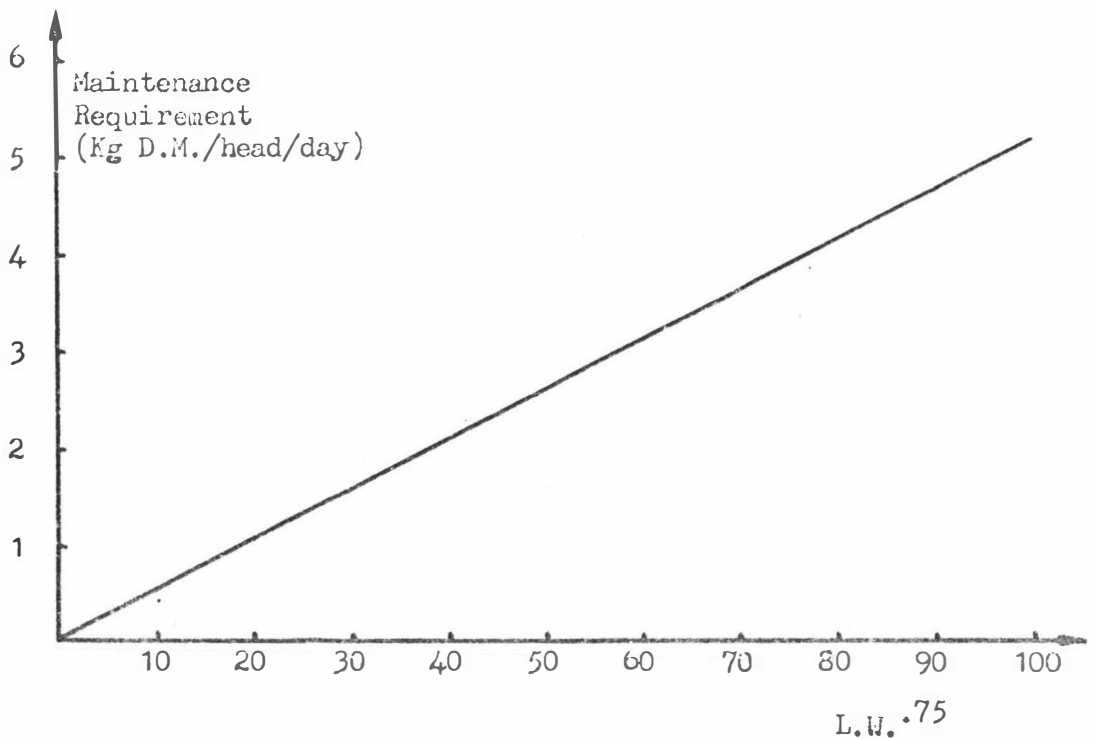


Table 4.2

Production Requirement For A Range Of Liveweights, And
Liveweight Gain (Kg D.M./Hd/day)

<u>L.W.G./</u>	<u>Liveweight (Kg)</u>				
	100	200	300	400	500
.25	.47	.79	1.08	1.34	1.58
.50	.98	1.63	2.21	2.75	3.25
.75	1.50	2.42	3.43	4.26	5.01
1.0	2.06	3.46	4.70	5.84	6.88
1.25	2.65	4.45	6.04	7.51	8.86
1.50	3.27	5.49	7.45	9.26	10.92

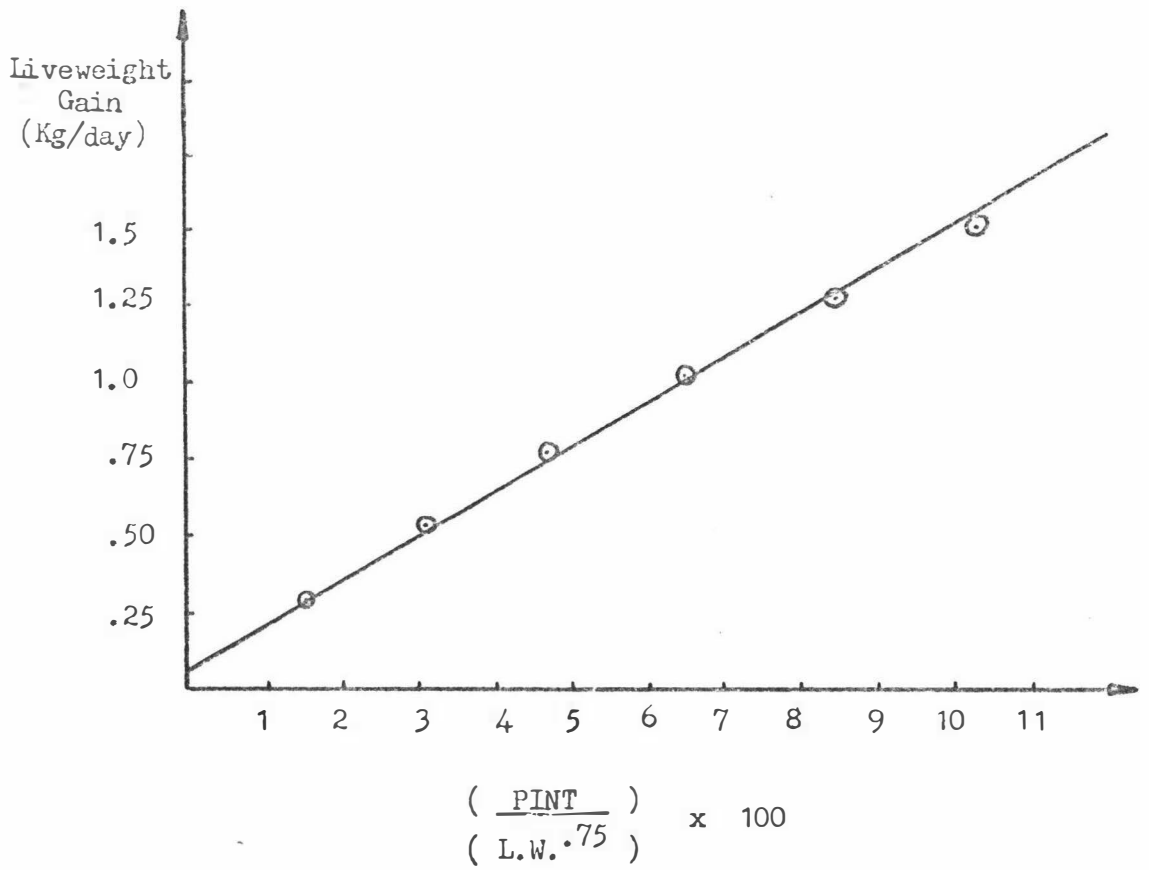
Table 4.3

Production Requirement/Kg L.W.^{.75} For A Range Of Liveweight
And Liveweight Gain (Kg D.M./Hd/day)

<u>L.W.G.</u> <u>(Kg)</u>	<u>Liveweight (Kg)</u>				
	100	200	300	400	500
	<u>L.W.^{.75} (Kg)</u>				
	31.62	53.19	72.07	89.45	105.7
.25	0.015	0.015	0.015	0.015	0.015
.50	0.031	0.031	0.031	0.031	0.031
.75	0.047	0.046	0.048	0.048	0.047
1.0	0.065	0.065	0.065	0.065	0.065
1.25	0.084	0.084	0.084	0.084	0.084
1.50	0.103	0.103	0.103	0.104	0.103

Fig. 4.9

Liveweight Gain As A Function Of Production
Intake/(Liveweight)^{.75}



4.5.1.2 The Relationship Between Animal Liveweight, Level Of Performance (L.W.G.), And Production Requirement (Continued)

By calculating the L.W.G. attained in each period, and the L.W.^{.75} in the middle of each period (MED L.W.^{.75}) the animal requirements model can use Equation (4.3) to calculate the average PLWT for each period. As in the calculation of MLWT, average PLWT times the number of days in the period gives the production requirement/animal/period.

4.5.1.3 The Effect Of Pasture Quality On Feeding Standards

Pasture quality within this study is defined in terms of the M.E. content per unit weight of pasture. As pasture digestibility changes throughout the year (Hutton 1962) it will be associated with changes in the M.E. content of pasture. Also the energy content of pasture will decrease as pasture regrowth becomes more mature (Armstrong 1964).

Changes in the M.E. content of pasture will affect feeding standards in two ways where the feeding standards, as included in the animal requirements model, are expressed in terms of D.M. Firstly increased (decreased) amount of M.E./Kg D.M. will lead to higher (lower) absolute levels of available energy from a given quantity of pasture. And secondly, the changes in M.E. content may lead to differences in the utilisation of available energy within the animal. In particular, the relationship assumed in Table 4.1:

$$\text{M.E.} = \frac{\text{N.E.}_m}{0.61} + \frac{\text{N.E.}_g}{0.37}$$

may not hold for all seasons of the year.

While differences in the utilisation of M.E. for production have clearly been shown to exist between different feedstuffs (A.R.C. (1965)), the situation with pasture is not so clear. Wyatt (1969, 1971) has shown that animal response does vary between different pasture species. However, he has been unable to link these differences to clearly defined measures of pasture quality (e.g. M.E. content).

The approach used within this modelling study is to assume that the relationships defining the utilisation of available energy, inherent in Table 4.1 hold throughout the year. The levels of available energy/Kg D.M. however, are varied between periods according to the recommendations of Hutton (cited Pollard (1972)). Furthermore, the M.E. concentrations used, are assumed to apply to all pasture available for grazing regardless of the length of spell between grazings. The M.E. concentrations used are presented in Table 4.4.

Table 4.4 Pasture Quality Changes Throughout The Year
(M. Cal. M.E./Kg D.M.)

Source: Pollard (1972)

<u>Period</u>	<u>M. Cal. M.E./Kg D.M.</u>
1 - 6	2.65
7 - 11	2.4
12 - 15	2.55
16 - 20	2.65
21 - 30	2.8

Hence feed requirements are calculated using the relationships discussed in Section 4.5.1.1, and 4.5.1.2, assuming that pasture contains 2.47 M. Cal. M.E./Kg D.M. The total feed requirement (Kg D.M./animal/period) is then adjusted by the relevant factor from Table 4.4. For example, a per animal requirement of 100 Kg D.M. for period 1 is adjusted, by the factor $\frac{2.47}{2.65}$ within the animal requirements model so that the actual feed requirement is 93 Kg D.M./animal.

4.5.1.4 A Consideration Of Compensatory Growth

Joblin (1969) has defined compensatory growth as:

"the capacity of cattle to grow more rapidly after a period of underfeeding than after a period of normal or high-level feeding."

The phenomenon of compensatory growth has been demonstrated in young cattle in New Zealand (e.g. Joblin 1969). The amount of extra

growth achieved has been variable between experiments, however, and has never entirely made up for the loss of growth caused by the period of underfeeding. Allden (1970) after a comprehensive review of compensatory growth concluded that it is often due to the underfed animals being lighter than the well-fed animals and hence eating more feed/unit L.W. when full-feeding is continued for both groups. Where underfed and full-fed animals of a similar L.W. show differences in L.W.G. when both are again subjected to ad lib feeding conditions, the explanation of compensatory growth may be either:

1. the lower basal metabolism and hence lower maintenance requirements of the previously underfed animals

or

2. an increased efficiency in the utilisation of feed energy for L.W.G. by the underfed animals

In the absence of reliable quantitative data on compensatory growth, no adjustments in the feeding standards used in this model are made. That is, the feeding requirements for maintenance and L.W.G. as defined in Equations (4.1) and (4.3) are assumed to hold regardless of the level of feeding in previous periods.

4.5.1.5 The Significance Of The Intake (Liveweight Gain) Restrictions In The Feed Requirements Model

Maximum daily intake per animal is dependant on animal liveweight, condition, and feed quality (discussed in Section 4.2.1). 3% of liveweight is often used as an approximation of the amount of D.M. beef animals may consume daily (Wright 1975).

In the absence of quantitative data on maximum daily intakes, a restriction has been placed on the animal requirements model so that the maximum daily L.W.G. animals may achieve is related to animal age. These maximum daily L.W.G.'s (presented in Table 4.5) are based on the author's knowledge of maximum L.W.G.'s that animals consistently achieve on commercial farms, and on unpublished data from Mathews (1973).

Under the assumption that the feeding standards used in the model are correct, then the maximum intakes possible within the model will not exceed those that are achieved in the real-life situation.

Table 4.5 Maximum Daily Liveweight Gain (L.W.G.) Allowed In The Model

<u>Age (months)</u>	<u>Periods</u>	<u>Maximum L.W.G./day</u>
3 - 10	1 - 16	.85 Kg
10 - 13	17 - 24	1.0 Kg
13 - slaughter	25 - slaughter	1.5 Kg

Where an animal purchased into the system in period 1, at 90 Kg L.W. grows at the maximum allowable rates, intake (D.M.) expressed as a percentage of L.W. varies from 2.6% to 3.4%. These figures are presented in Table 4.6. The feed requirements are calculated using the relationships from Equations (4.1) and (4.3) and the effect of pasture quality has not been taken into account.

Table 4.6 D.M. Intakes, Necessary To Support Maximum Daily Liveweight Gain, As A Percentage Of Liveweight

<u>Period</u>	<u>L.W. (Kg)</u>	<u>Maximum L.W.G. (Kg/Day)</u>	<u>Intake (Kg D.M.)</u>	$\left[\frac{\text{Intake}}{\text{L.W.}} \times \frac{100}{1} \right]$
Start of 1	90	.85	3.09	3.4%
End of 16	257	.85	6.79	2.6%
Start of 17	257	1.0	7.48	2.9%
End of 24	369	1.0	9.80	2.6%
Start of 25	369	1.5	12.80	3.4%

While this intake (L.W.G.) restriction is recognised as a simplified representation of the real-life situation, it is considered to be adequate for the purposes of the study.

4.6 Summary

The amount of available pasture that grazing beef animals will eat remains unclear. Little quantitative data exists on the potential

intake/head of grazing beef animals, and no satisfactory relationship between per head intake and available pasture (per head or per unit area) could be found in the relevant literature.

The assumption is made within the model that animals can harvest pasture D.M. down to either one of two grazing heights, and where necessary on-off grazing is employed so that pasture residue after grazing is always at the level specified in the pasture production model.

The utilisation of energy from pasture intake by beef animals is discussed, and published feeding standards are compared. A set of feeding standards based on N.R.C. (1970) N.E. studies are adopted and a model for calculating feed requirements is discussed. Maintenance requirement is shown to be a function of L.W. and the intake above maintenance required to sustain production is a function of L.W. and the level of L.W.G. desired.

Pasture quality (M.Cal. M.E./Kg D.M.) is assumed to vary throughout the year. No allowance is made for changes in quality due to the length of spell between grazings, or to the height to which pasture is grazed. Changes in feed requirements caused by previous low levels of feeding are not considered in the model.

CHAPTER FIVE

MODEL EXPERIMENTATION AND RESULTS

5.1 Introduction

Beef production is considered for Friesian bulls growing from 100 Kg to 380 Kg L.W. Four separate (length of) production processes are defined. The amount of beef carcass produced is then dependant on the number of animals grazed in each production process. An experimental procedure is developed so that the model can be used to maximise stocking rate for each production process.

Associated with each of these maximum stocking rates is a grazing management plan which supplies sufficient pasture so that the pattern of L.W.G. defined, is achieved. Grazing management plans for each production process are compared; and the complexity of these plans is discussed in relation to the real life situation.

A method of considering supplementary feeding in the model is outlined, and the increases in maximum stocking rate achieved through supplementary feeding are discussed.

5.2 The Animals Considered In The Model

The beef production system modelled in this study involves purchase of Friesian bulls at 3 months of age and 100 Kg L.W. and the grazing of these animals until they are sold for slaughter at 15 - 21 months of age and 380 Kg L.W.

Bull carcasses sold to Meat Exporting Companies fall into a single grade (manufacturing). Hence carcass weight and schedule price are the parameters determining carcass value in this model. In the past, an increase in schedule price has applied to carcass weights above 180 Kg. A slaughter weight of 380 Kg L.W. has been chosen in this study since this weight has been used by many farmers as a target liveweight to be achieved by Friesian bulls before their second winter. This weight (380 Kg) corresponds to a carcass weight of approximately 190 Kg, (Kirton 1973).

5.3 The Stocking Rate Decision

Where a farmer buys three month old weaners and finishes them before their second winter, he must decide each spring the number of animals to purchase. The stocking rate he chooses (number of animals/ha) is based on his knowledge of the beef production system and the level of production he requires the system to achieve. System production (in physical terms) is:

$$\left[\begin{array}{l} \text{Slaughter weight} \\ \text{per animal} \end{array} - \begin{array}{l} \text{Purchase weight} \\ \text{per animal} \end{array} \right] \times \text{Number of animals}$$

The farmer might also be interested in the length of time the animals need to be grazed within the system because:

1. schedule prices do vary throughout the year and generally are higher in the early spring period, and
2. animals carried into a second year of grazing compete for feed with the weaners purchased in that year.

To investigate the number of animals that could be grazed from purchase at 100 Kg L.W. until slaughter at 380 Kg L.W., assuming the pasture production possibilities as presented in Chapter 3, four beef production systems, BEEF 1, BEEF 2, BEEF 3 and BEEF 4, were defined. For each system, a length of production process was defined.

5.3.1 Beef Production Systems

Details of each system are presented in Table 5.1. For each system it is possible to define a level of L.W.G. (Kg/animal/period) for each period⁽¹⁾ of the grazing year so that the animals will achieve slaughter weight in the defined period. Daily L.W.G./animal (Period L.W.G./animal \div 14 or 7) must be constrained to the levels presented in Table 4.5.

(1) The periods of the grazing year are presented in Table 3.4.

Table 5.1

Beef Production Systems

System	Purchase L.W.(Kg)	Purchase Date (start of period)	Slaughter Weight (Kg)	Slaughter Date (start of period)*	Length of Production Process (Mths)
Beef 1	100	1	380	1	12
Beef 2	100	1	380	7	14
Beef 3	100	1	380	11	16
Beef 4	100	1	380	15	18

* Slaughter date periods are in the year following purchase date periods.

The animal requirements model (Section 4.5.1) can be used to calculate the feed requirements (Kg D.M./animal/period) for the animals in each system to meet the predetermined pattern of L.W.G.:

a pattern that ensures the animals reach slaughter weight in the prescribed period (from Table 5.1).

A status quo situation is assumed. That is, the same number of weaners are purchased each year. Because the length of production process for BEEF 1 is 12 months, finished cattle are slaughtered (sold from the system) at the same time as replacement weaners are purchased. The production processes for BEEF 2, 3 and 4 are longer than one year, and hence weaner cattle and yearlings are grazed together for some periods of the year. This doubling up of stock occurs in periods 1 - 6 for BEEF 2 periods 1 - 10 for BEEF 3 and periods 1 - 14 for BEEF 4. The feed requirements model aggregates the period feed requirements for weaners and yearling cattle where overlap of the classes occurs, so that feed requirements need only be considered for the (30) periods of one grazing year.

The per head feed requirements corresponding to a predetermined pattern of liveweight gain for any one of the BEEF systems are added to the pasture production model as a BEEF activity.⁽¹⁾ The linear programming model is then used to determine the grazing management that maximises

(1) See Appendix 2 for details.

stocking rate for this BEEF activity.

5.3.2 Maximisation Of Stocking Rates For Beef Activities

Let R_j be a vector of feed requirements for the j th BEEF activity (Kg D.M./head/period).

Let A be a vector of feed supplies made available by the pasture production model (Kg D.M./period). Then,

$$R_j x_j \leq A \quad (5.1)$$

where x_j is the number of animals grazed. For convenience, the area of land considered for the beef production system is 1 ha, so that x_j is stocking rate for the j th BEEF production system. The maximum stocking rate for each BEEF activity was estimated by an iterative process:

1. A pattern of liveweight gain and the corresponding feed requirement vector (R_j^1) was specified, and the model used to maximise stocking rate (x_j^1).
2. The feed constraint rows of the model were examined to identify periods in which supply (of feed) exceeded demand, i.e. $R_{ij}^1 x_j^1 < A_i$ and periods in which supply equalled demand, i.e. $R_{kj}^1 x_j^1 = A_k$
3. Liveweight gains, and hence feed requirements, were reduced for periods in which demand equalled supply; liveweight gains, and hence feed requirements, were increased for periods in which supply exceeded demand. These adjustments were made subject to the constraint that slaughter weight and length of the production period were maintained and subject to maximum rates of gain presented in Table 4.5. Thus a second vector of feed requirements was defined: R_j^2 .
4. The model was then used to maximise stocking rate (x_j^2) and the procedure repeated. (1)

(1) Where no slack existed in any feed row, shadow prices were used to indicate the "relative slackness" of the constraints.

The maximum stocking rates for each BEEF system are presented in Table 5.2.

Table 5.2

Maximum Stocking Rates For BEEF 1, 2, 3 And 4

<u>System</u>	<u>Maximum Stocking Rate</u> (Animals/ha.)
BEEF 1	6.08
BEEF 2	6.72
BEEF 3	6.22
BEEF 4	5.77

The liveweights achieved by the animals in each production system where stocking rate is a maximum are presented in Fig. 5.1. The vertical axis defines L.W. from purchase at 100 Kg to slaughter at 380 Kg. The three horizontal axes define the periods over which the animals are grazed. Periods 1 - 15 (bottom axis), and 16 - 30 (middle axis) account for the first 12 months that the animals are grazed within the system. (They account for the entire production process for BEEF 1). Periods 31 - 45 (top axis) represent the 15 periods in the following grazing year during which animals may be grazed, (i.e. the 31st - 45th periods that the animals are on the farm). As discussed earlier, the feed requirements for periods 31 - 45 of the production process are aggregated with those for periods 1 - 15 so that only one grazing year (30 periods) is considered.

The actual daily liveweight gain achieved by the animals at maximum stocking rate for BEEF 1 and BEEF 2 are presented in Fig. 5.2a and for BEEF 3 and BEEF 4 in Fig. 5.2b. As in Fig. 5.1, periods 31 - 45 are the first 15 periods of the second year of the production process. The dotted lines in Fig. 5.2 defines maximum allowable L.W.G. (Kg/animal/day), and the numbers in brackets define the number of days over which the specified level of L.W.G. is achieved.

Fig. 5.1 Patterns Of Liveweight Achieved By Animals In
Beef Production Systems At Maximum
Stocking Rates

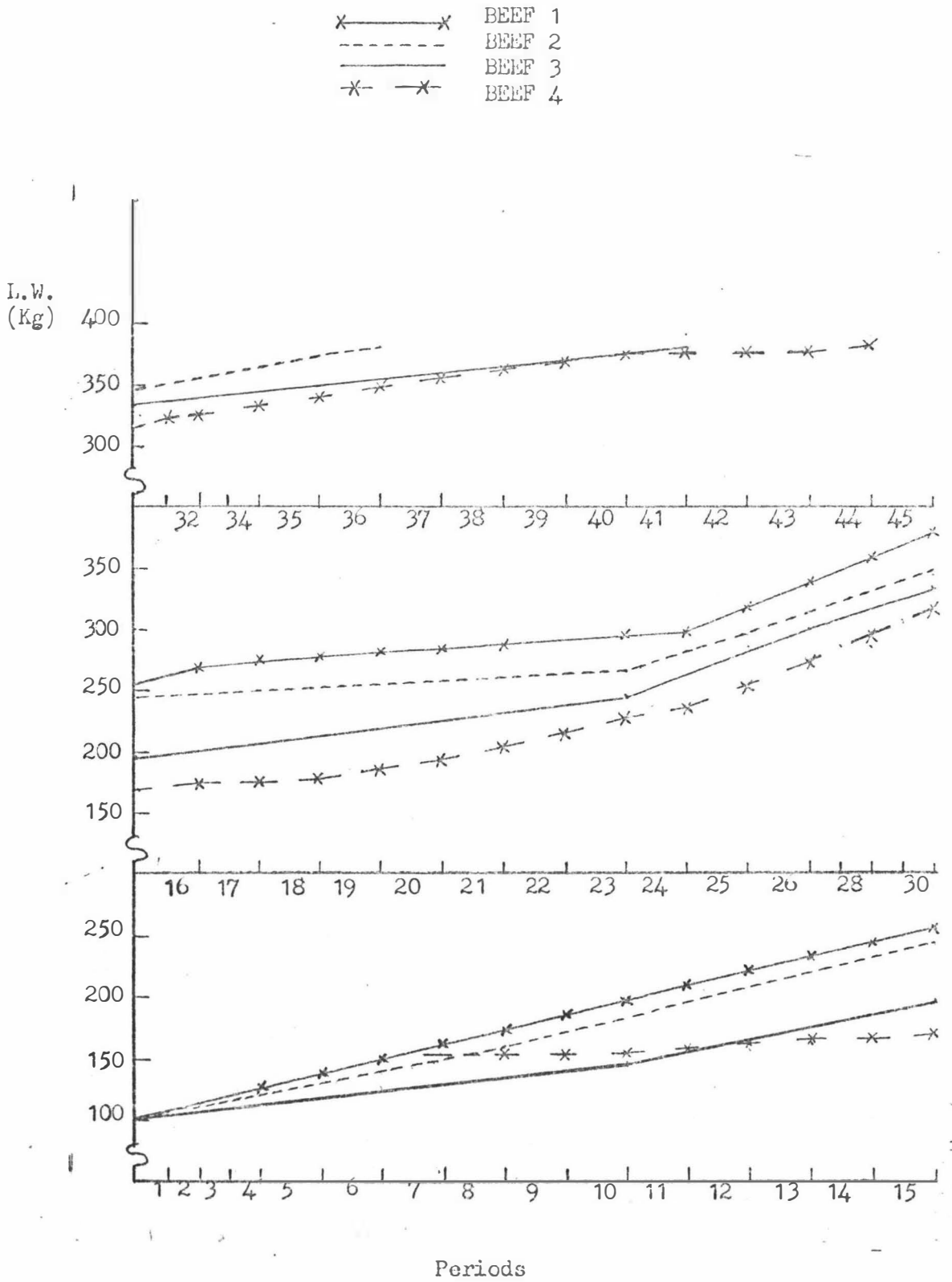


Fig. 5.2 (a)

Daily Liveweight Gain Achieved, BEEF 1, BEEF 2

———— Liveweight gain/head/day (L.W.G.)
 - - - - - Maximum allowable L.W.G.
 () Number of days L.W.G. is achieved

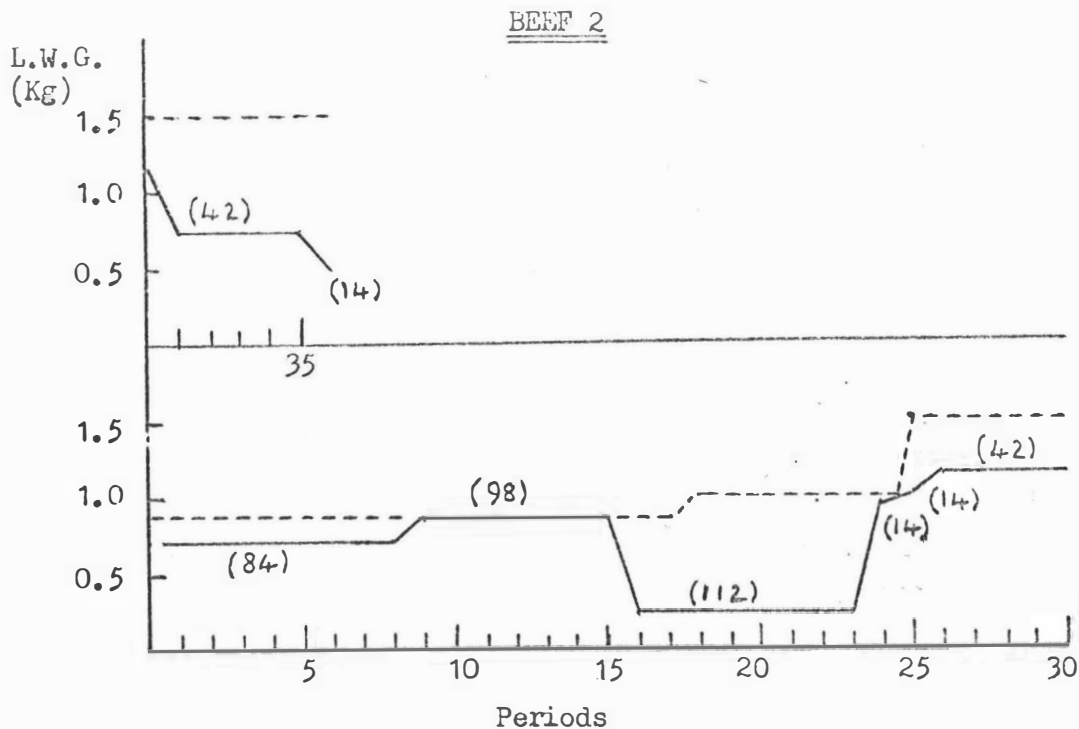
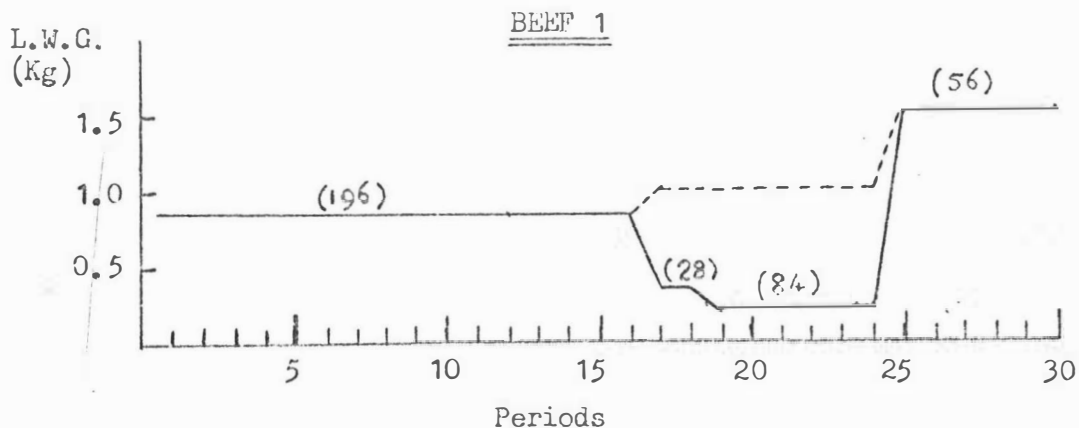
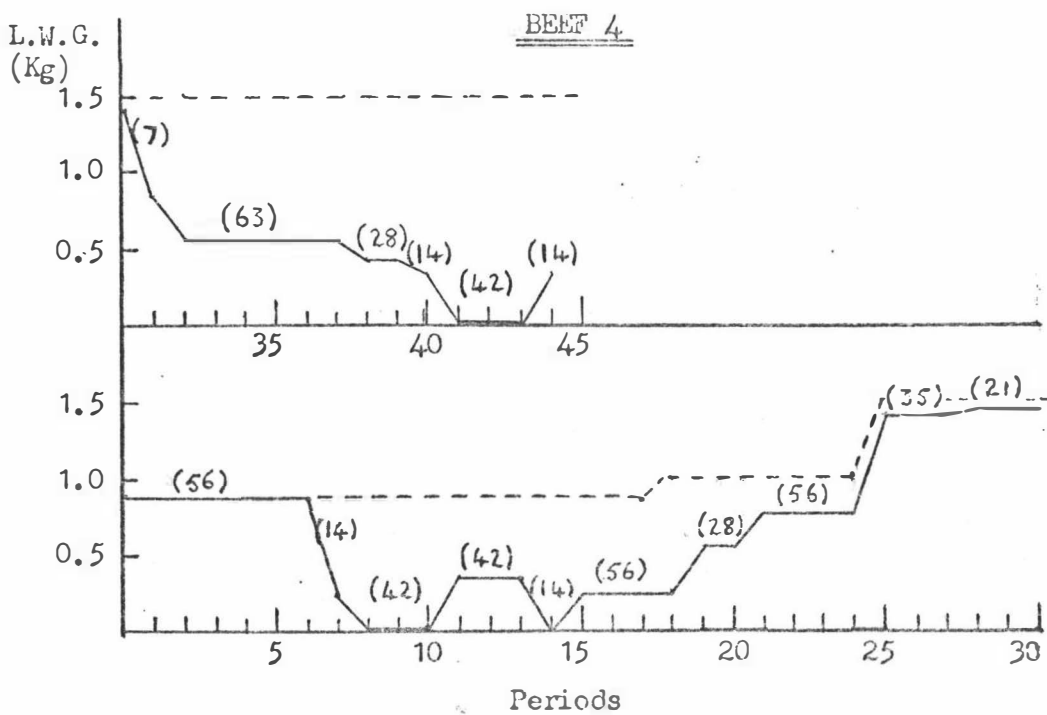
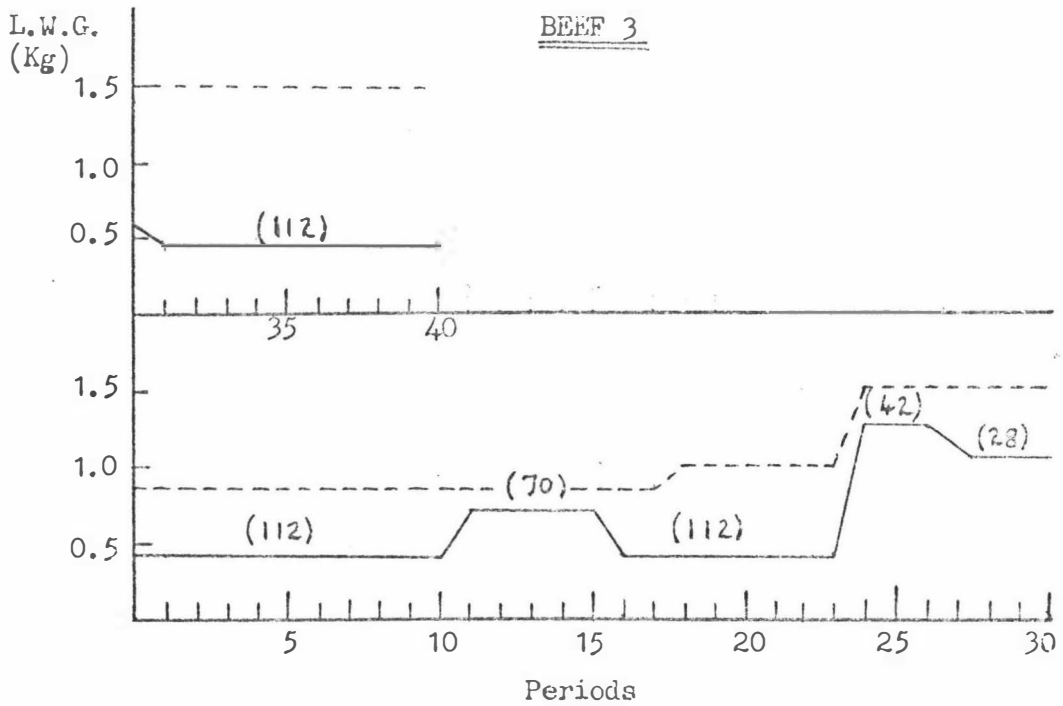


Fig. 5.2 (b)

Daily Liveweight Gain Achieved, BEEF 3, BEEF 4

————— Liveweight gain/head/day (L.W.G.)
 - - - - - Maximum allowable L.W.G.
 () Number of days L.W.G. is achieved



5.3.3 Conditions That Prevent Further Increases In Stocking Rate For Beef Systems

5.3.3.1 BEEF 1

Where 6.08 animals/ha are grazed to reach the target weights specified by BEEF 1 (Fig. 5.1), and feed is made available only by the management options (grazing severity and length of spell) defined in the pasture production model, feed is "tight"⁽¹⁾ in periods 13 - 30 and "slack"⁽²⁾ in periods 1 - 12 of the grazing year.

Decreasing the level of L.W.G. over periods 13 - 30 with an equivalent increase in periods 1 - 12 would allow more animals/ha to be grazed. However, maximum L.W.G. allowable in the model (.85 kg/Hd/day from Table 4.5) is already being achieved in periods 1 - 12. The shadow prices associated with feed periods 26 - 30 are slightly lower than those for the other "tight" feed periods. Hence decreased L.W.G. over periods 13 - 25 with a corresponding increase in periods 26 - 30 would be associated with a small increase in stocking rate. Again, such a change is not feasible since L.W.G. is already at the maximum (1.5 Kg/Hd/day) for periods 26 - 30 (see Fig. 5.2 (a)).

5.3.3.2 BEEF 2

Grazing 6.72 animals/ha so that the target weights are met, results in feed being "tight" in all periods of the year. The shadow prices associated with feed periods 1 - 13 and 26 - 30 are generally lower than those for periods 14 - 25. Small increases in stocking rate may therefore be expected if L.W.G. (and feed requirements) are reduced in periods 14 - 25, with a compensating increase in periods 1 - 13, 26 - 30. However, possible increases in stocking rate are likely to be small once these conditions (no surplus feed and shadow prices almost equal for all periods) have been reached.⁽³⁾

(1) The shadow prices associated with feed in those periods > 0 .

(2) Shadow prices = 0.

(3) A more detailed discussion of the shadow prices involved in this case (BEEF 2) is presented in Appendix 3. The results of one attempt to increase stocking rate are also presented in Appendix 3.

5.3.3.3 BEEF 3

The maximum stocking rate for BEEF 3 is 6.22 animals/ha. At this stocking rate feed is "tight" in all periods of the year. Shadow prices are (approximately) equal for periods 1 - 6 and 11 - 30, and lower than for periods 7 - 10. Animals do not achieve maximum L.W.G. in any period of the production process; hence, as discussed in Section 5.3.3.2, small increases in stocking rate could be obtained by further adjusting the pattern of L.W.G.

5.3.3.4 BEEF 4

At the maximum stocking rate (5.77 animals/ha) feed is "tight" in all periods of the year. Maximum L.W.G. is achieved in periods 1 - 6 (Fig. 5.2(b)). Shadow prices associated with feed periods 7 - 13 are slightly higher than those associated with the other feed periods. Feed requirement could be reduced in these periods by increasing the gain achieved by weaner cattle (from 0 in periods 8, 9 and 10) and reducing the gain achieved by yearling cattle (in periods 38, 39 and 40) because:

- (a) the feed requirements model aggregates the feed requirements in periods 8, 9 and 10 with 38, 39 and 40

and

- (b) from equation 4.3, the feed required to achieve the same level of L.W.G. is less for (lighter) weaner cattle than that required by (heavier) yearling cattle.

For the purposes of this study, however, the stocking rate, 5.77 animals/ha, is considered as the maximum possible for the length of production process defined by BEEF 4.

5.4 Discussion On Maximum Stocking Rates For Beef Systems

The liveweight gain per animal in the beef production activities,

BEEF 1, 2, 3 and 4, is 280 Kg. The length of time taken to achieve this gain is 364, 420, 476 and 532 days for BEEF 1, 2, 3 and 4 respectively. Average daily L.W.G./head therefore decreases from BEEF 1 through to BEEF 4. Hence, while intake/head required for production could be expected to decrease from BEEF 1 through to BEEF 4,⁽¹⁾ the maintenance requirements/head would be expected to increase from BEEF 1 to BEEF 4 because the animals are grazed for a longer period of time and maintenance requirements must be met each day.

Table 5.3 presents the maintenance, production and total feed requirements (Kg D.M./animal) for the patterns of L.W.G. that allow maximum stocking rate for each BEEF system.

Table 5.3

Feed Requirements/Animal For Beef Systems

Requirement/Animal (Kg D.M.)

	<u>BEEF 1</u>	<u>BEEF 2</u>	<u>BEEF 3</u>	<u>BEEF 4</u>
Maintenance	1038	1205	1350	1543
Production	<u>1005</u>	<u>1006</u>	<u>983</u>	<u>990</u>
Total	2043	2211	2333	2533

Maintenance requirements increase with increasing production period (BEEF 1 to BEEF 4), as discussed above. Production requirements however, remain relatively constant between the activities. Two assumptions inherent in the model appear to be masking the expected decrease in production requirement from BEEF 1 through to BEEF 4.

Firstly, pasture quality (M.Cal. M.E./Kg D.M.) is assumed to vary throughout the year as shown in Table 4.4. Hence the actual D.M. requirement/head for production is dependant on the amount of L.W.G. achieved in different periods of the year. Table 5.4 shows the production requirements/animal for BEEF 1, 2, 3 and 4 in terms of M.Cal.M.E.

(1) Since from Table 4.4 increments in L.W.G. are associated with increasing increments in production requirement for animals of the same liveweight.

Table 5.4

Available Energy Requirements For Beef Systems

	Production Requirement <u>(M. Cal. M.E./animal)</u>
BEEF 1	2689
BEEF 2	2642
BEEF 3	2607
BEEF 4	2636 *

* The pattern of L.W.G. for BEEF 4 includes 84 days of zero L.W.G. (Fig. 5.2(b)). Hence average daily L.W.G. on the days (448) that L.W.G. is achieved, is higher than for BEEF 3. Therefore the production requirement would be expected to be (and is) higher than that for BEEF 3.

Secondly, Equation 4.2 is a linear approximation of the relationship between L.W.G. and production intake/L.W.^{.75}. The actual relationship between L.W.G. and production intake/L.W.^{.75} exhibits decreasing returns (see Fig. 4.9). Hence, within the model the increase in production requirement with increasing liveweight gain is not as large as would be expected from Table 4.2.

Because of these two assumptions (pasture quality, and the linear approximation of production requirements), total feed requirements/head increase from BEEF 1 through to BEEF 4, due to the increase in maintenance requirements. Given this, the maximum stocking rates for each BEEF production activity can be discussed in relation to total system requirements (total per animal requirements x maximum stocking rate) and the overlap of the two classes of stock, (yearling cattle and replacement weaners).

Figs. 5.3 - 5.6 present the total system feed requirements for each period of the grazing year. Maintenance requirements and the total requirements are shown. The area between (the solid line and the dotted line) represents the total production requirement per period. The total system requirements on an annual basis are shown in Table 5.5.

Table 5.5

Total System Feed Requirements On An Annual Basis

	<u>Kg D.M./ha</u>
BEEF 1	12424
BEEF 2	14855
BEEF 3	14513
BEEF 4	14615

Increases in stocking rate from BEEF 1 to BEEF 2 then is due to the use of pasture that is surplus in some periods⁽¹⁾ for BEEF 1 but which cannot be utilised by this production system due to intake restrictions in those periods.

Decreases in stocking rate from BEEF 2 through BEEF 3 and BEEF 4 are due to increasing maintenance requirements/animal as the production period increases. This is illustrated by the maintenance requirements over periods 7 - 14 for BEEF 2, 3 and 4 from Figs. 5.4, 5.5 and 5.6 respectively.

5.5 Grazing Management Plans

The grazing management plan that maximised stocking rate for any BEEF production system was not unique. In all cases, some pasture production activities not included in the optimal plan could have been included without altering the maximum stocking rate. This result is not surprising. In real-life grazing management systems, the level of production actually achieved probably could have been obtained from a number of different grazing management decisions.

Since the grazing management plan that maximises stocking rate for any BEEF production system is not unique, comparisons between grazing management plans for the different BEEF production systems are difficult. In an attempt to rationalise comparisons between grazing management plans;

(1) Compare periods (1 - 6) in Figs. 5.3 and 5.4.

Fig. 5.3

Period Feed Requirements For BEEF 1 At Maximum Stocking Rate

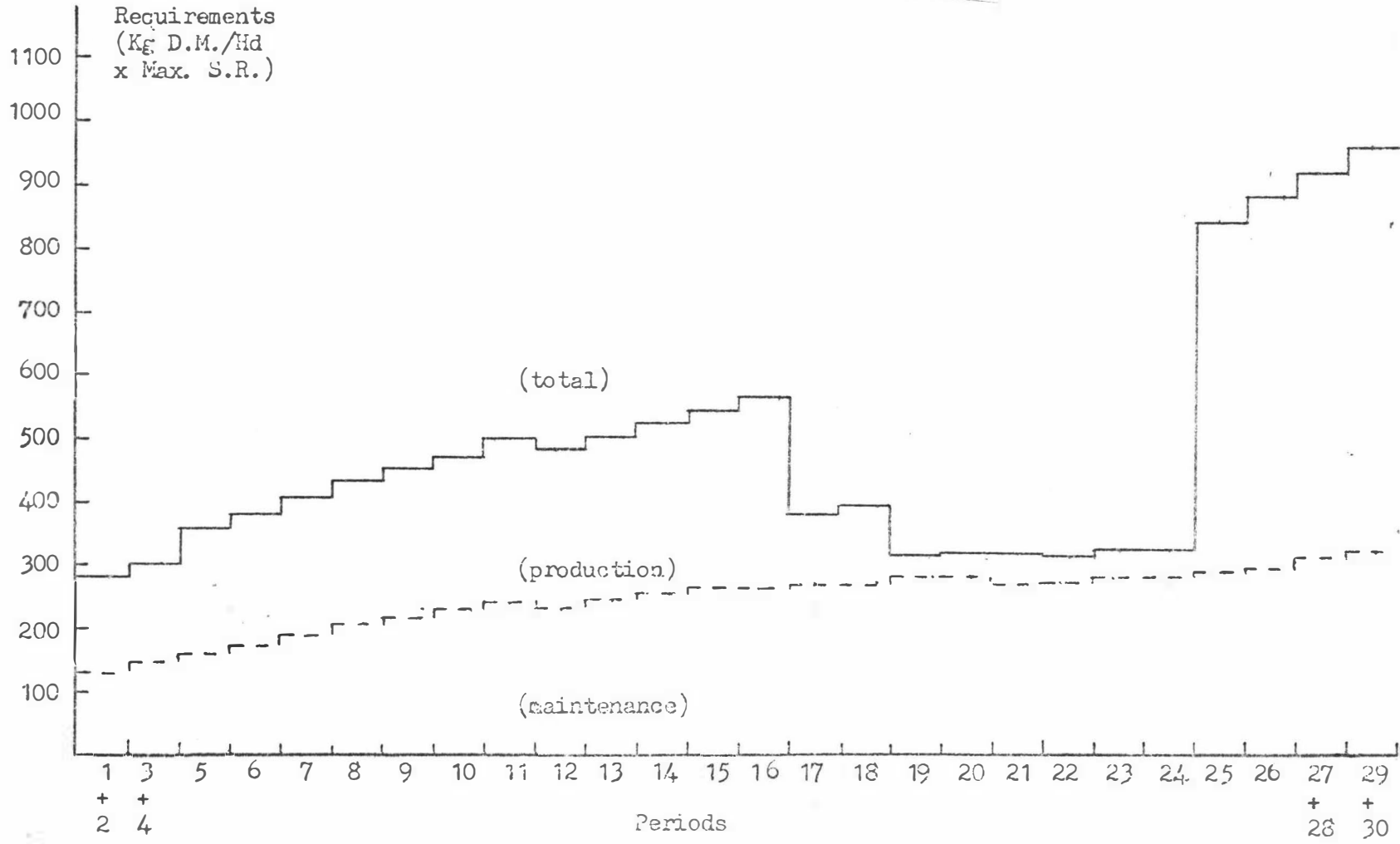


Fig. 5.4

Period Feed Requirements For BEMF 2 At Maximum Stocking Rate

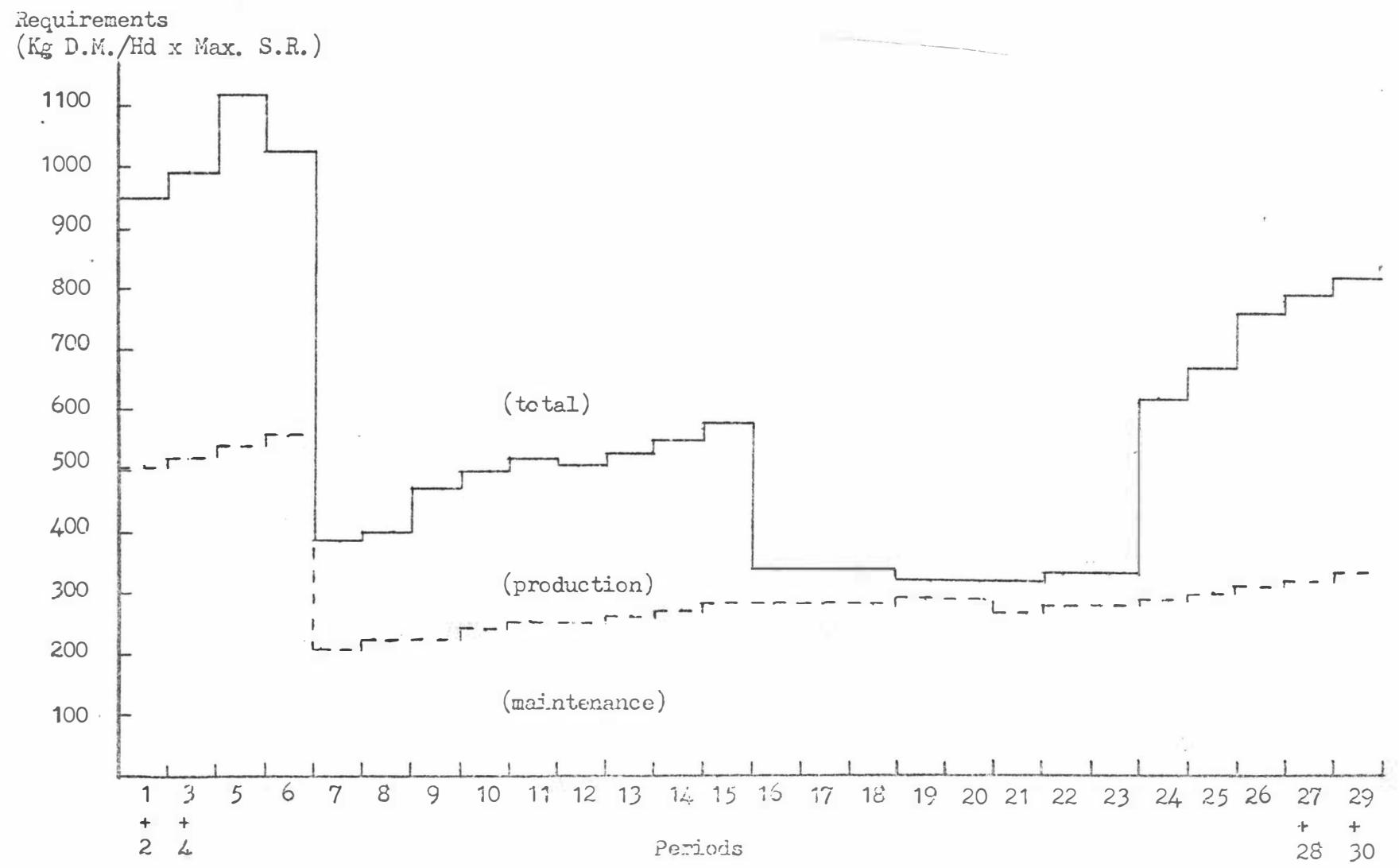


Fig. 5.5

Period Feed Requirements For BEEF 3 At Maximum Stocking Rate

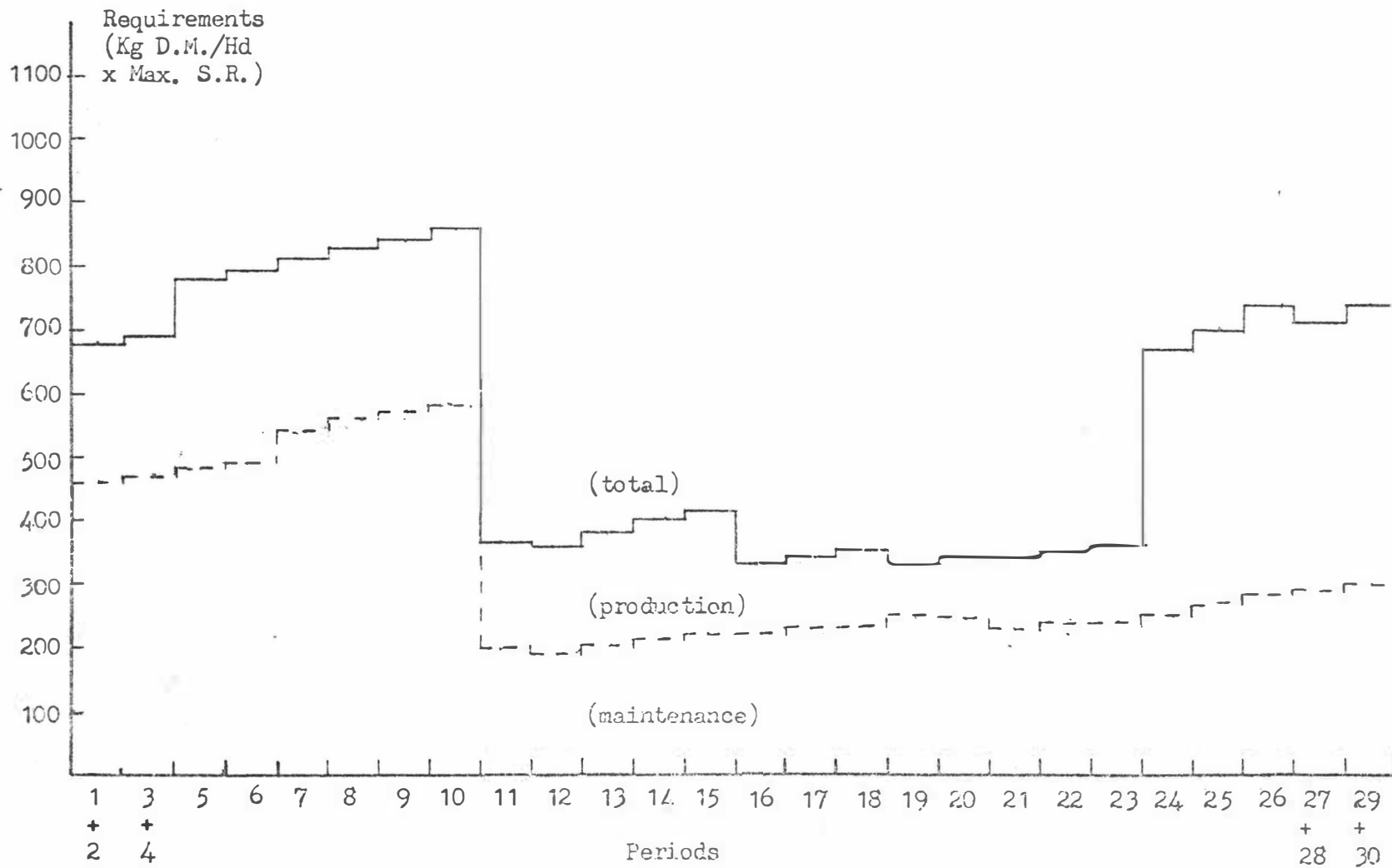
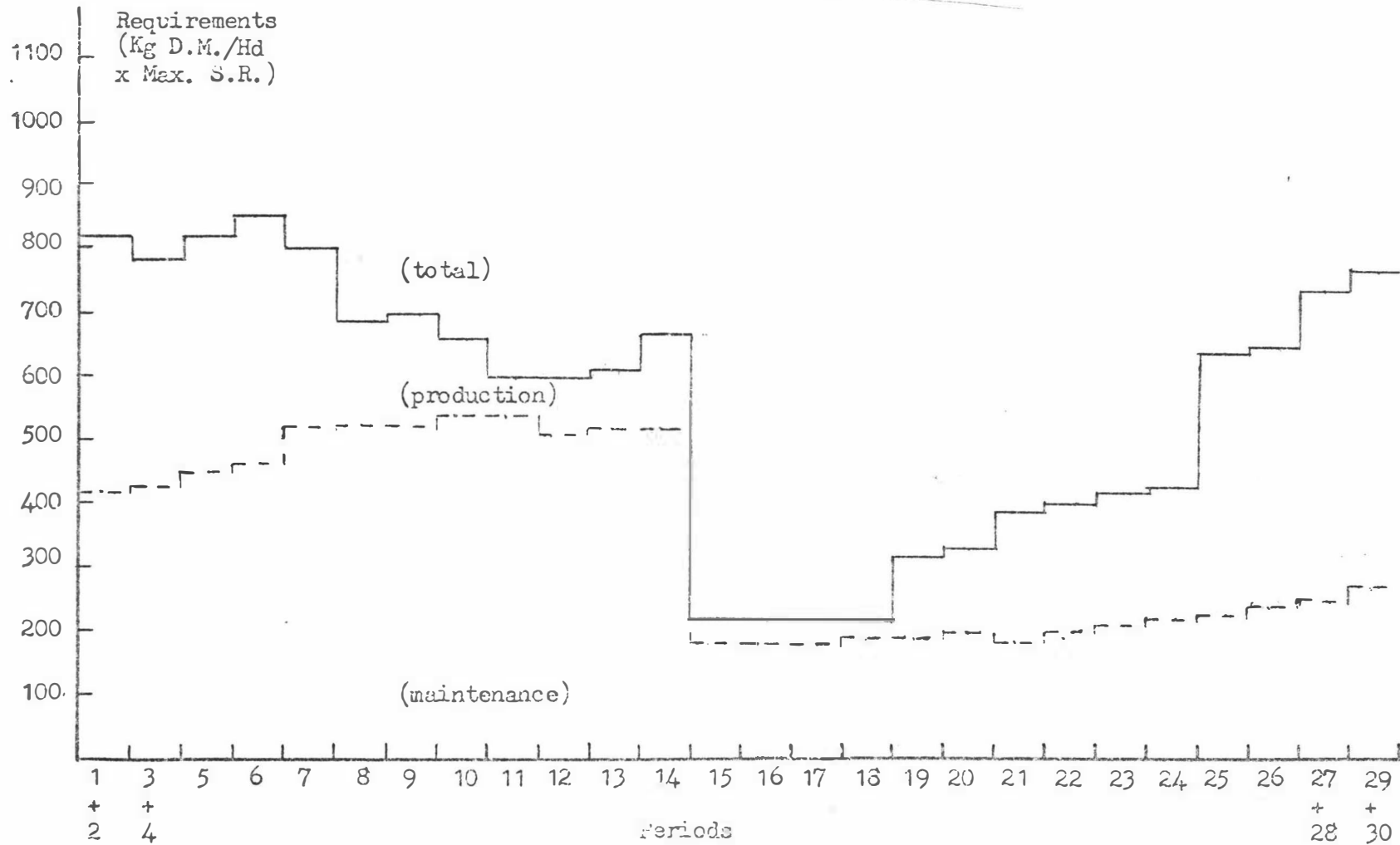


Fig. 5.6

Period Feed Requirements For BEEF 4 At Maximum Stocking Rate



5.5 Grazing Management Plans (Continued)

the model was used to maximise pasture D.M. production, surplus to feed requirements associated with the previously determined maximum stocking rate for each BEEF system.

The amounts of surplus pasture D.M. and the periods in which these occur, are presented in Table 5.6.

Table 5.6

Production Of Feed Surplus To Animal Requirements At
The Maximum Stocking Rate Of Beef 1, 2, 3, And 4

<u>Period</u>	<u>Extra Feed (Kg D.M.)</u>			
	<u>BEEF 1</u>	<u>BEEF 2</u>	<u>BEEF 3</u>	<u>BEEF 4</u>
4	108	-	14	-
6	1345	-	-	-
8	56	-	-	-
9	521	-	-	-
10	38	-	-	-
11	-	11	-	-
12	14	-	-	-
30	-	-	-	11
Total D.M. produced)				
annually above)				
animal requirements)	2082	11	14	11
(Kg D.M./ha))				

Maximising pasture D.M. production, surplus to animal requirements, did not produce unique grazing management plans for each BEEF system. However, in each case, the number of non-basic pasture production activities that could be included in the optimal plan without altering maximum stocking rates was reduced, (e.g. from 92 to 24 for BEEF 1). The solutions for BEEF 2, 3 and 4 contain 27, 27 and 21 non-basic pasture production activities, respectively, that could enter the optimal basis without cost.

To some extent then the grazing management plans chosen by the model are an arbitrary selection from the set of optimal plans for each BEEF production system. In order to improve on this situation it would be necessary to derive criteria for selecting between plans; but this matter has not been pursued further in this study.

The (arbitrary) optional grazing management plans for BEEF 1, 2, 3 and 4 are presented in Figs. 5.7, 5.8, 5.9 and 5.10 respectively. Columns (1 - 30) represent the periods of the grazing year. Each horizontal arrow (e.g. 19—→) represents an area of pasture spelled from the mid - point of one period, and available for grazing in some other period. Pasture available for HIGH grazing is shown by the solid arrows, and pasture available for LOW grazing by the dotted arrows. The number to the left of each arrow defines the area⁽¹⁾ of pasture involved, and the number is in the period (column) from which pasture is spelled. The head of the arrow defines the period in which pasture is available for grazing.

The numbers in brackets to the left of column (1) show the areas spelled from grazing at the end of the grazing year until grazing near the beginning of the next year. For example, in the grazing management plan for BEEF₁ (Fig. 5.7), the first row shows that 14 ha. of pasture are spelled from period (29) and grazed HIGH in period (2).

Table 5.7 is a more detailed representation of the optimal grazing management plan for BEEF 2. A grazing area of 100 ha. is assumed. In each row the total area of land in each period is reconciled to equal 100 ha. The first two columns contain the area grazed either HIGH or LOW in each period. Remaining columns contain the area (hectares) of pasture being spelled in each period, and the length of time since it was grazed either HIGH or LOW. For example, in period (13), 35 ha. are grazed HIGH; 32 ha. have been spelled for 14 days since HIGH grazing in period (12); and 33 ha. have been spelled for 28 days since HIGH grazing in period (11).

(1) A basic area of 1 hectare is considered in all experimentation. The areas in Figs. 5.7 - 5.10 are the areas grazed times 100. Alternatively they may be considered as the actual area grazed where the total area grazed is 100 ha. To simplify the presentation of these results, the areas grazed have been rounded off.

Fig. 5.8

Grazing Management Plan For BEEF 2

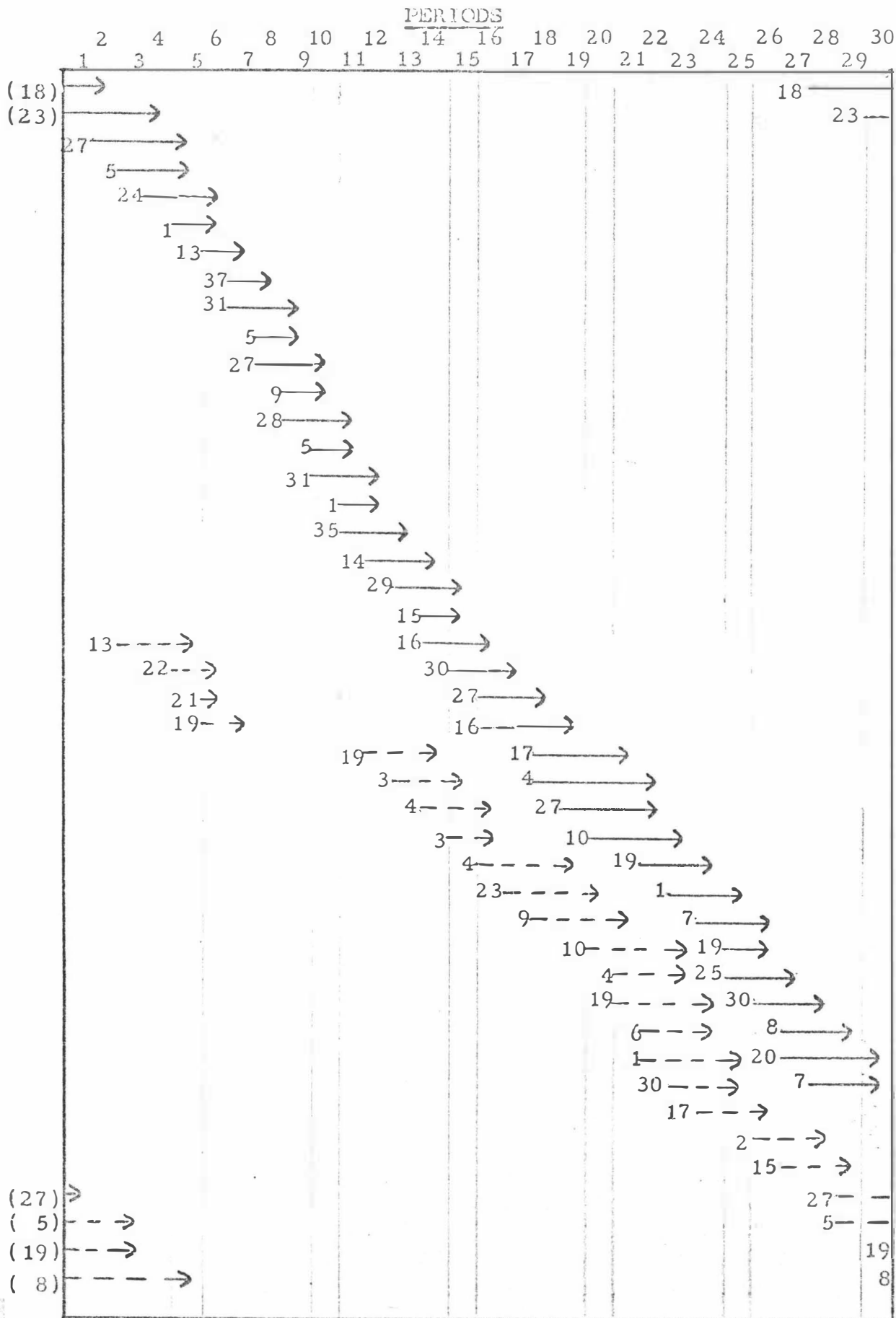


Fig. 5.10

Grazing Management Plan For BEEF 4

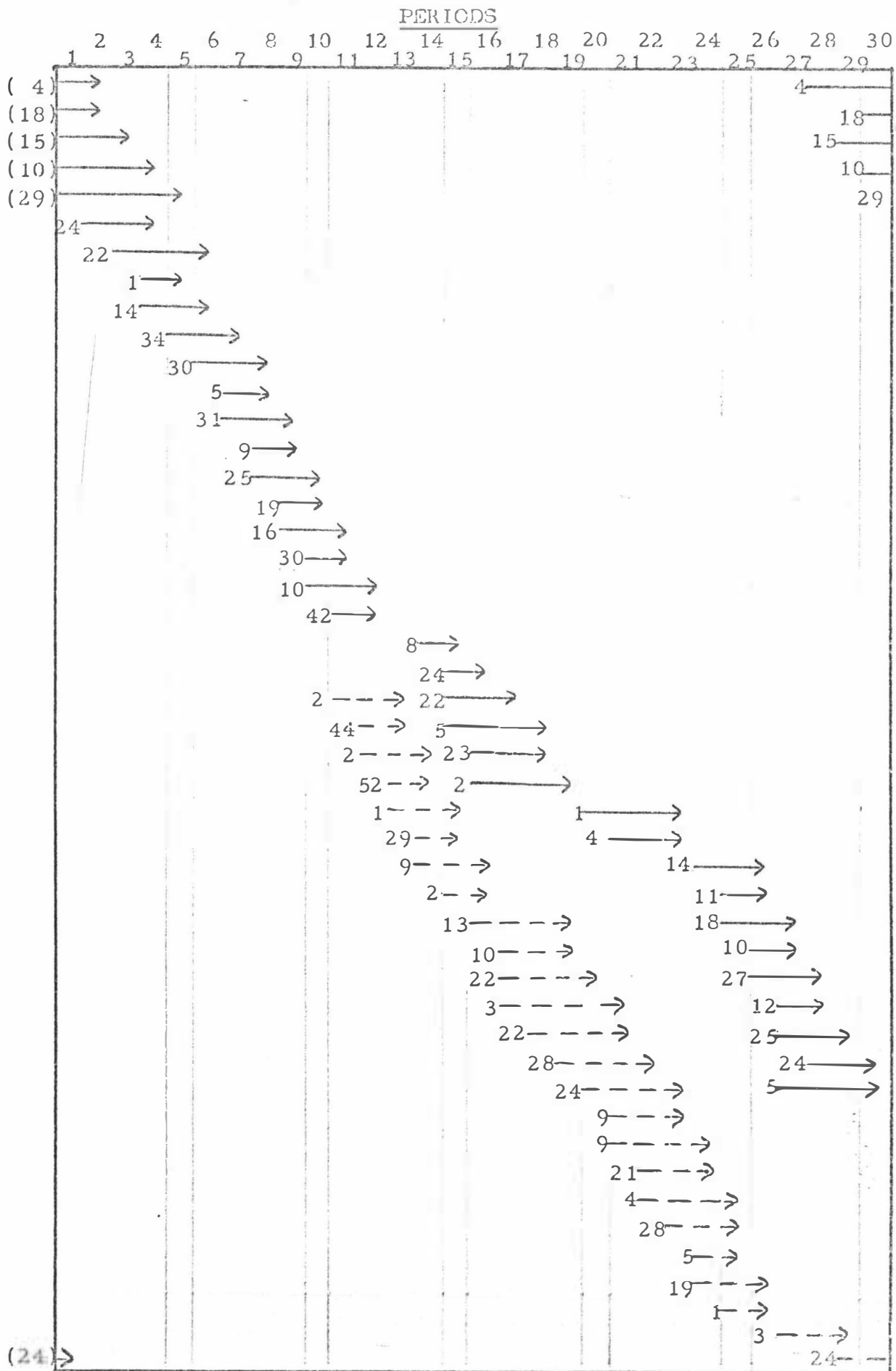


Table 5.7

Detailed Representation Of Grazing Plan For BEEF 2

Period	Area Grazed		Length Of Spell Since HIGH Grazing (Days)											Length Of Spell Since LOW Grazing (Days)											Total	
	HIGH	LOW	7	10	14	17	21	24	28	31	35	38	42	56	7	10	14	17	21	24	28	31	35	38		42
1		27	27		8		3		18							15		2								100
2	18				27		8		3					27			15		2							100
3		24	18				8		8						27					15						100
4	23				18				8					24				27								100
5	32	21		23													24									100
6	25	43			11											21										100
7	13	19			25										4.3											100
8	37				13										19					31						100
9	36				37			13												14						100
10	36				36			28																		100
11	33				36			31																		100
12	32				33			35																		100
13	35				32			33																		100
14	14	19			35			32																		100
15	44	3			14			20								19										100
16	16	7			44			11								3			19							100
17	30				16			44								7			3							100
18	27				30			16		20									7							100
19	16	4			27			30		16													7			100
20		23			16			27		30																100
21	17	9						16		27	4					23			4							100
22	31				17					16						9			23				4			100
23	10	14			31			17										9				19				100
24	19	25			10			31								14								1		100
25	1	31			19			10								25						14				100
26	26	17			1											31						25				100
27	25			26				1								17				31						100
28	30	2	25		26													17								100
29	8	15	30		25			3							2					17						100
30	27		8		30		18								15		2									100

5.5. Grazing Management Plans (Continued)

Lengths of spell that are not multiples of 7 or 14 days are brought about by spelling pasture from a 14 day period to a 7 day period or by spelling pasture from a 7 day period to a 14 day period.⁽¹⁾ For example, in period (26), 26 ha. are grazed HIGH. The mid-point of period (27), a 7 day period, is 10 days after the mid-point of period (26), a 14 day period. Thus in period (27) 26 ha. have been spelled for 10 days since grazing at the HIGH level. Similarly the 1 ha. of pasture that had been spelled after HIGH grazing for 14 days in period (26), and the 31 ha. spelled for 14 days since LOW grazing have both been spelled for 24 days by the mid-point of period (27).

5.5.1 Comparison Of Grazing Management Plans For BEEF 1 And BEEF 2

Extending the length of the production process until period 36 (BEEF 2) allows stocking rate to be increased from 6.08 animals/ha (maximum for BEEF 1) to 6.72 animals/ha, (maximum for BEEF 2). In order to simplify examination of the differences that exist between the two grazing management plans, the year has been divided into four periods. Spring accounts for grazing periods 24 - 30 - 4 inclusive, summer 5 - 11, autumn 12 - 17, and winter 18 - 23. The area of pasture grazed HIGH and LOW in each of these periods is presented in Table 5.8, along with the area grazed per day (i.e. total area grazed divided by the number of days in each period). A total area of 100 ha. is considered. D.M. available per grazing is calculated as the total feed requirements plus extra feed grown (Table 5.3) divided by the number of hectares grazed.

The length of spell between grazings over the spring period (as represented by the average area of pasture grazed per day) is shorter for BEEF 1 than for BEEF 2. The amount of pasture available at each grazing (on average) is also less. The rotation length over the summer for BEEF 1 however, is longer than for BEEF 2 and pasture available/ha. at each grazing is considerably more (a considerable amount of this summer production is extra D.M. above animal requirements - see Table 5.5). Length of spell between grazings and D.M. available/ha. at each

(1) See Section 3.4.4.

Table 5.8

Comparison Of Grazing Management Plans For BEEF 1 And
BEEF 2 (For a Total Area of 100 Hectares)

	Area Grazed (ha)		Total Area	Area Grazed	Average D.M.
	<u>HIGH</u>	<u>LOW</u>	<u>Grazed (ha)</u>	<u>Per Day</u>	<u>Available/ha At Each Grazing</u>
<u>BEEF 1</u>					
Spring	81	277	358	3.65	1286
Summer	237	-	237	2.42	2086
Autumn	147	52	199	2.37	1513
Winter	46	103	149	1.77	1315
<u>BEEF 2</u>					
Spring	177	141	318	3.24	1765
Summer	212	83	295	3.01	1506
Autumn	171	29	200	2.38	1423
Winter	101	50	151	1.80	1300

grazing are similar for both BEEF 1 and BEEF 2 over the autumn and winter periods.

Total D.M. production by both grazing plans is similar, (14500 Kg D.M./ha for BEEF 1 compared with 14866 Kg D.M. for BEEF 2), although the animals in BEEF 1 are unable to utilise approximately 2000 Kg D.M./ha of the feed grown. As discussed in Section 3.4.3.2, this extra D.M. is assumed to be removed mechanically from the pasture so that the pasture production relationships inherent in the model hold for all periods of the year.⁽¹⁾

5.5.2 Comparison Of Grazing Management Plans That Maximise Stocking Rate For BEEF 2 With The Plans For BEEF 3 And BEEF 4.

Table 5.9 compares the grazing management plans that result in the maximum stocking rates of BEEF 2, 3 and 4 being run. As in Table 5.8, the plans have been simplified into 4 periods.

Major differences between the plans occur in the summer period

(1) Making supplementary feed as a means of utilising extra feed is considered in Section 5.7.

Table 5.9

Comparison Of Grazing Management For BEEF 2 With Plans For
BEEF 3 And BEEF 4 At Maximum Stocking Rates

	Area Grazed (ha)		Total Area	Area Grazed	Average D.M.
	<u>HIGH</u>	<u>LOW</u>	<u>Grazed (ha)</u>	<u>Per Day</u>	<u>Available/ha At Each Grazing</u>
<u>BEEF 2</u>					
Spring	177	141	318	3.24	1765
Summer	212	83	295	3.01	1506
Autumn	171	29	200	2.38	1423
Winter	101	50	151	1.80	1300
<u>BEEF 3</u>					
Spring	116	200	316	3.22	1569
Summer	152	93	245	2.50	2153
Autumn	160	44	204	2.43	1091
Winter	76	72	148	1.76	1398
<u>BEEF 4</u>					
Spring	193	114	307	3.13	1584
Summer	243	-	243	2.48	2114
Autumn	106	140	246	2.93	1123
Winter	34	131	165	1.96	1130

5.5.2 Comparison Of Grazing Management Plans That Maximise Stocking Rate For BEEF 2 With The Plans For BEEF 3 And BEEF 4 (Continued)

when the slower rotations of BEEF 3 and BEEF 4 result in higher levels of available pasture/ha at each grazing.

Total annual D.M. production from the three plans is similar (14866, 14527 and 14626 Kg D.M./ha for BEEF 2, 3 and 4 respectively) despite the differences in management plans.

5.6 Relating Grazing Management Plans To Farmer Practice

The grazing management plans devised by the model are complex in the number and areas of feed sources used in any one period. For example, from Table 5.7, the 68 ha of pasture grazed in period (6) is made up of 21 ha, that has been grazed HIGH 14 days previously, 23 ha that had been grazed HIGH 24 days previously, and 24 ha that had been grazed 31 days previously. In the on-farm situation where an electric fence is used, the area of pasture grazed in any one period (day) will almost certainly have been spelled for different lengths of time and have been subject to varying degrees of grazing intensity. However, in this practical situation the entire area of a paddock grazed in some previous period (t) will usually be completely grazed again once a start has been made on that area in period (t + k). That is, where 10 ha are grazed in period (t), and the manager feeds smaller areas (< 10 ha) in the subsequent (k - 1) periods (i.e. to slow down the rotation) then the 10 ha grazed as a paddock in period (t) will probably not be completely grazed in period (t + k). If 4 ha of that paddock are grazed in conjunction with 2 ha of some other paddock in period (t + k) then it is most likely that some of the remaining 6 ha will be grazed in period (t + k + 1) and the remainder in period (t + k + 2).

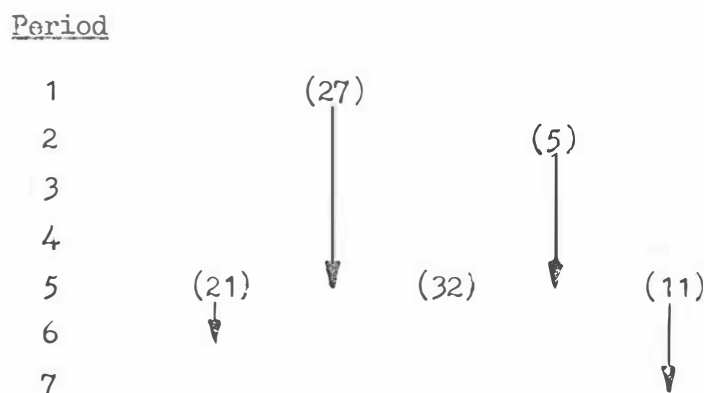
The areas selected by the model to be grazed in each period are not constrained by the practical consideration of grazing an entire paddock once a start has been made on that paddock. Areas of pasture grazed HIGH in a period are pooled by the area constraints⁽¹⁾ and the pooled area is thus available for grazing at either HIGH or LOW levels

(1) Area constraints are described in Appendix 1.

in subsequent periods. Similarly, the areas grazed LOW in a period are pooled for subsequent grazing. The fact that the model "pools" areas grazed in any period makes the task of defining a management plan which could be applied to the real-life situation a difficult task.

This problem may be illustrated with the help of Fig. 5.11, which has been derived from the detailed computer output for BEEF 2.

Fig. 5.11 The Fate Of 27ha Grazed LOW In Period (1)



The 27ha grazed LOW in period (1) is grazed HIGH in period (5). This area has been pooled with 5ha that has also been grazed HIGH in period (5). The pooled area of 32ha has been subdivided into two areas: 21ha grazed LOW in period (6) and 11ha grazed LOW in period (7). The model does not partition the 27ha into the area grazed LOW in period (6) and the area grazed LOW in period (7).

The problem of tracing the fate of the 27ha grazed LOW in period (1), so that the same 27ha is grazed LOW in period (1) in the subsequent year is not trivial but can be solved. A system of equations can be derived that describe the fate of all areas for a period, and this system can then be solved (e.g. by linear programming) to provide a grazing management plan that is consistent in the sense described above. ⁽¹⁾

(1) Professor R.J. Townsley, Massey University, formulated a linear programming model of this problem for the BEEF 2 grazing system, but at the time of writing the computer output was not available.

For the example shown in Fig. 5.11, let:

x_1 = area grazed LOW in period (6) that was also grazed HIGH in period (5) and LOW in period (1)

x_2 = area grazed LOW in period (7) that was also grazed HIGH in period (5) and LOW in period (1)

y_1 = area grazed LOW in period (6) that was also grazed HIGH in period (5) and LOW in period (2)

y_2 = area grazed LOW in period (7) that was also grazed HIGH in period (5) and LOW in period (2)

Then,

$$\begin{array}{rcl} x_1 + x_2 & & = 27 \\ & y_1 + y_2 & = 5 \\ x_1 & + y_1 & = 21 \\ & x_2 & + y_2 = 11 \\ x_1, x_2, y_1, y_2 & \geq & 0 \end{array}$$

Since these four equations are not linearly independent we would expect to find that the solution to this problem is not unique.

An alternative approach would be to attempt to devise a pasture production model that does take account of paddock areas. However, this possibility has not been explored in this study.

5.6.1 Uses Of The Model For Grazing Management Studies

The model as specified cannot (easily) be used for devising grazing management plans. However, because the plans devised by the model are feasible (Section 5.6) and because the model contains an optimising routine, the "cost" associated with simplifying these plans to a form that is acceptable for comparison with real-life systems can be calculated by further experimentation with the model. To achieve this it would be necessary to devise some simplified management plan, "force" this into

the pasture production model, and then using the iterative procedure already outlined calculate the differences in maximum stocking rate between the original complex plan and the simplified plan. These differences provide a bench-mark for calculating the "cost" involved in adopting the simplified plan.

While the methodology of such experimentation is clear, the usefulness of the results obtained is dependant on the degree of reality achieved by the relationships inherent in the model. In the absence of sufficient quantitative data to validate the production processes represented in the model, and because the study was carried out in isolation from a research organisation where subjective attempts at validation might have been readily made, further experimentation was considered outside the scope of this study, (the development of supplementary feeding activities is however, considered in Section 5.7). Further discussion on the development of experimental techniques that may be used with grazing system models, especially those that include an optimising routine, is presented in Section 6.3.

5.7 Supplementary Feeding

The modelling exercise up to this point has only considered feeding possibilities offered by grazing pasture in situ. Farmers involved in the production of beef do however make hay and silage. Reasons for making supplementary feed include the need to conserve feed surpluses where stocking rate is not sufficiently high to control pasture growth especially in the spring, early summer period; and the desire to have some supplementary feed available as an "insurance" against reduced pasture growth (e.g. in dry summers or cold winters) at some future time.

A method of including both the making and feeding out of supplementary feed within the model was devised, and some experimentation was carried out.

5.7.1. Hay And Silage Making Activities⁽¹⁾

Information in the literature on the D.M. losses associated with

(1) The mathematical details of supplementary feed activities are presented in Appendix 4.

the making of hay and silage is limited.⁽¹⁾ Seventeen supplementary feed-making activities were included in the model under the assumption that losses associated with hay and silage are equal.

Hence the supplementary feed assumed to be made by the model can be either hay or silage. Each supplementary feed activity spells pasture after a HIGH grazing and the harvesting for supplementary feed is assumed to occur at the LOW grazing level. Hence regrowth of pasture after supplementary feed has been made, is defined by pasture production activities (LOW - HIGH), already described in the model. The spelling and harvesting dates for the making of supplementary feed are presented in Table 5.10.

Table 5.10

Spelling And Harvest Dates For Supplementary Feed
Making Activities

<u>Name</u>	<u>Spelled From Mid-</u> <u>Point Of Period</u>	<u>Harvested at Mid-</u> <u>Point Of Period</u>
SUP 01	27	1
SUP 02	27	2
SUP 03	28	3
SUP 04	29	4
SUP 05	30	5
SUP 06	2	6
SUP 07	4	7
SUP 08	5	8
SUP 09	6	9
SUP 10	7	10
SUP 11	8	11

D.M. harvested/ha from each of these activities is included as 0.765⁽²⁾ of the D.M. available/ha above the LOW grazing (harvesting)

(1) E.g. Minson (1963).

(2) 15% losses are assumed to occur in the harvesting process, and a further 10% of D.M. is assumed lost in feeding the supplementary feed to animals. $(1 - (.15) - (\frac{.10 \times .85}{1})) = 0.765$

height. This amount (0.765 D.M. available x area of supplementary feed made) is available for feeding in any period of the year subject to the feeding restrictions presented in Section 5.7.2.

5.7.2. Supplementary Feeding Activities

The feeding of hay or silage will lower the amount of pasture that grazing animals may eat (Reardon (1975)). Intake/head has been constrained within the model by limiting the level of L.W.G. that animals may achieve. To include some restriction on the amount of supplementary feed that the animals may consume the assumption was made that animals could meet their maintenance requirement by eating either hay or silage.

30 supplementary feeding activities (SUPF 01 - SUPF 30) were included in the model. Each activity represents 1 Kg of supplementary feed D.M. made available for consumption (losses involved in making and feeding supplementary feed are included in the supplementary feed-making activities).

Each Kg of supplementary feed D.M. eaten by the animals is assumed to contain 1.9 M.Cal. M.E. Hence the amount of pasture D.M. replaced by one Kg of supplementary feed D.M. changes throughout the year, since the M.E. content of pasture varies throughout the year. (see Table 4.4). The actual replacement values used are presented in Table 5.11.

Table 5.11 Pasture D.M. Replaced By 1 Kg Of Supplementary Feed D.M.

<u>Period</u>	<u>Kg Pasture D.M. Replaced By 1 Kg Supplementary Feed D.M.</u>
1 - 6	.717
7 - 11	.792
12 - 15	.745
16 - 20	.717
21 - 30	.679

In each period of the year the amount of supplementary feed consumed is restricted to the maintenance requirement, (Kg D.M./animal x stocking rate), adjusted for M.E. content of the pasture D.M. in that

period. The coefficients used for this adjustment are presented in Table 5.12. They are calculated as:

$$\frac{\text{M.E. Content Of Pasture D.M.}}{\text{M.E. Content Of Supplementary Feed D.M.}}$$

Table 5.12

Correction Factors For The Calculation Of Supplementary Feed D.M. Restriction For Each Period Of The Year

<u>Period</u>	<u>Supplementary Feed D.M. Restriction (Kg D.M.) Is Maintenance Requirement Per Animal Multiplied By</u>
1 - 6	1.39
7 - 11	1.26
12 - 15	1.34
16 - 20	1.39
21 - 30	1.47

Hence where one animal required 14 Kg of pasture D.M. for maintenance in period 1, the model may provide this by feeding (from Table 5.11).

$$\frac{14}{.717} = 19.5 \text{ Kg of supplementary feed D.M.}$$

From Table 5.12 it can be seen that where maintenance requirement is 14 Kg of pasture D.M. for period 1, then the maximum amount of supplementary feed D.M. that may be fed equals

$$14 \times 1.39 = 19.5 \text{ Kg}$$

5.7.3 Experimentation With Supplementary Feeding Possibilities

The information provided by the stocking rate experimentation (Section 5.3.3) suggests that including supplementary feeding possibilities would allow an increase in the stocking rate for BEEF 1 since at the maximum stocking rate (6.08 animals/ha) surplus feed is available in periods (1 - 12), and further increases in stocking rate cannot be

brought about by altering the pattern of L.W.G. since maximum L.W.G. is achieved in those periods.

Including the feed requirements as defined for BEEF 1 and allowing supplementary feed to be made, resulted in maximum stocking rate increasing to 6.9 animals/ha; an increase of .82 animals/ha.

The areas of pasture made into supplementary feed, and the amount of supplementary feed used per period are presented in Table 5.13.

Table 5.13 Areas Of Supplementary Feed Made And Amounts Of Supplementary Feed Used In BEEF 1 At Maximum Stocking Rate
(Total area considered = 1 ha)

<u>Period</u>	<u>Area Of Supplementary Feed Made (ha)</u>	<u>Period</u>	<u>Amount Of Supplementary Feed Used (Kg D.M.)</u>
3	.18	13	115
4	.19	14	122
5	.19	15	90
6	.11	16	332
7	.07	20	474
8	.03	22	32
		24	90
		25	532
		26	11

In this solution feed is "tight" in all periods of the year, and the shadow prices associated with the feed rows are almost equal.

Small increases in the maximum stocking rates of BEEF 2, 3 and 4 are also achieved when supplementary feeding possibilities are included in the model. (0.02, 0.10 and 0.05 animals/ha for BEEF 2, 3 and 4 respectively). This result is expected since the shadow prices associated with the feed rows were not equal when maximum stocking rates were determined without considering supplementary feeding possibilities. The inclusion of the supplementary feeding alternatives gives the model a method by which some of these inequalities may be evened out. The

same response may have been achieved by further adjustments in the pattern of L.W.G. for BEEF 2, 3 and 4, without considering supplementary feed.

5.7.4. Discussion On The Increased Stocking Rate Due To Supplementary Feeding

The inclusion of supplementary feeding activities allows more animals to be grazed in the BEEF 1 production process than in BEEF 2, (which allowed the highest stocking rate where only grazed pasture was considered).

This result must be considered in relation to the assumptions included in the supplementary feeding matrix; in particular the assumption which allows animals to eat up to their maintenance requirement from supplementary feed D.M. and still achieve the maximum levels of L.W.G. allowable in the model (see Table 4.5). Animals in BEEF 1 achieve the limit to supplementary feed intake in two periods of the year. In one of these periods (period 25) the animals also achieve the maximum liveweight gain (1.5 Kg/head/day). Total D.M. intake/head/day (including supplementary D.M.) during this period is 11.57 Kg. This D.M. intake is 3.8% of animal L.W. which in view of information available on animal intake (see Section 4.2.1) appears unrealistically high.

Furthermore, no financial considerations have been taken into account; in particular the cost of conserving supplementary feed. While such considerations could easily be incorporated within the supplementary feeding matrix, this has not been done in this study due to lack of model validation.

The supplementary feeding matrix was included to illustrate that supplementary feeding could be handled in such a model. Given quantitative data on the losses associated with making and feeding out supplementary feeds, and information on the likely intakes of supplementary feed in relation to total feed intake, the model could be used to further investigate the use of supplementary feed within a beef production system.

5.7.5 Further Experimentation Possible With The Model Including Supplementary Feeding Possibilities

Where valid assumptions concerning the harvesting, feeding out, and per animal intake of supplementary feeds are included, the model as outlined could be used to investigate the cost - efficiency of feed conservation as a means of transferring feed from periods of surplus to these periods where feed supply limits further increases in stocking rate. The model could also be used as a means of "hedging" against the uncertain nature of climatic factors and the effects they have on pasture production. That is, stocking rates for each of the BEEF activities could be maximised using the iterative procedure outlined, subject to the constraint that x bales of hay (Kg of supplementary feed D.M.) are made per animal. Again, since the model contains an optimising routine, the "cost" of providing such insurance against climatic uncertainty could be calculated.

The supplementary feeding model could also be used to investigate the effect of taking out of grazing, specialist hay (or silage crop) areas, as opposed to the harvesting of surplus feed after a relatively short spell. This latter approach was the one used in the supplementary feeding model as defined in this study. Supplementary feed crop areas are closed from grazing for no longer than the maximum spell that is allowed between grazings; (see Table 5.10). As a result, the highest yield of supplementary feed harvested is 2450 Kg D.M./ha, (approximately equivalent to 120 bales of hay/hectare). From the pasture D.M. production data on which the model is based however, it would be possible to define supplementary feed making activities that allow pasture to be spelled for longer periods before harvesting.

Hence the supplementary feeding model could be used to conduct useful research; in particular on the "cost" (in physical or financial terms) of using supplementary feed for beef production. As discussed in Section 5.6, the methods of conducting such analyses are clear; the usefulness of the results depends on how well the model represents reality.

5.8 Summary

The beef production system studied has been outlined; (type of animal, length of production process, and carcass weight achieved). An iterative procedure by which stocking rate for four production processes may be maximised is discussed, and the conditions which prevent further increases in stocking rate are examined.

The total system feed requirements and the grazing management plans associated with the maximum stocking rates for each system are presented. The problem of relating these plans to on-farm practices is recognised; and the usefulness of this model for grazing management research is briefly discussed.

A method of considering supplementary feeding is outlined. Including supplementary feeding possibilities within the model allows the stocking rate for the shortest production process (BEEF 1) to increase. No consideration is taken of the financial aspects of hay or silage making, although they could readily be incorporated in the model. Some further possible uses of the supplementary feeding matrix are discussed.

CHAPTER SIX

EVALUATION OF THE STUDY

6.1 Introduction

While discussing verification and validation in relation to systems models, Wright (1971) noted that some confusion exists in the literature as to the definition of these terms. In order that the model presented may be examined in relation to the goals of the study, the terms verification and validation are used in the following contexts:

Verification - is concerned with assessing the descriptive nature of the model in relation to the real-life situation. Thus it may involve comparing components of the model, (component analysis)⁽¹⁾ and output from the model (output analysis)⁽¹⁾ with data available from real-life systems (experiments).

Validation - is concerned with assessing the capability of the model for analysing management problems. Validation, therefore, is particularly concerned with the matter of output analysis that embodies functions of control and design⁽²⁾ in the context of the particular model chosen to describe the system. The emphasis in validation is on model characteristics and the comparison of different types of models e.g. L.P. v's simulation for solving farm management problems.

Hence, a model may be considered verified when, in view of current knowledge, it appears to represent the real-life situation. A model may be considered valid in that it is capable of analysing management problems. Where a model is both verified and validated (in the contexts discussed above) it may be used for solving practical farm management problems. However, where lack of quantitative research data prevents verification of a model, further examination of the problem - solving

(1) Component analysis and output analysis are discussed as two aspects of Systems Analysis in Section 1.2.1.

(2) Control and design are the two aspects of Systems Synthesis discussed in Section 1.2.1.

capability of that model may be justifiable study for a farm management analyst.

This chapter discusses verification of the model presented in this study. The validity of the model for solving a particular farm management problem (the stocking-rate decision) is discussed, and the capability of the model for solving other farm management problems is assessed. Finally the study is evaluated in relation to the goals presented in Section 1.3.

6.2 Verification Of The Model

The model, as presented, may be considered as having three distinct sections: a description of pasture D.M. production (which is made available for feeding either in situ, or as supplementary D.M.); a description of the amount of animal production resulting from a given D.M. intake; and the interface between these two components where assumptions are made on the amount of D.M. animals will eat, given some level of feed availability. A shortage of data that may be used to verify each of these three sections separately, or output from the model as a whole, was recognised at an early stage in this study.

The pasture production and animal production relationships used, have been discussed in relation to the information available (Chapters 3 and 4 respectively). Given better information on these two sections, it could be included in the model. Structural changes that may be required are discussed below, in Sections 6.2.1. and 6.2.2.

Assumptions on the relationships that occur at the pasture-animal interface have been presented in Section 4.3. Given quantitative data on these relationships the degree of reality achieved by the model may be verified. This point is examined further in Section 6.2.3.

6.2.1 Pasture Production

Pasture regrowth over time has been defined for an average year in the Palmerston North region. Differences that are likely to occur

in regrowth due to the severity of grazing (2 levels) were defined using information from a simulation study (Wright 1973b). The severity of grazing has not been quantified in terms Kg D.M./ha that remain after grazing. If pasture production data for a range of spelling lengths and grazing severities were made available from a real-life experiment they could be included in an enlarged pasture production model.

6.2.2 Animal Production As A Function Of Intake

The feeding standards used in the model (Table 4.1) are considered to be a reasonable representation of the New Zealand situation.

Adjustments in feed requirement are made on the assumption that:

1. feed quality (M.E./Kg D.M.) in any one period is the same regardless of the length of spell between grazing, and the height to which pasture is grazed;

and

2. the utilisation of available energy (M.E.) by animals is the same regardless of pasture quality, (for the range of pasture qualities presented in Table 4.4).

Should the first assumption limit the model from representing reality, it would be necessary to express feed supply and hence animal requirements in terms of available energy (M.E.). In this way M.E. production from pasture would vary with length of spell and severity of grazing rather than directly with D.M. production.

Should the second assumption limit the model from representing reality, then both feed supply and animal requirements would need to be expressed in terms of productive energy (N.E.).

Since animal requirements in this study have been based on N.E. requirements for liveweight gain ($N.E._g$) and for maintenance ($N.E._m$), (NRC, 1970), use of productive energy units for animal requirements would not be difficult. Given that the second assumption is not

violated and that (Scott, 1973):

$$M.E. = \frac{N.E.}{0.37} + \frac{N.E.}{0.61}$$

animal requirements could be expressed in available energy units. However, the real problem in using either of the above approaches would be specification of feed supply in energy terms for the range of spelling dates and grazing heights required.

6.2.3 The Intake Of Grazing Animals

Two assumptions are made; one regarding the maximum intake that animals may achieve, and a second relating to the height to which animals can graze to meet daily requirements.

In this model maximum intake is constrained by animal age, (Table 4.5). If quantitative data were available on the relationship between L.W. pasture quality, and maximum intake/head/day, the animal requirements model could be restructured so that the relationship between these variables is included. The experimental procedure used to maximise stocking rate would then not be as simple as the one outlined in this study. The adjustments in intake, made after "tight" and "slack" feed periods are identified by an initial run of the model, would need to be considered with regard to the level of L.W.G. that had been achieved in previous periods, since now intake at any time would be related to L.W. and hence L.W.G. in previous periods.

As discussed in Section 4.3, animal requirements are specified on a per head basis for each period of the year so that a given pattern of liveweight gain will be achieved. The model then determines the area of pasture and height (severity) of grazing in each period so that stocking rate is maximised. Once the model has determined the number of animals to be run, feed requirements in any period are met by either grazing HIGH or LOW. The assumption has been made that D.M. requirement specified for period t , (y_t) , can be consumed under severe grazing. The level of pasture D.M. available per head under severe (LOW) grazing (x_t^S) is less than the level available under lax (HIGH)

grazing (x_t^L) for a given number of animals. Hence, as discussed in Section 4.3, whenever D.M. requirement is less than ad libitum we would expect intake under lax grazing (y_t^L) to exceed y_t . In order to overcome this problem the practice of on - off grazing is assumed. While farmers do not generally practise on - off grazing the approach is being used by Brougham on a beef production farmlet experiment at D.S.I.R. Grasslands Division, Aorangi Research Station in the Manawatu. (1)

More precise quantitative information about the relationship between available D.M./head and intake/head under rotational grazing is required before the assumptions used in the model can be verified. Similarly, lack of quantitative data on the intake of supplementary feed in relation to total intake prevented a realistic (verified) consideration of supplementary feeding from being included in the model.

6.3 Analysis Of Farm Management Problems Using L.P. Models

As stated previously, it was recognised at an early stage in this study that sufficient quantitative research data was not available to verify the descriptive function of the model. However, all information that was available was included in the model, and a study of the capability of the model for solving farm management problems was recognised as a justifiable research project.

In particular, the stocking-rate decision was investigated. An iterative procedure, already discussed, was used to maximise stocking-rate for four BEEF production processes. The grazing management plans from the model, that result in the achieved level of performance, defined by each process, cannot readily be interpreted as grazing plans for the practical farm situation (discussed in Section 5.5) This fact is not a serious limitation of the model for investigating the stocking-rate decision since:

1. a method for deriving practical plans has been devised, (see Section 5.5);

(1) This experiment which is still in progress, is examining controlled v's uncontrolled grazing of summer pasture.

and

2. the maximum stocking rate corresponding to simple grazing management plans, acceptable in the practical farm management situation, can be derived by the model. The "cost" of any simplification can then be calculated by comparison of stocking rates with the optimum but complex plan.

Furthermore, animals within each production process are assumed to grow at the same rate, and hence to achieve slaughter weight at the same time. In the practical farm situation, animals exhibit different rates of L.W.G. when grazed together and the production process will vary between animals. The approach used in the model represents an "average" situation. For example, in the process BEEF 2, 6.72 animals/ha are grazed on average for 36 periods. In the practical situation some of these animals will not reach slaughter weight until after period 36, and some will reach slaughter weight before period 36. An attempt to assess the change in maximum stocking-rate, that might occur where a proportion of the 6.72 animals/ha are sold before period 36 and a proportion after period 36, would require information on:

1. the reasons for differences in L.W.G. between animals (e.g. an intake effect, or a feed conversion effect)

and

2. the extent of differences in average L.W.G. that is likely to occur in any one herd of cattle grazed together.

However, it is not clear how this information could be incorporated into the L.P. model in order to perform the desired analysis. In this situation it would be possible to compare the results from simulation models, that can easily incorporate this information (Wright, 1975), with results from L.P. models that are based on information for the average situation.

The use of supplementary feed was also analysed using the L.P. model. The maximum stocking rates with and without supplementary feeds provided a measure of the opportunity cost of not making hay or silage

for any BEEF production process.

Other farm management problems that may have been analysed using the model have been discussed in Chapter 5. In all cases the optimising routine inherent in the L.P. model is seen as an advantage over modelling techniques (simulation) that do not include such a routine, although the inability of L.P. to handle stochastic variables is recognised as a limitation to the approach. The extent of this limitation is not clear since:

1. simulation studies rarely include stochastic variables;

and

2. the approach most commonly used in such studies involves running the model under given (historical) conditions, and a set of decision rules. Model output is then compared with that from a re-run of the model under changed conditions. Decision rules may be changed until a set that is thought to be near optimal is obtained. Such an approach can be carried out within a L.P. framework, but the optimising routine is an advantage since the decisions made by the model are optimal for the given conditions.

This discussion has attempted to highlight some of the difficulties associated with the use of L.P. models for solving grazing management problems. These difficulties fall into two categories:

1. those associated with model verification,

and

2. those associated with the use of L.P. as a tool for farm management analysis.

The magnitude of difficulties in the first category cannot be quantified until comparisons of model output are made with real-life management systems. The relative value of L.P. models for farm management analysis can only be made by comparisons with alternative analytical techniques. However, the use of L.P. would appear to have some potential advantage in that the optimising routine inherent in this technique provides an estimate of optimal system performance. As a consequence,

sub-optimal plans can be derived and the cost of sub-optimal decisions calculated.

6.4 Evaluation Of This Study

The prime objective of the study (Section 1.3) was to investigate the components of a beef production system. The decision to use a mathematical model to achieve this objective was based on the lack of quantitative data available from the practical farm situation. A secondary objective was to assess the suitability of L.P. as a technique for describing the system of interest, and for solving farm management problems associated with that system.

The L.P. framework has been shown to be suitable for use in a descriptive sense, at least for the information that is currently available on beef production. Future research results on pasture production and animal production requirements could be incorporated in the model. However, future research results relating to animal intake under grazing management conditions may prove difficult to incorporate in a L.P. framework.

The amount of problem analysis carried out with the model has been limited. As in the study of Pollard (1972), a considerable amount of the limited time available for this study has been spent on assembling available information and incorporating this in the model. ⁽¹⁾

While one can compare the characteristics of different models, an assessment of their comparative usefulness for solving farm management problems must depend on our ability to estimate the real cost of simplification of the real-world situation that is inherent in these models. For this reason, all available information possible should be included in the model constructed. Further development of problem-solving techniques that utilise the component analysis already carried

(1) Pollard (1972) also cites the limited computing facilities available as a constraint on the amount of problem analysis he could carry out. The availability of larger computers (e.g. the Massey University B6700 computer) and advanced computer software (e.g. the Mathematical Programming System, TEMPO) have led to large reductions in computing time. Each run of the model described in this study took from 3-7 minutes. Furthermore the size of models that can now be handled is virtually unlimited.

out for this and similar studies (e.g. Pollard 1972) would appear to be an efficient use of farm management research resources in the future.

The ultimate use of systems models must be in the solving of management problems at the practical farm level, and hence in the evolution of improved management systems. Hutton (1973b) has stated that faralet-type experimentation, in conjunction with component analysis (in the sense of physical experiments) may be a more satisfactory approach than modelling, to derive improved management systems. Before the solution to the original problems is obtained from the faralet experiment, information from the experiment may lead to a redefinition of the problem to be solved and a consequent redirection of research. This evolutionary process is only possible in the context of real-life production systems.

The complementary use of systems modelling and physical research (faralet-type and component analysis) appears to offer a compromise that may be more efficient in the use of research resources than either approach used in isolation. Wright (1975) is currently involved in such a study at Ruakura Agricultural Research Centre. Conceptually it is difficult to define a method by which the complementary involvement of model and physical research could be shown to be a more (or less) efficient use of research resources than either approach used in isolation. The nature of the research process and the scarcity of research resources would not allow more than one approach to be run in parallel.

Although L.P. models may not be entirely suitable for the purpose of providing practical solutions to grazing management problems, the optimising routine inherent in a L.P. model may provide useful benchmark plans. These plans could provide a useful reference point for more practical plans derived from simulation studies or small-farm experiments.

APPENDIX ONE

THE PASTURE PRODUCTION MODEL

The pasture production matrix is represented in Table A1.1. Activities (columns) represent pasture grazed at different times of the year (periods). Constraints (rows) ensure that all land in any period is either grazed or spelled (rows 1 to 60), account for total pasture production in each period (rows 61 to 90), limit the area of land (row 91) and record total annual pasture DM made available for grazing (row 92).

A1.1 Activities

Grazing activities were named so that the output from each run of the model could be easily analysed. The following format was used:

AA, bb, c (eg GH012)

AA: either GH, GL, HL, LH

GH refers to grazed HIGH after spelling from the HIGH level.

GL refers to grazed LOW after spelling from the LOW level.

HL refers to grazed LOW after spelling from the HIGH level.

LH refers to grazed HIGH after spelling from the LOW level.

bb: 01 to 30, refers to the grazing period from which the pasture was spelled.

c : 2 to 10, refers to length of spell (weeks) between grazings.

A total of 300 pasture grazing activities are included in the model, 75 for each of the GH, GL, HL and LH possibilities. Thus, for example, activity GH012 provides pasture for grazing at the HIGH level in period 3 (bb + c) after this same pasture has been grazed at the HIGH level in period 1 (bb). Similarly,

activity LH305 provides pasture for grazing at the HIGH level in period 5⁽¹⁾ after this same pasture has been grazed at the LOW level in period 30.

A1.2 Constraints

A1.2.1 Area Constraints (rows 1 - 60)

Rows 1 - 30 constrain the area spelled from the HIGH defoliation level in any period to equal the area grazed HIGH in that period. The type of constraint is an equality since all pasture grazed HIGH must be spelled from the HIGH defoliation level. By definition, GH and HL grazing activities require pasture to be grazed at the HIGH level in the period from which spelling is commenced. Since the unit of each grazing activity is one ha., these activities have a +1 coefficient in the row corresponding to the period from which pasture is spelled. The ACHbb row refers to the constraint for the area grazed HIGH, and hence spelled from the HIGH defoliation level, in period bb. By definition, GH and LH grazing activities defoliate pasture at the HIGH level, hence these activities enable pasture to be spelled from the HIGH level and have a -1 coefficient in the ACH(bb + c) row. For example, one unit of activity LH303 supplies one ha. (-1) of pasture in period 3 (30 + 3 = 03) that is then spelled from this period.

Rows 31 - 60, ACLbb, constrain the area spelled from the LOW defoliation level in period bb to equal the area grazed LOW in period bb. GLbbc and LHBbc grazing activities require pasture to be grazed at the LOW level in period bb, hence +1 in the ACLbb row. GLbbc and HLbbc grazing activities defoliate pasture at the LOW level in period (bb + c), hence -1 in the ACL(bb + c) row.

(1) In this example, $bb + c = 35$, but the year has been divided into 30 periods so that period 35, becomes period 5.

A1.2.2 Feed Reconciliation Rows

The FEED(bb + c) rows of Table A1.1 constrain feed supplied in period (bb + c) to be at least sufficient to meet feed demand for livestock production in that period.

Feed supply \geq Feed demand by livestock.

$0 \geq$ -Feed supply + Feed demand by livestock.

Pasture DM made available by one unit (ha.) of each grazing activity is therefore represented by a negative quantity in the appropriate FEED row. For example, from Table 3.2, pasture DM available from a HIGH grazing after two weeks spell from a previous HIGH grazing in period 1 (November), is 750 Kg./ha. Thus, one unit of grazing activity GH012 supplies (negative coefficient) 750 Kg. pasture DM to the FEED03 row. Since grazing LOW after a previous HIGH grazing supplies an additional 400 Kg. DM/ha., one unit of grazing activity HL012 supplies 1150 Kg. pasture DM to the FEED03 row.

A1.2.3 Total Area Constraints

Rows 1 - 30 and 31 - 60 ensure that the areas of pasture grazed HIGH and LOW respectively in each period of the year equal the areas of pasture spelled from the HIGH and LOW grazing heights in each period of the year.

To constrain the area of pasture under consideration and to ensure that all pasture is accounted for in each period of the year as being either grazed or spelled, 30 TOTAC (total area) constraints can be defined; one for each period. Since the area grazed in each period equals the area spelled from that period (rows 1 - 60) the TOTAC constraint for period 1 may take the form of either:

$$\text{TOTAL AREA (PERIOD 1)} = \text{AREA GRAZED (PERIOD 1)} + \text{AREA BEING SPELLED (PERIOD 1)}$$

or,

$$\text{TOTAL AREA} = \text{AREA SPELLED FROM PERIOD 1} + \text{AREA SPELLED IN PERIOD 1}$$

The TOTAC constraint (row 91 in Table A1.1) for period 1 takes the latter form. Hence, activity GH012 has a +1 coefficient in the TOTAC row, since that activity represents 1 hectare of pasture spelled from period 1. Similarly, activity GH013 has a +1 in the TOTAC row. Activity GH303 has a +1 coefficient in the TOTAC row because it represents 1 hectare of land being spelled from period 30, through period 1, until period 3; likewise activity GH305 has a +1 in the TOTAC row.

Pollard (1972) has demonstrated that where all the area constraints (rows 1 - 60) are present in such a model, only 1 TOTAC row need be included; the remainder (29 in this case) are inferred.

TABLE A1.1 THE PASTURE PRODUCTION MODEL

		P _j B	P1	P2	P4	P74	P75	P76	P77	P79	P149	P150	P151	P152	P154	P224	P225	P226	P227	P229	P299	P300
			GH012	GH013	GH023	GH303	GH305	GL012	GL013	GL023	GL303	GL305	HL012	HL013	HL023	HL303	HL305	LH012	LH013	LH023	LH303	LH305
1	ACH01	0 =	1	1									1	1								
2	ACH02	0 =			1										1							
3	ACH03	0 =	-1			-1												-1			-1	
4	ACH04	0 =		-1															-1			
5	ACH05	0 =			-1		-1													-1		-1
	⋮																					
30	ACH30	0 =				1	1									1	1					
31	ACLO1	0 =						1	1									1	1			
32	ACLO2	0 =								1										1		
33	ACLO3	0 =						-1			-1		-1			-1						
34	ACLO4	0 =							-1					-1								
35	ACLO5	0 =								-1		-1			-1			-1				
	⋮																					
60	ACL30	0 =									1	1									1	1
61	FEED01	0 ≥																				
62	FEED02	0 ≥																				
63	FEED03	0 ≥	-750			-1400		-520			-1015		-1150			-1800		-120			-615	
64	FEED04	0 ≥		-1400					-1000					-1800					-600			
65	FEED05	0 ≥			-1740		-2815			-1190		-2540			-2140		-3217			-790		-2140
	⋮																					
90	FEED30	0 ≥																				
91	TOTAC	1 =	1	1		1	1	1	1		1	1	1	1		1	1	1	1		1	1
92	DMPRO	free	750	1400	1740	1400	2815	520	1000	1190	1015	2540	1150	1800	2140	1800	3217	120	600	790	615	2140

APPENDIX TWO

BEEF ACTIVITIES

The j'th BEEF activity is included in the model as a vector of feed requirements, a_{ij} 's, where:

- a = DM requirement/head/period (Kg.);
- j : 1 - 4, and denotes the BEEF activity being studied;
- i : 1 - 30, and denotes the period of the year in which the requirement occurs.

Where supplementary feeding is considered by the model (see Appendix 4), the j'th BEEF vector contains another 30 coefficients, r_{ij} 's, that limit the amount of supplementary feed each animal may consume. That is:

- r = maximum supplementary DM intake/head/period and is calculated as maintenance requirement in terms of Kg. supplementary DM;
- j : 1 - 4, denotes the BEEF activity being studied;
- i : 1 - 30, denotes the supplementary restriction row to which the coefficient applies.

The j'th BEEF activity is represented in Table A2.1. Feed rows 1 - 30 (rows 61 - 90) are the feed reconciliation rows discussed in Appendix 1. Since:

$$\begin{aligned} \text{Feed supplied} &\geq \text{Feed eaten} \\ 0 &\geq \text{Feed eaten} - \text{Feed supplied} \end{aligned}$$

the a_{ij} 's are positive coefficients.

SUPRX rows 1 - 30 (rows 194 - 224) are the supplementary restriction rows discussed in Appendix 4. Since:

$$\begin{aligned} \text{Supplementary Feed Eaten} &\leq \text{Supplementary Feed} \\ &\quad \text{Restriction} \\ 0 &\leq \text{Supplementary Feed Restriction} - \text{Supplementary} \\ &\quad \text{Feed Eaten} \end{aligned}$$

the r_{ij} 's are positive coefficients.

The SRATE row (row 126) is the objective function where stocking rate is maximized. Since each unit of BEEF_j represents one animal, the j'th BEEF activity has a (+1) coefficient in the SRATE row.

TABLE A2.1

The j'th BEEF Activity

<u>ROW</u>			<u>BEEF_j</u>
61	FEED01	$0 \geq$	a_{1j}
62	FEED02	$0 \geq$	a_{2j}
90	FEED30	$0 \geq$	a_{30j}
94	SUPRX01	$0 \leq$	r_{1j}
95	SUPRX02	$0 \leq$	r_{2j}
124	SUPRX30	$0 \leq$	r_{30j}
126	SRATE	obj.	1

APPENDIX THREE

SHADOW PRICES ASSOCIATED WITH THE MAXIMUM
STOCKING RATE FOR BEEF 2

A3.1 Shadow Prices

Shadow prices are usually discussed as the marginal value product (M.V.P.) of an increase in supply of a resource. The $(z_j - c_j)$ value associated with the slack variable for some row (resource) in a maximization problem will be ≤ 0 in an optimal solution. This value shows the decrease in the value of the objective function for a marginal decrease in resource supply. So, the negative of the $(z_j - c_j)$ gives the M.V.P. of the resource.

A3.2 Shadow Prices on Feed Rows in BEEF 2

The shadow prices associated with the feed rows where 6.72 animals/ha. are grazed (see Section 5.3.3.2) are presented in Table A3.1. The shadow prices associated with the feed rows after the pattern of L.W.G. is changed in an attempt to increase stocking are also presented. The attempt to increase stocking rate is discussed below.

When 6.72 animals are grazed to meet the pattern of L.W.G. defined by BEEF 2, feed is tight in all periods of the year, i.e. $M.V.P. > 0$ for all feed rows (Table A3.1). The highest shadow prices are associated with feed periods (rows) 14 - 16. The lowest shadow prices are associated with rows 1 - 10. In an attempt to increase stocking rate, the rate of L.W.G. was reduced in periods 14 and 15 by 0.43 Kg./head/day and increased by 0.14 Kg./head/day for the weaner cattle in periods 1 - 8. (In Table A3.1 the L.W.G. for yearling cattle are in brackets).

The new BEEF activity was designated BEEF 2X and the model was used to maximize stocking rate. The maximum achieved for BEEF 2X was 6.70 animals/ha. (0.02 animals/ha. less than for BEEF 2). The M.V.P.'s associated with the feed rows when

BEEF 2X was maximized are shown in Table A3.1. M.V.P.'s on feed periods 14, 15 are now higher than those associated with rows 1 - 8. While a smaller change in the pattern of L.W.G. than that used in this example may have resulted in an increase in stocking rate, such a course of action was not pursued. The maximum stocking rate for BEEF 2 (6.72 animals/ha.) is considered on the maximum for the length of production process specified in BEEF 2.

Table A3.1

SHADOW PRICES FOR BEEF 2 AT MAXIMUM STOCKING RATE,
AND AFTER A CHANGE IN THE PATTERN OF L.W.G.

PERIODS	SHADOW PRICES	DAILY L.W.G.	SHADOW PRICES	DAILY L.W.G.
	(x 1000) BEEF 2	(Kg.) BEEF 2	(x 1000) BEEF 2X	(Kg.) BEEF 2X
1	.30	.71 (.71)	.69	.85 (.71)
2	.25	.71 (.71)	.46	.85 (.71)
3	.25	.71 (.71)	.58	.85 (.71)
4	.25	.71 (.71)	.57	.85 (.71)
5	.23	.71 (.71)	.54	.85 (.71)
6	.18	.71 (.50)	.44	.85 (.50)
7	.13	.71	.34	.85
8	.10	.71	.28	.85
9	.08	.85	.24	.85
10	.09	.85	.23	.85
11	.08	.85	.24	.85
12	.19	.85	.23	.85
13	.50	.85	.22	.85
14	.79	.85	.19	.42
15	.96	.85	.16	.42
16	.86	.21	.18	.21
17	.72	.21	.17	.21
18	.57	.21	.25	.21
19	.76	.21	.44	.21
20	.86	.21	.69	.21
21	.80	.21	.73	.21
22	.83	.21	.77	.21
23	.76	.21	.69	.21
24	.80	.92	.72	.92
25	.70	1.00	.64	1.00
26	.60	1.14	.50	1.14
27	.45	1.14	.49	1.14
28	.46	1.14	.37	1.14
29	.40	1.14	.53	1.14
30	.35	1.14	.51	1.14

A4.2.2 Supplementary Feed Reconciliation Row (row 93)

Each unit (hectare) of SUPdd activity supplies (negative coefficient) supplementary feed. DM losses associated with making and feeding out supplementary feed DM are deducted from the DM present/ha. before harvesting. (See Sect. 5.7.1). Hence, each unit (hectare) of SUP25 makes 1858 Kg. of supplementary feed DM available for feeding. Since:

$$\begin{array}{l} \text{Supplementary DM} \\ \text{made (less losses)} \end{array} \geq \begin{array}{l} \text{Supplementary DM} \\ \text{eaten.} \end{array}$$

$$0 \geq - \begin{array}{l} \text{Supplementary DM} \\ \text{made (less losses)} \end{array} + \begin{array}{l} \text{Supplementary DM} \\ \text{eaten} \end{array}$$

SUPdd activity has a (-ve) coefficient in the SUPDM row, (row 93); and SUPFee activity, which represents 1 Kg. of supplementary DM eaten has a (+1) coefficient in the SUPDM row.

A4.2.3 Supplementary Feeding Restrictions (rows 96 - 126)

Where supplementary feed is considered BEEF activities define the amount of supplementary feed that may be fed/animal/period (see Appendix 2).

Since 1 unit of SUPFee represent 1 Kg. of supplementary feed DM eaten, and because:

$$\begin{array}{l} \text{Supplementary} \\ \text{DM eaten} \end{array} \leq \begin{array}{l} \text{Supplementary} \\ \text{DM restriction} \end{array}$$

$$0 \leq \begin{array}{l} \text{Supplementary} \\ \text{DM restriction} \end{array} - \begin{array}{l} \text{Supplementary} \\ \text{DM eaten} \end{array}$$

SUPFee activity has a (-1) coefficient in SUPRX row (ee).

TABLE A4.1 SUPPLEMENTARY FEED MODEL

		P _j	1-75	76-150	150-225	226-300	301	306	309	317	318	328	332	336	348		
		B	GH	GL	HL	LH	SUP25	SUP30	SUP03	SUP11	SUPFC1	SUPF10	SUPF14	SUPF18	SUPF30		
1	ACH01	0 =	1		1												
			-1			-1	1	1	1	1							
30	ACH30	0 =															
31	ACL01	0 =		1		1											
				-1	-1		-1		-1	-1							
50	ACL30	0 =						-1									
61	FEED01	0 ≥	-DM _{GH}													-.717	
70	FEED10	0 ≥		-DM _{GL}													-.792
74	FEED14	0 ≥															-.745
78	FEED18	0 ≥			-DM _{HL}												-.717
90	FEED30	0 ≥				-DM _{LH}											-.679
91	TOTAC	1 =	1	1	1	1			1								
92	DMPRO	free	DM _{GH}	DM _{GL}	DM _{HL}	DM _{LH}											
93	SUPDM	0 ≥					-1858	-1925	-2355	-1605	1	1	1	1	1		
94	SUPRX01	0 ≤									-1						
												-1					
													-1				
124	SUPRX30	0 ≤												-1			
125	SUPRO	free					1858	1925	2355	1605							

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