SIMULATION OF COW-CALF SYSTEMS IN THE SALADO REGION OF ARGENTINA

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To Cecilia and Joaquina

ABSTRACT

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The Salado region of Argentina covers 9.5 million ha, is located in the centre-East of the Buenos Aires Province, and concentrates about 6.9 million cattle. Cow-calf systems are predominant in the area. A simulation model was developed with the purpose of assisting in the design and evaluation of cow-calf systems in the Salado Region. The model was designed to produce long term simulations of the dynamic interactions between herd structure, climatic variation and farm management over periods of several decades using daily weather data, real or simulated. Existing models were used to describe soil, pasture and animal components of the farm, linked with management actions in a dynamic framework. The model was driven by decision rules entered by the user, which allowed the representation of management options that respond to changing farm conditions according to a predetermined policy. An object-oriented approach (OOA) was used in the design and implementation of the model. In the OOA, objects in the real world (e.g. cows, paddocks) are represented as objects in the computer program. The simulation of individual cows and individual paddocks made it possible to distribute feed resources flexibly among animals and provided many other points of flexibility in management strategies.

The management strategies simulated in trying to improve cow-calf systems in the Salado region were based on Reserva 6, an experimental cow-calf farm located at the INTA-Balcarce Experimental Station. Every spring-summer, 30% of the area is devoted to make low quality hay (by cutting at high herbage mass), most of which is destined to provide maintenance feed for pregnant adult cows in winter. Cows are kept on a small paddock from weaning (March) to calving (August-September), during which time they receive 6-9kg DM of hay per day. A set of decision rules was developed to represent (on a 100ha farm) the management applied in Reserva 6 and, using this as a base system, a series of simulation experiments was conducted.

Firstly, three preliminary experiments, aimed at gaining insight into the system and testing the model, were carried out. In the first of these, the effect of delaying the breeding season 15 and 30 days was analysed. The model was run over 30 consecutive years using a real weather sequence, 1970-2000, from INTA-Balcarce, for each scenario. It was found that, when the appropriate management variables (i.e. weaning and sale dates) were adjusted accordingly, changing the calving period had little effect on the productivity of a cow-calf system. In the second experiment, the dynamic consequences of three different heifer replacement policies on the production outcomes of the system were explored. The policies produced different patterns of oscillations in key farm outputs as a result of periodic behaviour in the age structure of the herd, and the differences between strategies were shown to be dependent on the environmental variability being simulated. The third experiment analysed different policies for hay use during the autumn-winter period, including a control strategy in which no hay was harvested or used. The results suggested that, provided hay was utilized on the farm, the pattern of use did not make much difference to liveweight production.

Secondly, the long term performance, in terms of annual liveweight sold, of a range of hay quantity-quality combinations was compared. Each policy was simulated across a range of cow numbers (170 to 350, cows plus heifers in a 100ha farm) and was replicated 20 times. Each replication consisted of 50 years of random weather sampled from the real sequence (1970-2000). The benefit of using hay and the contrasts between the effects of different haymaking strategies on animal outputs increased as the cow numbers increased. The long term analysis suggested that the liveweight production of cow-calf farms, under a calendar-based haymaking policy like that followed in Reserva 6, would be maximized by harvesting 40-50% (but not more) of the total farm area and aiming to harvest hay at medium herbage mass (therefore medium quality). Therefore, the policy currently followed in Reserva 6 of allocating 30% of the farm to haymaking could be considered as conservative, and its productivity might be increased by making hay at lower herbage mass.

Thirdly, the possible advantages of incorporating flexibility into the haymaking policy used in Reserva 6 were evaluated using the same experimental design. The results indicated that controlling haymaking in a flexible fashion, basing the decisions of closing, releasing and cutting paddocks on a simple pasture budget, would give the system productive advantages (i.e. increases in productivity and reductions in variability) in relation to a calendar-based approach. Using a flexible haymaking policy allows the manager to make more hay than required for the next winter, providing a buffer for the system. A flexible haymaking policy permitted significantly greater levels of herbage utilization by making large amounts of hay without negative effects on the carrying capacity of the system. A preliminary analysis of risk and costs highlighted major advantages in using hay in cow-calf systems, especially when a flexible approach to haymaking is implemented.

Keywords: cow-calf systems, computer model, long term simulation, haymaking policy.

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CHAPTER 1

INTRODUCTION

This thesis is about the use of a simulation model to study the management of cow-calf systems in the Salado Region of Argentina. The model, that was developed during the course of this project, is described in detail and is used to study different haymaking strategies. This document begins by briefly exploring the industry context, followed by a discussion of the problems to be analysed and of the expectations of the project.

1.1. THE SALADO REGION OF ARGENTINA

Beef production is an important economic activity in Argentina. As depicted in Figure 1.1, the country can be subdivided into five macro-regions with clear differences in terms of cattle stock density and agro-ecological characteristics. The Pampeana region is the most productive, and supports more that 60% of a total of about 55 million cattle.

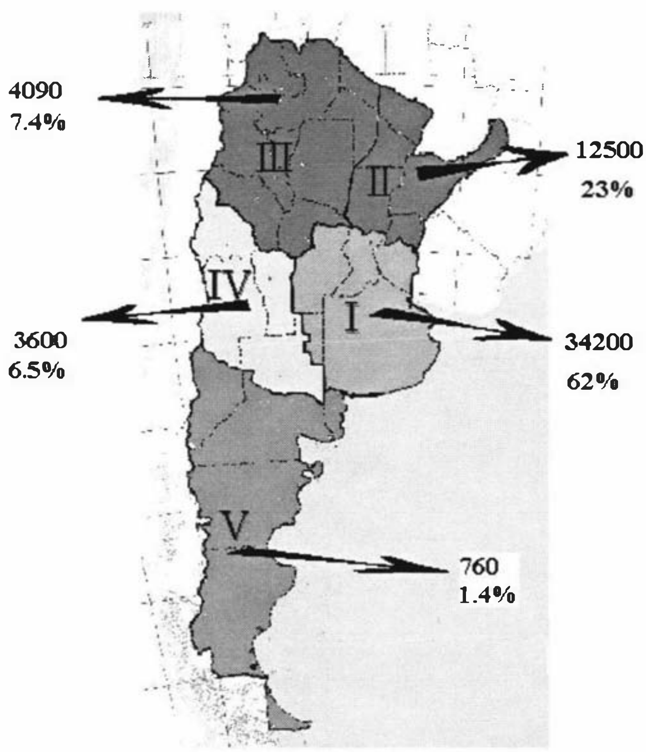

Figure 1.1: Regions of Argentina and number of cattle (in thousands and percentage of the total). Pampeana (I), Northeast (II), Northwest (III), Semiarid (IV) and Patagonia (V) (Source: Secretary of Agriculture, Livestock, Fisheries and Food of Argentina, http://www.sagpya.mecon.gov.ar).

Within the Pampeana region three sub-regions can be identified according to the predominant farming activities (Figure 1.2). One is mainly dedicated to crops (I in the figure), the second is a mixture of cropping and cattle production (II) and the third is the Salado region (III), where cow-calf operations are predominant (Soriano, 1992).

The Salado Region, located in the centre-East of the Buenos Aires Province, and its cow-calf systems are the centre of interest of this study. According to official estimations (Secretary of Agriculture, Livestock, Fisheries and Food of Argentina), there are 3.1 million cows and a total of 6.9 million cattle in the area. Approximately 2.4 million calves are produced annually, most of which are finished in other regions (Rearte, 1998). According to Rearte (1998), no more than 20% of the calves born in the region are finished on the same farm.

Area: 55 186 thousands of ha
Cattle: 34 258 thousands of head
Cows: 12 150 thousands of cow

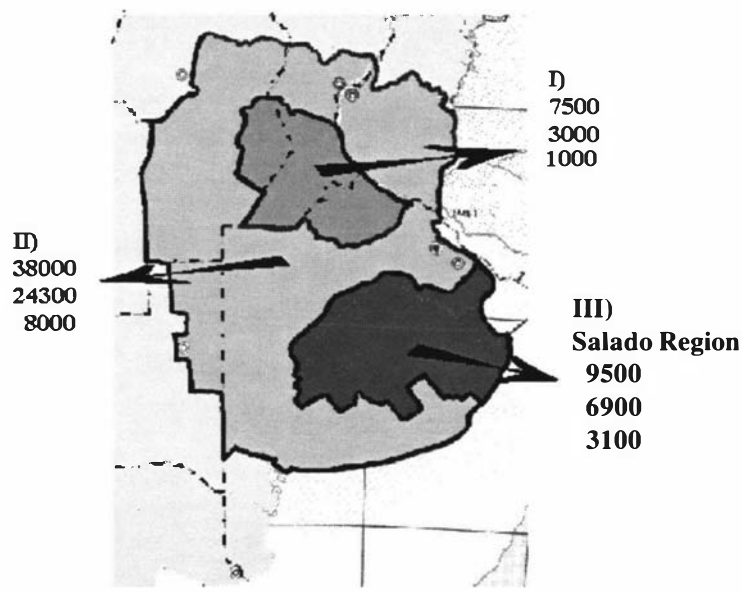

Figure 1.2: Area and cattle numbers in the Pampeana region, total and for its three sub-region (Source: Secretary of Agriculture, Livestock, Fisheries and Food of Argentina, http://www.sagpya.mecon.gov.ar).

The Salado region constitutes an extremely flat plain, with slopes of about 1-2% (Taboada and Lavado, 1988). Most of the soils are halo-hydromorfic associations and the principal groups are Natraquolls and Natraqualfs (Paruelo and Sala, 1990). The main soil limitations are deficient drainage; alkalinity (excess of exchangeable sodium); presence of a procalictic horizon in parts, and increased salinity of soils near the coast (Soriano, 1992). Only 10-15% of the land is arable and can be sown with cereal crops or pasture species like *Lolium*, *Dactylis* and *Trifolium*. The most common pasture species cultivated in the lower soils belong to the genera *Festuca* and *Thynopyrum* (locally known as agropiro), associated with *Trifolium*, *Lotus* and *Melilotus* (Rearte, 1998). More that 90% of the area, however, is covered with natural grasslands.

The Salado Region has a temperate climate, humid towards the Atlantic and sub-humid in the West. For illustrative purposes, the monthly averages for air temperature and rainfall from the weather station at INTA[1] Balcarce (in the south of the Salado Region) are presented in Figure 1.3 in comparison with the same variables for Palmerston North in New Zealand. Note that the weather in Balcarce is hotter in spring and summer, but cooler in winter. The rainfall distribution is markedly different, although the annual rainfall is very similar between the two places (915 and 960mm/year, for Balcarce and Palmerston North, respectively for the period 1971-2000).

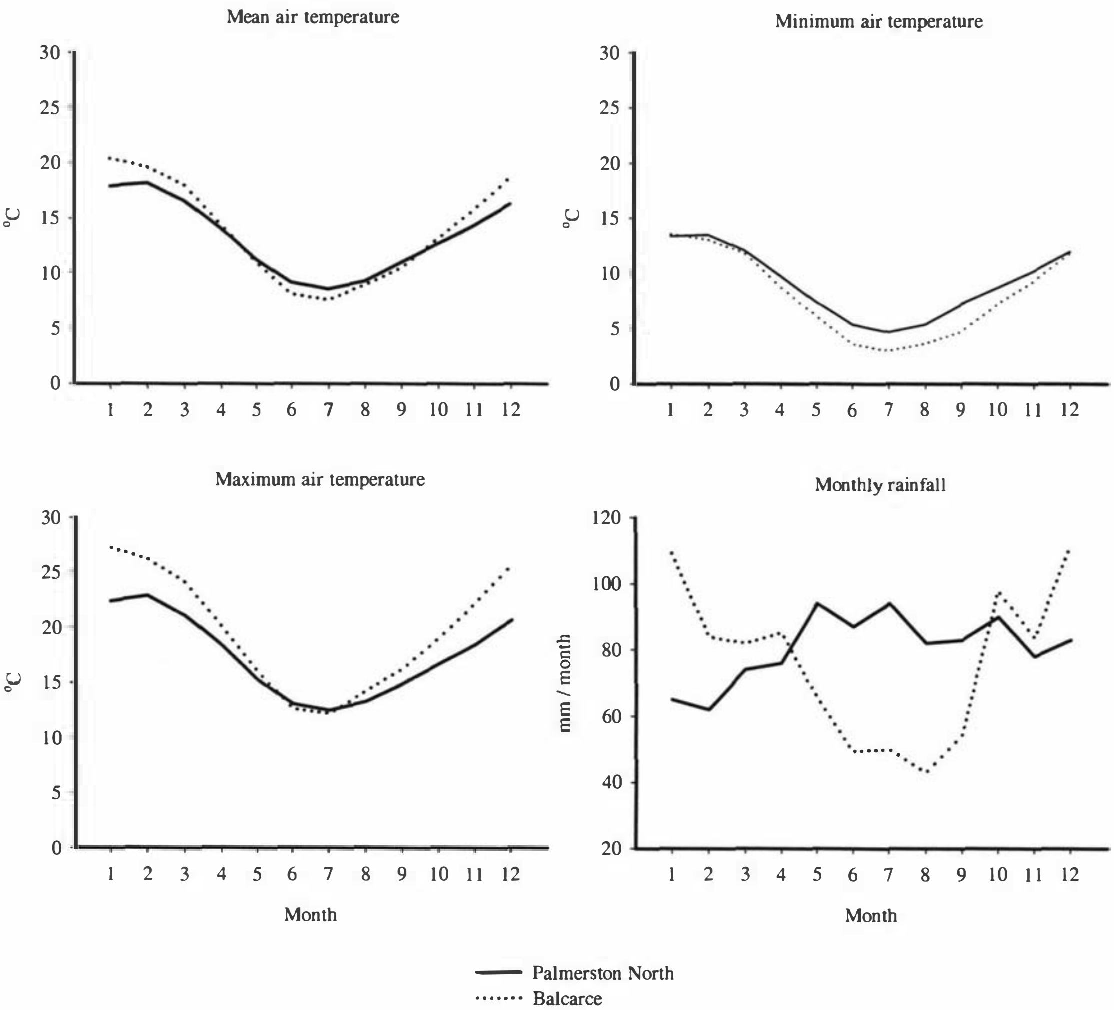

Figure 1.3: Average daily temperature (mean, minimum and maximum) and rainfall for Palmerston North (New Zealand, source: NIWA) and Balcarce (Argentina, source: EEEA INTA-Balcarce), from 1971 to 2000.

Most of the farms in the Salado region have historically been dedicated to producing weaner cattle of 6 to 10 months of age to be sold for finishing in other regions with better soils. Weaning normally occurs in autumn (from April to June) with live weights of 150 to 200kg, but in some cases weaners are retained on the farm to be sold in the following spring (a system known as "recría"), when the demand for them tends to increase. There are no systematic statistics available, but several authors (Carrillo, 1975; Carrillo and Shiersmann, 1992; Carrillo et al., 1998; Rearte, 1998) have described the

[1] INTA: Instituto Nacional de Tecnología Agropecuaria (National Institute of Agricultural Technology)

typical operations as highly extensive, characterized by low stocking rates (0.5 – 1 cow-equivalents/ha), long mating periods (usually 6 months during spring-summer), low weaning rates (60-70%), and low productivities (60-80 kg live weight/ha/year). The use of cultivated pastures, fertilizers and forage conservation is minimal, and natural pastures, grazed continuously or semi-continuously, are the main nutritional source for the cattle.

However, some top farmers run much more intensive production systems, reaching production levels in the order of 150 to 200 kg live weight/ha/year, indicating that major improvements are biologically and economically feasible. An experimental unit, identified as "Reserva 6", has demonstrated that it is possible to achieve consistent production of more than 270 kg live weight/ha/year (Carrillo, 1975; Carrillo et al., 1998).

Reserva 6 was established in 1966 and is located at the Experimental Station of INTA-Balcarce, in the south of the Salado Region. In terms of climate and soil characteristics, the unit can be considered as representative of a large part of the Salado Region. Alkaline soils are predominant, with pH values at the surface of 8 on average (ranging from 7 to 10) and high exchangeable sodium content (up to 35% or more) (Carrillo, 1975). Management of the system is based on a technological package that has long been available to farmers, and will be described in the thesis.

1.2. PROBLEM DEFINITION

Reserva 6 has served as a prototype system and became the official technical package proposed by INTA to increase productivity of cow-calf systems of the Salado Region. The unit is regularly visited by farmers, students and professional consultants and is well known today. Nevertheless, despite all these years of promotion, exposure and demonstration of the merits of the Reserva 6 concept, its adoption has been restricted to a limited group of more progressive farmers.

The problem of technological adoption is complex, has been discussed by many authors before, and is not within the scope of this study, but it is reasonable to suppose that the Reserva 6 system does not suit every cow-calf farmer in the region. Different types of farmer may have different requirements, and Reserva 6 is only one alternative in a broad spectrum of possibilities. To adopt the Reserva 6 system, some farms may require minor modifications, while others would need major changes to the existing system. The costs, time and space required to operate experimental farms like Reserva 6 would make it unfeasible to investigate many alternatives to Reserva 6.

Apart from demonstration, Reserva 6 has had research uses, in that a particular technological package has been implemented and monitored for more that 30 years. During this time, the researchers involved in the project have felt the necessity of evaluating the effect that certain modifications would have on the system, for example cross-breeding, early mating, early weaning, use of supplements and use of nitrogen fertilizers. More radical explorations has involved changing the mating season from spring to autumn (Burges and Romera, 2000a; Burges and Romera, 2000b). Even though studies have been done in each of these areas, it has not been possible to integrate the results or to evaluate the impacts at a system level. Clearly, the pilot farm (or farmlet) approach was not suitable for this kind of evaluation given the multiplicity of factors and the multiple interactions involved.

The behaviour of a system is driven by influences from the environment in interaction with its internal structure. According to Bossel (1994) an environment can be characterized by a normal state (e.g. mean annual temperature), scarce resources (e.g. water); variety (e.g. seasons); variability (e.g. a long drought); change (e.g. climate change) and other systems (e.g. neighbouring farms). The same author explains that those fundamental properties of the environment force certain "design" criteria upon the system (termed "basic orientors") that must be fulfilled if the system is to survive and develop in its environment in the long term. Weather, and particularly rainfall, is the most important source of environmental influence and uncertainty in the Salado region. Errors in forecasting the environment are inevitable; therefore, when designing systems the focus should be on the development of decision rules and strategies that are robust to those errors (Sterman, 2000).

There are different levers that a cow-calf farmer can use to make his system more robust and adaptable. The use of low stocking rates is the most obvious strategy. Another is keeping stock classes in the herd that could be sold at any time and/or whose performance could be reduced without major future consequences; for example culled cows could be retained and fattened on the farm. This study in particular evaluated the role of forage conservation on the productivity and stability of cow-calf systems. By conserving herbage in times of surplus to be used in times of deficit, haymaking gives the system the capacity to cope with certain aspects of environmental variety like the seasonal growth of pastures. Haymaking can also reduce risks and manage weather variability by conferring a certain degree of independence from current herbage growth. Making hay contributes to the effectiveness of the system to capture a scarce resource, since part of the herbage conserved would have been otherwise lost to senescence. Questions of central interest in this study are how much hay should be made and what policy should be followed to control the process. It is worth noting here that Reserva 6 uses significant quantities of hay, and that haymaking represents approximately one third of its direct production costs of production (unpublished data).

1.3. THE METHODOLOGY

Considering the need to evaluate the responses to management actions at a farm level, and the limitations of using real models like farmlets, one sensible way in which farm systems can be studied is through the use of computer simulation models. This was the approach taken in this study. Simulation increases the possibility of estimating the effects of different alternatives of action, and new alternatives can be tested which would be normally not possible to execute in reality due to the risk or costs involved (Skittner, 2001). As pointed out by Rykiel (1996), one of the primary reasons for building a simulation model is that it is impossible to deduce the behaviour of a complex set of interacting components on purely logical grounds. In this sense, simulation models can help to show consequences that humans cannot compute in their heads, and have been aptly described as "assumption analysers" (Rykiel, 1996). Furthermore, according to Richmond (1997), there is considerable evidence which shows that humans are not very good at intuiting the dynamic behaviour that will be produced by the interaction of even a few simple structural relationships.

A model was required that represented the views of the cow-calf system research team at INTA-Balcarce. Such a model also had to be able to provide insight into the research questions of interest to the team and relevant for the cow-calf farmers of the Salado region. A computer model is a representation of a system in the real world, and since every person holds a different vision of the real world (Mingers, 2000), a computer model is to a large extent a representation of the modeller's mental models. It is therefore generally difficult to find an existing model that is totally appropriate for a new situation.

The main benefit of modelling comes from learning about the system under study (Checkland, 1985), more than from direct "black box" solutions provided by a model (Andrews, 2000). In practice, learning from models occurs best, and perhaps only, when a person participates actively in the development of the models (Vennix et al., 1997; Sterman, 2000). The use of a model, after it has been finished, is only part of the modelling process. Building local system analysis and modelling capabilities in Balcarce was another important objective of this project, and this could only be accomplished by direct involvement in designing and building the required computer model.

In view of these considerations, the decision was made to build a model of a cow-calf system, but using existing bio-physical models instead of starting from scratch. This was also the approach followed by Sherlock et al. (1997) for simulating pastoral dairy systems. Using modern Object Oriented programming techniques (Rumbaugh et al., 1991), a dynamic framework was built linking the third party models for bio-physical sub-systems with real and simulated weather databases and with system management rules. An expert system approach (Gonzalez and Dankel, 1993), using flexible decision rules, provided a powerful means for representing a broad variety of management strategies. The intention was to benefit from existing knowledge (in the form of models for sub-systems) while developing new elements according to the specific needs of the project.

1.4. OBJECTIVES

Given the problems and requirements identified in the previous sections, the general objective of this research was therefore to build a simulation model of a cow-calf farm and use it to gain better understanding of the system dynamics. Specifically, the model was used to explore the effect of different haymaking strategies on a well known cow-calf system like Reserva 6 in the face of the characteristic weather conditions of the Salado region of Argentina.

The particular objectives for this study were:

- To build a dynamic computer model to simulate cow-calf grazing systems over long periods of time, capable of responding to weather conditions. The model should have enough flexibility to implement the major management options available for the farmer.

- To evaluate the potential of forage conservation to increase and stabilise animal production in cow-calf farms of the Salado Region.

- To study the interaction between forage conservation strategies and decisions related to the stocking rate of the farm.

1.5. EXPECTED RESULTS

The first expectation of the project was to produce a model to be used as an analytical tool for the study of pastoral beef cattle systems of the Buenos Aires Province. The focus of the model, and the project, would be on management problems at strategic level, instead of day to day decision making. The resulting model would be able to be expanded in future research activities in the region and to be adapted for use in a range of situations.

The model should be reasonably flexible in terms of the variations in the management strategies that it is able to simulate and in terms of the outputs it can produce. It is primarily a research model as opposed to an applied model (Campbell, 1999), and its main purpose is learning and understanding, hopefully leading to a better conceptualisation of the system to be managed. The model is not intended for distribution.

The words of John Sterman may serve to present the philosophy that guided the design of the model and the type of product that was expected:

> *"The usefulness of models lies in the fact that they simplify reality, creating a representation of it we can comprehend. A truly comprehensive model would be just as complex as the system itself and just as inscrutable. Von Clausewitz famously cautioned that the map is not the territory. It's a good thing it isn't : A map as detailed as the territory would be of no use (as well as being hard to fold)."* (Sterman, 2000, pg 89)

Therefore, it was known from the beginning that the model was not going to be perfect (as no model is) and that many aspects of real systems were not going to be considered.

In using this model to analyse the Reserva 6 system, the study was expected to provide understanding to answer questions such as:

1. What is the impact of forage conservation on production?

2. How much forage should be conserved each year? Of what quality?
3. When should pastures be mown for conservation?
4. Is it beneficial to store hay for more than one year?
5. Which paddocks should be closed for conservation purposes?

It was not expected to obtain absolute answers to these questions. The interest of the study was rather to identify some factors (characteristics of the system and its management) on which the answers depend.

The study was expected to make a contribution to the knowledge and experience in the Salado region related to the management of pastoral cow-calf systems. At the same time, it was also expected to identify gaps in information and provide a framework for future research in the region.

1.6. THESIS OUTLINE

This thesis is organized into five parts, covering different aspects of the study and following a logical sequence:

PART I:

- **Chapter 1**: Introduction

PART II: Description of the methodology used in the study

- **Chapter 2**: Description of the structure and design principles in the model [2]
- **Chapter 3**: Detailed description of the third party models used to simulate the biological components of the system. Some difficulties were experienced when trying to incorporate those models and these are discussed.

PART III: Pilot studies with the model

- **Chapter 4**: Presents three preliminary experiments carried out with the model with the aim of building confidence in its performance and exploring particular issues before the final studies. *Experiment 1*[3] evaluated the effects of changing

[2] Published in its entirety as: Romera, A. J., Morris, S. T., Hodgson, J., Stirling, W. D., and Woodward, S. J. R., 2004. A model for simulating rule-based management of cow-calf systems. Computers and Electronics in Agriculture 42: 67-86.

[3] Published in its entirety as Romera, A. J., Hodgson, J., Morris, S. T., Stirling, W. D., and Woodward, S. J. R., 2002. Simulation of the effect of changing calving date in cow-calf systems of the Salado region (Buenos Aires Province). Revista Argentina de Producción Animal 22:341-342.

the mating dates in cow-calf systems. *Experiment* [4]2 studied the long-term consequences of using different replacement policies. *Experiment 3*[5] evaluated the effect of using hay in a cow-calf systems at a stocking rate similar to Reserva 6. Lessons learned while using the model and justification of the experimental approach followed in the subsequent parts of the study are also discussed.

PART IV: Simulation experiments to study the effect of using different haymaking strategies in cow-calf systems of the Salado Region. The Reserva 6 system is used as a baseline.

- **Chapter 5**: Factorial experiments to study the combined effect of two management parameters of the "calendar-based" haymaking policy used in Reserva 6, the area allocated for haymaking and the point at which mowing is decided. A large set of different combinations is tested across a range of stocking rates.

- **Chapter 6**: A more flexible haymaking policy than the "calendar-based" approach used in Reserva 6 was developed and tested following the same scheme as in chapter 5.

- **Chapter 7**: In this chapter the implication of the different haymaking policies in terms of pasture utilization efficiency and risk were considered in outline. The aim of the chapter is to only present some ideas on these two topics as they were too important to be left aside, but too extensive to be tackled in more depth here.

PART V:

- **Chapter 8**: Conclusions are given, including a summary of the previous chapters and a retrospective evaluation of the usefulness of the approach used. Future possibilities to use and expand the model are also discussed.

The thesis includes both published papers, submitted and unpublished material, as is indicated by footnotes in the corresponding sections. Apart from minimal adaptation, the published papers have been maintained in their entirety, which resulted in some duplications and overlapping. Chapters 5 to 7 have been written in journal format for subsequent publication.

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[4] Submitted in its entirety as a paper to Agricultural Systems.

[5] Included as an example in Romera, A. J., Morris, S. T., Hodgson, J., Stirling, W. D., and Woodward, S. J. R., 2004. A model for simulating rule-based management of cow-calf systems. Computers and Electronics in Agriculture 42: 67-86.

CHAPTER 2

MODEL STRUCTURE AND DESIGN PRINCIPLES [6]

Abstract

A research simulation model was developed to study the long term dynamics of cow-calf production systems for the Salado Region of Argentina. The purpose of the model is to assist in the design and evaluation of pastoral beef breeding systems. An Object Oriented approach was applied in the design and implementation of the model, and decision rules were used to represent the management of the farm. Real or simulated weather databases are used as inputs to the model. This chapter describes the model architecture in detail and discusses the advantages of the design principles used.

2.1. INTRODUCTION

Pastoral livestock systems are complex open systems. Farm production in a given year depends not only on the environmental conditions and decisions in that year but also on the carryover effects of climatic conditions and management decisions in previous years. The consequences of management actions frequently extend far beyond their immediate impacts, and management systems should therefore be evaluated by their long term performance.

Nevertheless, even in such a difficult context it should be possible in theory to devise management strategies which have good chance of controlling the system to achieve specific goals while coping with environmental and system-generated variation (Sørensen and Kristensen, 1992; Bossel, 1994). Since it is not possible to make accurate predictions about the future, a good management strategies must be robust to these variations on the environment (Coyle, 1978; van Keulen and Penning de Vries, 1993). This implies farming in such a way as to minimize or keep system fluctuations under control. In pastoral livestock systems then, this will typically be achieved by conservative stocking policies and tactical use of conserved forages.

Dynamic and climatically driven models have been useful tools to evaluate and compare different production strategies in terms of expected results, robustness against external influences, and dynamic behaviour. If well implemented, they can contribute to the

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[6] This Chapter has been published as: Romera, A. J., Morris, S. T., Hodgson, J., Stirling, W. D., and Woodward, S. J. R., 2004. A model for simulating rule-based management of cow-calf systems. Computers and Electronics in Agriculture 42: 67-86. The original paper included a series of simulation experiments, which for organization purposes are now presented in Chapter 4 (see section 4.4).

understanding of complex systems and consequently could improve decision making. The usefulness of these models resides in their efficacy for studying patterns of dynamic behaviour and in assessing the relative long term merit of different management alternatives more than in their ability to predict the exact outcomes of a system.

The objective of this study was the analysis of different management problems in cow-calf systems of the Salado Region, or Flooding Pampa, in Argentina (Soriano, 1992). A simulation model was developed for this purpose, and this chapter presents details of the model.

2.2. MATERIALS AND METHODS

2.2.1. Model overview

The model developed is a dynamic, whole farm model aimed at assisting in the design and evaluation of pastoral beef breeding systems. It is a tool intended to be used by researchers studying livestock systems management, with particular reference to the cow-calf systems of the Salado Region. User-friendliness was not a major consideration, and attention was concentrated on the flexibility of the model to simulate a broad spectrum of management alternatives. It is climatically driven and represents farm management using dynamic decision rules.

The model was designed to produce long term simulations of the dynamic interactions between herd structure, climatic variations and farm management over periods of several decades. The decision was made to use existing models to describe the biological components of the farm such as soil (Allen et al., 1998), pastures (McCall, 1984) and cattle (Freer et al., 1997). These components are linked with other components describing management actions in a dynamic framework. The model is driven by decision rules entered by the user, which allow the representation of many different kinds of management options that respond to changing farm conditions according to a predetermined policy (Sherlock et al., 1997; Cros et al., 1997). This kind of flexibility had not always been adequately addressed in previous models (e.g. Sanders and Cartwright, 1979).

An object-oriented approach (OOA) was used in the design and construction of the model (Power, 1993; Shaffer et al., 2000). Object-oriented design has become standard in simulation modelling of complex systems, Sherlock et al. (1999) for example describe the use of object-oriented methods to simulate a dairy farm where the farm objects (pasture, cows, etc.) are legacy models (Neil et al., 1997).

For the current model, Java was used as the implementation language, so the software can run on any platform. Java was chosen because it is completely object-oriented, is freely available, and is relatively easy to learn compared with alternatives (e.g. C++, Smalltalk, Delphi).

2.2.2. Model architecture

Figure 2.1 shows a partial class[7] diagram with the most important classes in the model and some of their methods and attributes. A class diagram is a Unified Modelling Language (UML, Rumbaugh et al., 1999) diagram that shows classes, their attributes and methods together with the association between classes (Bennett et al., 1999). Some details of the classes in Figure 2.1 are explained in the following sections. In the text, the names of the classes and the methods are underlined. References to classes start with capital letters (e.g. *Cow*), whereas references to objects (particular instances of a class) start with lower case letters (e.g. *cow*).

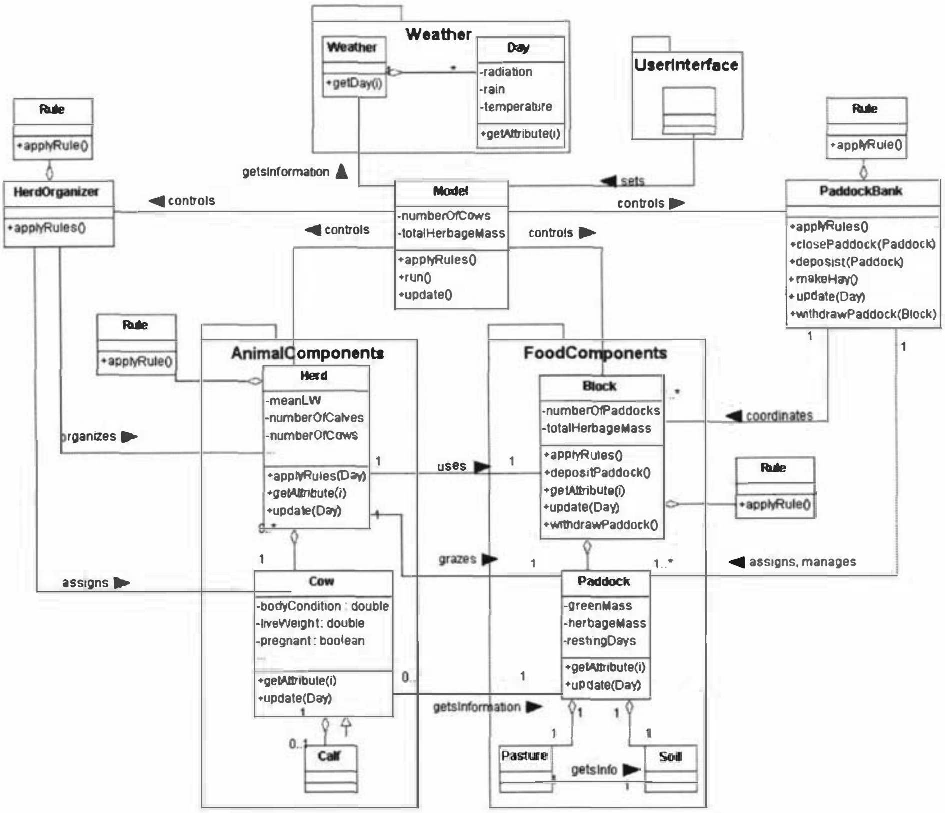

Figure 2.1: UML class diagram of the model showing the relationships between the principal classes of the model.

2.2.3. Management simulation

The dynamics of a farm system are dominated by management actions, which interact with the biophysical components and the environment to produce a pattern of production. In the model, the management of the farm is simulated according to rules

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[7] A central concept in OOA is the class, which is a description of a set of objects that share the same attributes, methods, relationships and semantics (Bennett et al., 1999). A class is a template that is used to construct objects (Brookshear, 2000), and an object is an instance (or occurrence) of a class.

entered by the user. The software implements the rules to manipulate the different components and so simulate the system dynamics.

The most important physical components of a pastoral cow-calf farm are the cows, usually grouped into herds, and paddocks, which can be grouped into "blocks". Each herd has its own block, although there could be blocks without herd. Farm management actions operate on one or more elements of the farm. Those elements could be cows, herds, paddocks or blocks. It is the author's contention that the management of a farm can be satisfactorily represented by a limited set of actions (Table 2.1), so that the difference between management strategies lies in how the decisions to perform each particular action are made.

Table 2.1: Actions that can be applied to the different elements of the farm and the agents (classes) that contain and apply them.

Type	Scope	Action	Agent
Cow Action	A single cow	Sell	*Herd*
		Wean	*Herd*
		Assign to a herd	*HerdOrganizer*
Herd Action	One herd as a whole	Feed hay	*Herd*
		Change paddock	*Herd*
		Bulls in	*Herd*
Paddock Action	A single paddock	Close for hay	*PaddockBank*
		Release for grazing	*PaddockBank*
		Make hay	*PaddockBank*
		Clean by cutting	*Block*
		Assign to a block	*PaddockBank*
		Deposit in the bank	*Block*
Block Action	One block as a whole	Withdraw a paddock from the bank	*Block*

The concept of a "paddock bank" was introduced to handle flexible assignment of paddocks to blocks. When a block has more pasture than it needs for its animals, it may loan paddocks to the bank. Paddocks in the bank are available for use by other blocks, which might require additional feed. This interchange of paddocks is driven by rules entered by the user.

Farmer decision rules are stored in the agents that implement them (*Herd*, *Block*, *PaddockBank* and *HerdOrganizer*, see below). In line with the object-oriented approach, any action triggered by a rule only affects the particular agent containing it. Another solution would have been to concentrate the rules in a farm manager object (Sherlock et al. 1997). This is merely a matter of programming style. The rules consist of conditions and actions in the classic "if *condition is true* then *action*" formula. The conditions may depend on the physical attributes of the cow, herd, paddock or block in question, the environmental situation, the calendar date or on decision variables such as whole farm average pasture state. The conditions may also be composite, testing several sub-conditions at once. Every condition consists of at least one comparison of an attribute of any component of the system against a constant or another attribute.

2.2.4. Biophysical components

The biophysical classes represent real entities on the farm. Each of them has a version of the methods *update()* and *getAttribute(index)*. *Update()* is called daily, and recalculates the value of the attributes of the object (refer to Chapter 3 for details in the updating). The method *getAttribute(index)* returns the value of the attribute of the object specified by the index. It can be called, for example, when a *rule's* condition is evaluating a cow. For example, a call of *getAttribute(Age)* in a *cow* object would return the age in days of this particular cow.

2.2.4.1. Class Cow

This class simulates an individual cow. The method *update()* in the class *Cow* calls other methods in the following sequence:

1. Update reproductive status. This is accomplished by the method *updateReproductiveStatus()*, which controls gestation/lactation status, reproductive cycles, pregnancy and calving.

2. Calculate dry matter intake. The intake model used by McCall (1984) (recently published as McCall and Bishop-Hurley, 2003) was modified so that each cow uses a portion of the paddock being grazed proportional to its potential dry matter intake in relation to the potential intake of the whole *herd* to which it belongs. The herbage intake is calculated from animal potential intake, herbage mass, herbage green/dead ratio and area of pasture offered per animal. It is also affected by the relative quality and quantity of hay offered. If hay (the only type of supplement considered presently in the model) is being offered, hay intake is also calculated.

3. Calculate energy partitioning between maintenance, pregnancy, lactation and live weight change (Freer et al., 1997).

4. If the cow is nursing a calf (represented by a subclass of *Cow*), the *update()* method of the calf is called.

2.2.4.2. Class Herd

This class represents a group of cows and keeps track of data about the group as a whole, such us the number of cows in the herd or the averages of the cows' attributes. The method *update()* in the class *Herd* activates the *update()* method of all the *cows* in the *herd*. The method *update()* also updates the attributes of the *herd* and sends the intake information to the paddock being grazed.

Each *herd* holds a list of *rules* related to herd actions and cow actions. The method *applyRules()*, called daily, loops through this list calling the method *applyRule()* for each of the *rules*. In the case of rules containing cow actions, the rule is applied to each of the cows in the *herd*.

2.2.4.3. *Class Paddock*

This represents an area of land managed as a single unit. This class is responsible for simulating herbage production, and provides all the necessary information for the *cows* to calculate herbage intake.

Each *paddock* contains an object of the class *Pasture* and an object of the class *Soil*. The class *Pasture* simulates a sward following the method used by McCall (1984). The class *Soil* maintains a water balance by accounting for rain and estimated daily evapotranspiration (Allen et al., 1998). The mineral nutrition of the pasture is not currently modelled, and soil fertility and pasture species are represented by constants as described by McCall (1984).

The method *update()* calls the *update()* methods in the corresponding *soil* and *pasture* objects, and then updates the attributes of the *paddock* itself.

Even though the model uses paddocks to simulate herbage production and grazing, the rules to manage the use of individual paddocks are entered at the *Block*, *Herd* or *PaddockBank* level. Unless single paddocks blocks are defined, the user cannot refer to particular paddocks when entering the rules. This ensures that management rules are generic, and can be more easily translated into recommendations for real farms with different number and sizes of paddocks.

2.2.4.4. *Class Block*

This class represents the group of paddocks that is used as a unit, and keeps records about the group, such as the number of paddocks and the averages of certain attributes of those paddocks. The grouping of the paddocks does not mean that they are spatially close, but only that they are being used by the same herd.

The *paddocks* can be temporarily reassigned to different *blocks* (see class *PaddockBank*). Each *block* has two methods relating to the interchange of *paddocks*, which are *withdrawPaddock()* and *depositPaddock()*. The first method requests a *paddock* from the *PaddockBank* and the second deposits a *paddock* to the *PaddockBank*. Both methods can only be activated by rules.

The method *update()* in this class activates the update methods of all the *paddocks* in the block and also updates the attributes of the *block*.

Each *block* holds a list of *rules* related to block actions or paddock actions. The method *applyRules()* calls the method *applyRule()* for each *rule* in the list. *Rules* containing paddock actions are applied to each *paddock* in the *block*.

2.2.4.5. *Class Weather*

This class is in charge of maintaining and producing the weather information. The user must provide the weather data via a specifically formatted text file. This file is read and an object of the class *Day* (containing all the calendar and climatic information for one day) is created for each day in the series. These objects are stored in a list by the class *Weather*. The method *getDay(i)* returns the i[th] day in the list. The class *Weather* can also randomly generate weather data by sampling years from the data originally provided by the user.

2.2.5. Management classes

2.2.5.1. Class PaddockBank

This is a control class that has responsibility for managing the allocation of *paddocks* to the different *blocks* and controlling the haymaking process by applying rules related to close paddock, release paddock and make hay actions. *PaddockBank* contains references to all the *blocks* associated with *herds*, plus two extra *blocks* which do not correspond to particular *herds*: "inOfferBlock", containing paddocks that can be borrowed by any of the normal *blocks* and "closedBlock", holding paddocks that are closed to grazing.

When the *PaddockBank* receives a *withdrawPaddock()* message it decides whether to lend the *paddock* to the candidate *block*, taking into account the availability of *paddocks* on offer and the candidate's balance of deposited minus withdrawn *paddocks*.

2.2.5.2. Class HerdOrganizer

This class decides which *herd* each cow will be assigned to. The model does not assume any predetermined criteria of animal grouping, and the characteristics of each herd are completely defined by the rules that the user associates with it. The rules can take into account aspects as diverse as animal state, time of year, pasture conditions and hay availability.

This approach allows almost complete flexibility in the way the animals are grouped, in contrast to previous models, such as Rotz et al. (1999) or Sanders and Cartwright (1979), where the animals are assigned to fixed groups. Animal grouping can be an important management tool in pastoral systems. The farmers in the Salado region do not maintain large numbers of herds, but the criteria for grouping change significantly between farmers (Cittadini et al., 2002).

2.2.5.3. Class Rule

Each object of the class *Rule* contains an instance of the class *BooleanExpression* and an instance of the class *ModelAction*. The first tests a particular condition and the second applies a specific action. The method *applyRule()* in the class *Rule* calls the *evaluate()* method in the *BooleanExpression* object: if the condition tested is true, the message *applyAction()* is sent to the *ModelAction* object, otherwise nothing happens.

The class *ModelAction* has several subclasses, each one representing the different types of management of actions described in Table 2.1. A call to the method *applyAction()* of an object of this class, from the rule containing it, will result in the implementation of an specific action. To do this, the *modelAction* object sends the corresponding message to the agent that will finally apply the action.

The attributes that compose the conditions are represented by the class *ModelAttributeExpression*. This class has the responsibility for storing and evaluating the attributes entered into particular rules by the user. The attribute evaluated can be numerical or boolean.

2.2.6. Running the simulation

The class *Model* is a control class (Brown, 1997) that coordinates the model operation. It keeps track of the time, triggers operation of the rules by the agents in the model and initiates the daily update of the state of all the objects in the model. It provides the required synchronization for the operation of the model, while the substance of the simulation is carried out in the biophysical and management classes.

Each day, all decision rules are first applied. The biophysical components are then updated, so that cows graze pasture, grow and become pregnant, pastures grow, and so on. This is controlled by the method *update()* in the class *Model* following the sequence: 1) call the method *applyRules()* in the *herds*, *blocks*, *HerdOrganizer* and *PaddockBank*; 2) call the method *update()* in all the *herds* and *blocks* and 3) call the method *update()* in the *OutputManager* (the class in charge of storing and printing the outputs of the simulations).

The rules are applied in the order that they were entered by the user. The model is robust in the obvious cases where the sequencing of events is obligatory. For example, weaning must obviously happen after calving, and a rule trying to wean calves not yet born will not have any effect. In general the model will not crash if a rule tries to violate this logical sequence, so the user does not need to prevent it. But, when the strategy requires a specific sequence of actions, then it is the responsibility of the user to enter rules that trigger the actions in the desired timing. For example, a rule selling dry cows after weaning, without any other specification, will sell all the cows in the herd, which is probably not the desired effect.

2.2.7. Model inputs

In order to initiate a simulation, the user must enter four types of inputs: 1) farm characteristics, 2) decision rules, 3) initial state and 4) weather data. Details of each type of input are given below.

2.2.7.1. Farm characteristics

The user must enter the total area of the farm, the number and identification of the herds and the number of paddocks assigned to each block. Note that this initial allocation of *paddocks* can be altered by rules applied by the *blocks* or by the *PaddockBank*.

To simplify the user's specification of the model, at this stage all the paddocks have the same area, which is calculated by dividing the total area of the farm by the number of paddocks, both of which are entered by the user.

2.2.7.2. Decision rules

The model offers a simple graphical user interface to create (and edit) the rules. The user must: 1) select the kind of component that will contain the rule, 2) select the specific component (agent) that will execute the rule, 3) select the action to be triggered and 4) type a condition (or modify an existing condition). Before a rule can be accepted, the model checks the syntax of the condition (names of the attributes, key words, mathematical expressions) and that there are no references to non existent *herds* or *blocks*. Once created, the complete set of rules can be stored as an XML (Extensible Markup Language) file.

Specific syntax was developed to declare the attributes and create the conditions (Table 2.2).

Table 2.2: Syntax used to enter the attributes that compose the decision rules.

Type	Keyword	Syntax	Example
System	SA	SA[attribute name] COUNT[condition][1]	SA[month] COUNT[CA[pregnant] = true]
Cow	CA	CA[herd name, attribute name][2] CA[attribute name][3]	CA[heifers, liveWeight] CA[liveWeight]
Herd	HA	HA[herd name, attribute name] COUNT[condition][1] MEAN[CA[attribute name]] MIN[CA[attribute name]] MAX[CA[attribute name]]	HA[heifers, number] COUNT[CA[heifers, pregnant]=true] MEAN[CA[heifers, liveWeight]]
Paddock	PA	PA[herd name, attribute name][4] PA[attribute name][5] GP[herd name, attribute name][6]	PA[heifers, herbageMass] PA[herbageMass]
Block	BA	BA[herd name, attribute name] COUNT[condition][1] MEAN[PA[attribute name]] MIN[PA[attribute name]] MAX[PA[attribute name]]	BA[heifers, totalHerbageMass]

[1] System attribute referring to the number of cows or paddocks for which the condition is true.
[2] Cow attribute referring to a cow contained in a specific herd.
[3] Cow attribute referring to a cow contained in any herd.
[4] Paddock attribute referring to paddock contained in a specific block.
[5] Paddock attribute referring a paddock contained in any block.
[6] Paddock attribute referring to the paddock under grazing in a specific block.

The following is an example of a rule applying to a herd named "heifers" :

if: GP[heifers, herbageMass] < 1000

then: move to new Paddock

where: herbageMass= total paddock herbage mass in kg dry matter/ha.

This rule states that, if the herbage mass in the paddock currently being grazed by the "heifers" herd is less than 1000kg of dry matter per ha, then move this herd to a new paddock. By default, herds are always moved to the paddock with the greatest number of resting days in the block, this normally coincides with the greatest herbage mass, which according to Woodward and Wake (1995) maximizes their intake.

Complete sets of decision rules for a farm system are presented in the following chapter.

2.2.7.3. *Initial state*

The initial state of the farm defines the initial values of the attributes of the components of the farm. The model creates a default initial state from user entered values of:

- Number of cows in each herd.
- Maximum and minimum herbage mass in each block.
- Maximum and minimum proportion of green material in each block.
- Soil water content.

By default, the program creates instances of the class *Cow* which are non-lactating, non-pregnant and with a body condition equal to one (see Freer et al., 1997 for details of the body condition scale) in a wedge of ages from 2 to 7 years (i.e. 2 years old are most numerous, 7 years are least numerous).

The paddocks are initialised using a linear scale from the maximum to the minimum herbage mass and from the minimum to the maximum proportion of green material.

At the end of a simulation, the state of the farm can be saved in an XML file, and can then be used to initialise the model for a subsequent simulation.

2.2.7.4. *Weather*

The weather is specified in a text file with the following information for each day:

- Date (as day/month/year)
- Mean, minimum and maximum temperature (in °C)
- Wind speed (in km/day at 2m above ground)
- Global radiation (in $MJ/m^2/day$)
- Rain (in mm/day)

The user must provide the initial date, final date and the location of the file. The model reads the file and creates an object of the class Weather.

2.3. DISCUSSION

Most previous farm models have only simulated simple fixed-date management systems, a sequence of actions rather that a strategy (Cros et al., 1997). This approach cannot properly represent the feedback processes that operate in the management of a real farm, where the decision maker is constantly monitoring the state of the system and the environmental conditions in order to decide what to do (Sørensen and Kristensen, 1992). Recently other authors have proposed to overcome this by using decision rules to simulate manager interventions (Sherlock et al., 1997; Cros et al., 1997; Shaffer and Brodahl, 1998; Aubry et al., 1998; Keating and McCown, 2001).

It has been argued that farmers operate their farms following a predetermined strategy (Cros et al., 2001). A strategy can be defined as a series of prepared responses to different possible situations (decision rules). The cyclical and recurrent nature of farming activities reinforces this proposition (Aubry et al., 1998). These rules encapsulate both long term goals or policies (e.g. target stocking rate, willingness to use hay) as well as short term tactical actions to manage immediate problems or opportunities (e.g. sale of cows in response to a severe feed deficit) (Aubry et al., 1998). Rule-based approaches to system management, whether agricultural systems (MacDonald and Penno, 1998) or business systems (Warren and Langley, 1999) have been found to be very effective in defining good management. Warren and Langley (1999) found that simple sets of decision rules may perform extremely well, and even better than real managers in certain situations. The model reported here adopts this approach: one of its main features is that management of the farm is completely rule driven. In the simulation experiments described in the following chapters, a limited set of rules (less than 50) was able to control a farm with 40 paddocks (total farm area: 100 ha), and up to 290 cows (plus calves) grouped into 2 or 3 herds, over long periods of time subject to an extensive range of weather situations.

Object-orientation is another essential characteristic of this model. The general advantages of this approach have been abundantly discussed by many other authors (see for example Power, 1993 and Brown, 1997): this is another example of its application. The decision to model individual cows, paddocks and rules as objects considerably facilitated the analysis, design and programming stages of the project. It also gave great flexibility to the model, which has been one of the main objectives since the beginning of the study.

The model can be used to study a variety of management issues, focusing on the biophysical components of the farm, rather that the economic or social aspects of farming. The model was used to evaluate aspects as diverse as replacement heifer policies and mating dates (Chapter 4) and haymaking strategies (Chapter 5 to 7) in cow-calf systems. However, it is important to acknowledge that many of the important decisions affecting real farm systems are based on socio-economic factors (Edwards-Jones et al., 1998b; Cittadini et al., 2002). For example, sale and purchase decisions would be driven by market considerations or family needs rather than by production criteria. Instead of trying to include all these aspects in the model, and recognizing the limitations that this may impose, it was assumed that it is possible to devise a long term production strategy, having these aspects in mind, but without actually including them in the model. The model is intended to study the impact of management strategies on the physical outcomes of the farm. Even though it can potentially produce enough information to allow any type of ex-post economic analysis, at this stage only biophysical variables can be included in the decision rules.

The central interest of the present project lies in developing a model that is able, in principle, to simulate any reasonable management strategy for pastoral cow-calf farms. For this reason, existing and previously tested sub-models have been used for the bio-physical components of the farm, with as little modification as possible. At this stage, validation of such models is not considered an issue. There was no reason *a priori* to suppose that the animal model would not behave properly. In the case of the soil and pasture models, suitable parameters were modified to fit Argentinean conditions. Preliminary tests against herbage accumulation data from six different cutting trials showed close agreement between real and simulated results.

As will be demonstrated in the following chapters, the model that has been developed is flexible enough to represent different management strategies and perform simulations over long periods of time. The use of flexible management rules allows the model to react to changing circumstances, as a farmer would do, instead of applying a rigid sequence of actions. The simulation of individual cows and individual paddocks makes it possible to distribute feed resources flexibly among the animals and provides many other points of flexibility in management strategies.

CHAPTER 3

BIO-PHYSICAL COMPONENTS

3.1. INTRODUCTION

In Chapter 2, the general architecture of the present model was described but no details of the bio-physical components were given. This is the objective of this chapter. As was stated in Chapter 1, it was not the purpose of this thesis to develop these components, so all the daily updating of bio-physical components is based on models and formulae that has been previously published. Therefore, the criteria for choosing the biological model were:

- Access to detailed descriptions of the procedures
- Published in accessible and refereed literature
- Previously used and tested
- As comprehensive as possible, so as to minimize the number of models required
- As mutually compatible as possible, reducing the interfacing difficulties
- Realistic in terms of the inputs required

Three different sources were used; Allen et al. (1998) for the climatic and soil components; McCall (1984) (also published as McCall and Bishop-Hurley, 2003) for the pasture model and Freer et al. (1997) for the animal model. All the relevant equations are described in detail, but no theoretical justifications are given as extensive discussion has been offered in the original publications. Minor changes were introduced when necessary, and these are also explained and justified in this chapter.

3.2. CLIMATIC VARIABLES

As described in Chapter 2, the class *Day* stores the climatic information for a day and calculates the reference evapotranspiration (ET_0) (Allen et al., 1998). ET_0 is calculated using the Penman-Monteith method as described by Allen et al. (1998) (equation 6 in the source):

$$ET_0 = \frac{0.408 * \Delta * (R_n - G) + \gamma * \frac{900}{T_{mean}+273} * u_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 * u_2)}$$ **Equation 3.1**

where: 0.408 = constant (kg/MJ)

R_n = net radiation at the sward surface (MJ/m^2/day, Equation 40 in the source).

G = soil heat flux density (MJ/m^2/day, ≈0 Equation 42 in the source)

T_{mean}= mean daily air temperature at 2 m height (°C)

u_2 = wind speed at 2 m height (m/s)

e_s = saturation vapour pressure (kPa, Equation 12 in the source)

e_a = actual vapour pressure (kPa, Equation 19 in the source)

e_s-e_a = saturation vapour pressure deficit (kPa)

Δ = slope of vapour pressure curve (kPa/°C, Equation 13 in the source)

γ = psychrometric constant (kPa/°C, Equation 8 in the source)

The calculations required to obtain the parameters included in this equation are meticulously described in Allen et al. (1998), including the derivation of the formulas and alternative procedures that may be used according to the meteorological data available. Table 3.1 presents a summary of the acronyms related to weather variables.

Table 3.1: Weather parameters used in the model, symbols, brief description and units.

Parameter	Description	Units
T_{mean}	mean daily air temperature	°C
T_{max}	maximum daily air temperature	°C
T_{min}	minimum daily air temperature	°C
ET_0	reference evapotranspiration	mm/day
AET	actual evapotranspiration	mm/day
R_g	global radiation	MJ/m^2/day
R_n	net radiation at the sward surface	MJ/m^2/day
RAIN	daily rainfall	mm/day
wind	wind speed at 2m height	m/s
RH	relative humidity	%

3.3. SOIL WATER MODEL

The soil water balance is computed by the <u>*Soil*</u> class, following the method of Allen et al. (1998). This is the only responsibility of the class (apart from providing soil data to the other classes). The amount of available water in the root zone (*AW*) is calculated by balancing water entering and leaving the soil:

$$AW_{(t)} = \min(TAW, \quad AW_{(t-1)} + RAIN_{(t)} - AET_{(t)})$$ **Equation 3.2**

where: *TAW* = total available water in the root zone

$AW_{(t-1)}$ = soil water content at the end of day t-1

$RAIN_{(t)}$= precipitation on day t (mm)

$AET_{(t)}$ = evapotranspiration on day t

A sward is considered to be in reproductive state from 1 October until it is "cleaned" out (i.e. grazed or cut below 1000 kg GDM).

TF represents the effect of temperature on herbage growth. It was approximated from Fig. 5.4 in McCall (1984), which is reproduced in Figure 3.1. As suggested by McCall (1984), maximum daily temperature (T_{max}) is used during the winter months (April - August) and T_{mean} at other times.

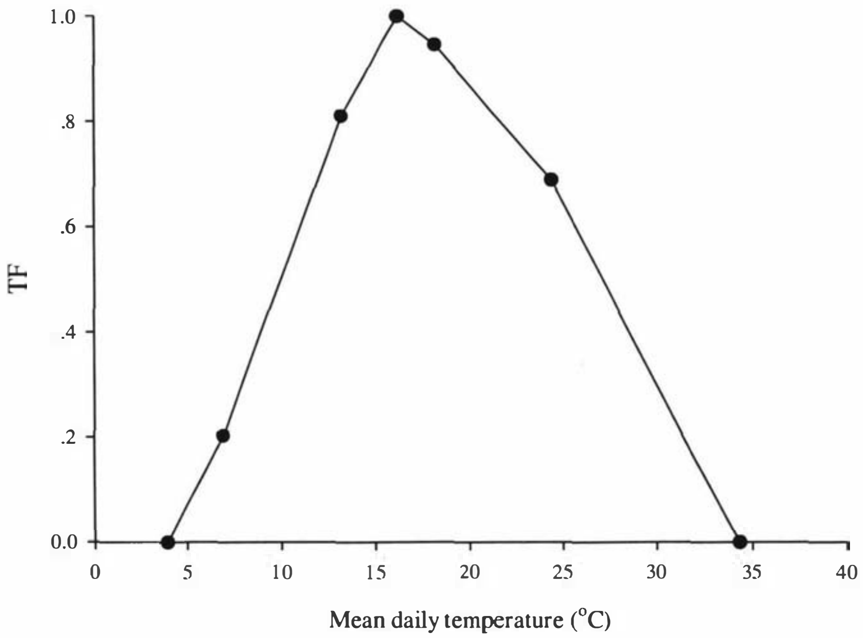

Figure 3.1: Relative effect of temperature on herbage growth (TF) (McCall, 1984)

The factor *REF* represents seasonal differences in efficiency of net photosynthesis, and is mainly related to reproductive development and the associated changes in plant physiology (Parsons and Chapman, 2000). REF takes two different values according to the time of the year (0.75 and 1, Figure 3.2). In the present model, the seasonal variation in *REF* was adjusted to represent the behaviour of an adapted species for the Salado Region, using data of stem elongation in Agropyron (*Thinopyrum ponticum*) from Borrajo (1998) (see Figure 3.2).

The parameter *MR* in Equation 3.6 is calculated as a linear function of mean daily temperature (T_{mean}) when T_{mean} is greater that 4°C:

$$MR = \begin{cases} 0.0001 * T_{mean} & \text{if } T_{mean} > 4^{\circ}C \\ 0 & \text{otherwise} \end{cases}$$ **Equation 3.9**

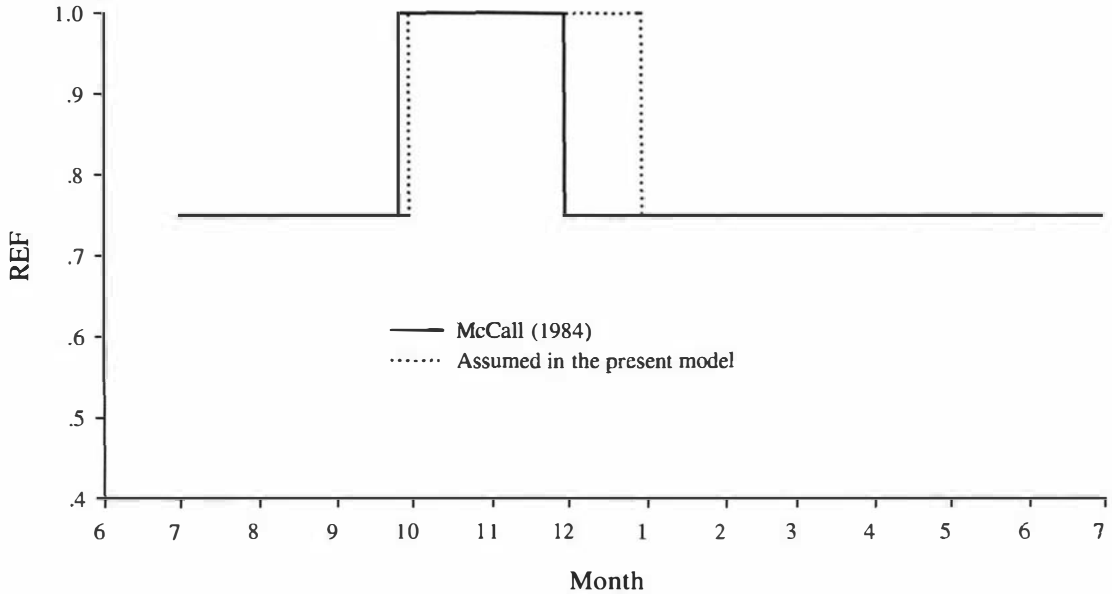

Figure 3.2: Relative seasonal efficiencies of herbage growth (*REF*) assumed in the present model compared with McCall (1984).

3.4.2. Senescence rate

Senescence is assumed to be a constant proportion (*ALPHA*) of the green herbage mass (*GDM*) per day. Two different values for *ALPHA* are used, *VALPHA* (0.0065) and *RALPHA* (0.0131), corresponding to swards in vegetative and reproductive states respectively.

The basal senescence rate (*PS*) is increased by a factor *DF* in cases of drought stress (Figure 3.3). *DF* increased linearly from 1 at the point (*DRTD*) when available soil water (*AW*) reaches 18% of the total available water (*TAW*), to 3.07 (*WDT*) when *AW* is zero.

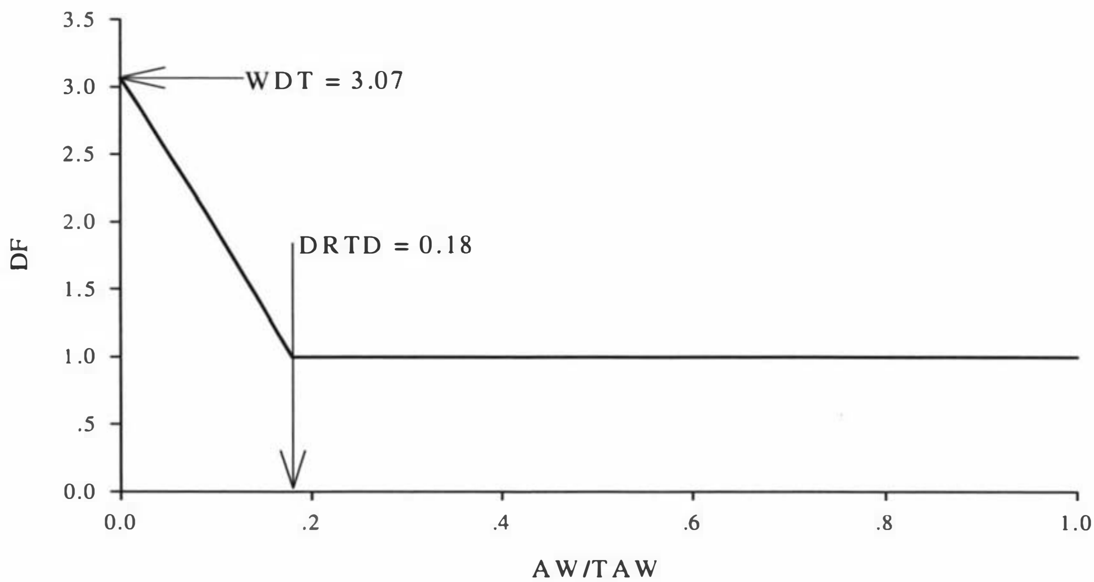

Figure 3.3: Multiplying factor (*DF*) affecting herbage senescence rate depending on the soil water content (*AW*) relative to total available water (*TAW*) (McCall, 1984).

The dead material is stored in two pools, soluble and insoluble material; 30% (*SOL*) of the newly senesced material goes to the soluble pool, and the rest to the insoluble pool. Each pool has a different dynamic, as described in the following section.

3.4.3. Decay rate

Losses from leaching, microbial decomposition and removal by earthworms are considered.

The leaching losses (*LL*), applying only to the soluble pool, are calculated as a function of the temperature and soil moisture. Potential leaching loss rate increases linearly with rainfall from 0 (in days without rain) to 50% of the soluble material present in days with 10mm rain or more. The actual loss is dependent on temperature:

$$LL = \max\left(0.5,\ \frac{0.5}{10} * RAIN * (0.3 + 0.0167 * T_{mean})\right) \quad \textbf{Equation 3.10}$$

Microbial decay operates on both pools. The potential rates are 90% and 3% for the soluble and insoluble pool respectively. The actual rates are calculated as functions of soil moisture and temperature (Figure 3.4). Soil moisture is not limiting on days with rain. The temperature factor was modified as depicted in Figure 3.4, because the original calculation resulted in decomposition rates which were too low even in summer (average T_{mean} 15-20°C) leading to unrealistic accumulations of dead material.

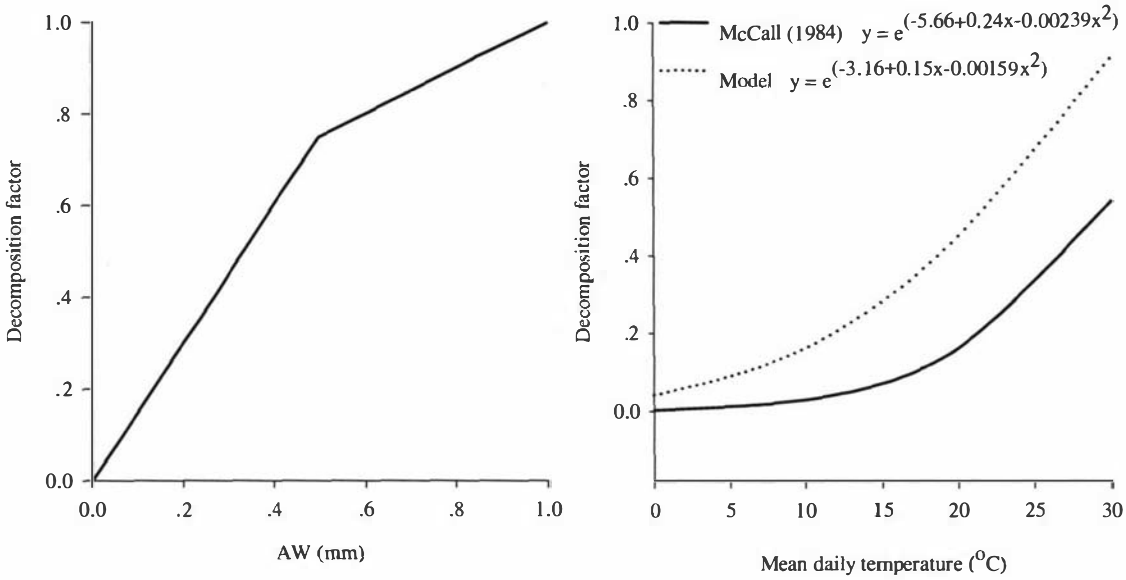

Figure 3.4: Soil moisture (*AW*) and temperature multipliers for dead herbage losses by decomposition (McCall, 1984).

Removal by earthworms operates only on the insoluble pool. The daily rate of material removal takes different values according to season, being important only during the autumn/winter period (Figure 3.5).

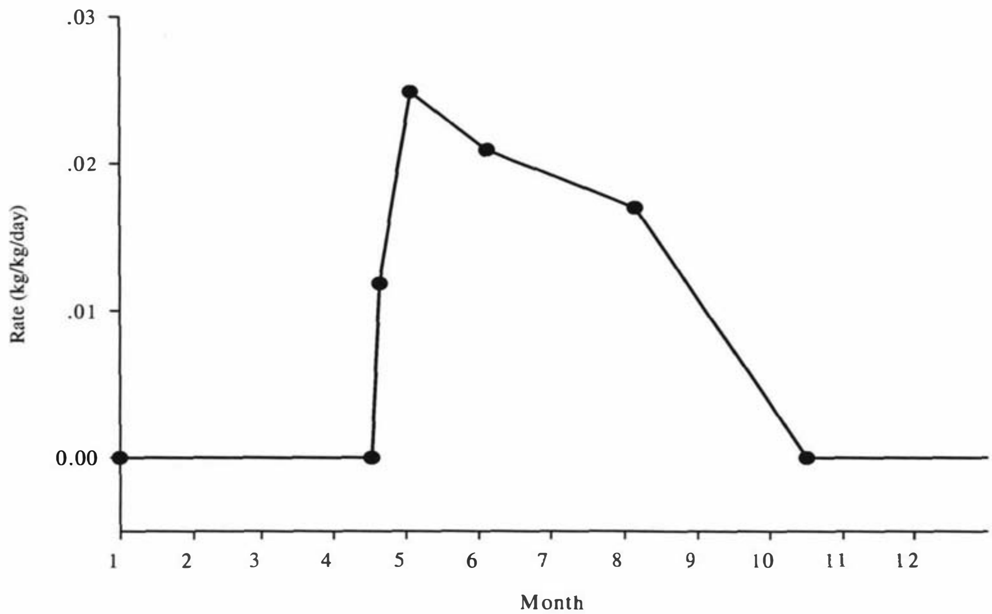

Figure 3.5: Effect of the month on the rate of dead herbage removal by earthworms (McCall, 1984).

3.4.4. Herbage and diet quality

The digestibility of the green herbage dry matter is calculated from peak seasonal digestibility. McCall (1984) used data from browntop swards to derive the value for each month of the year. In the present model, Argentinean data from Agropiro pastures managed under a scheme of frequent cutting (Orbea et al., 1971) were used (Figure 3.6). Using McCall (1984), when the sward is in a reproductive stage, the peak digestibility decreases with increasing green herbage cover as showed in Figure 3.7.

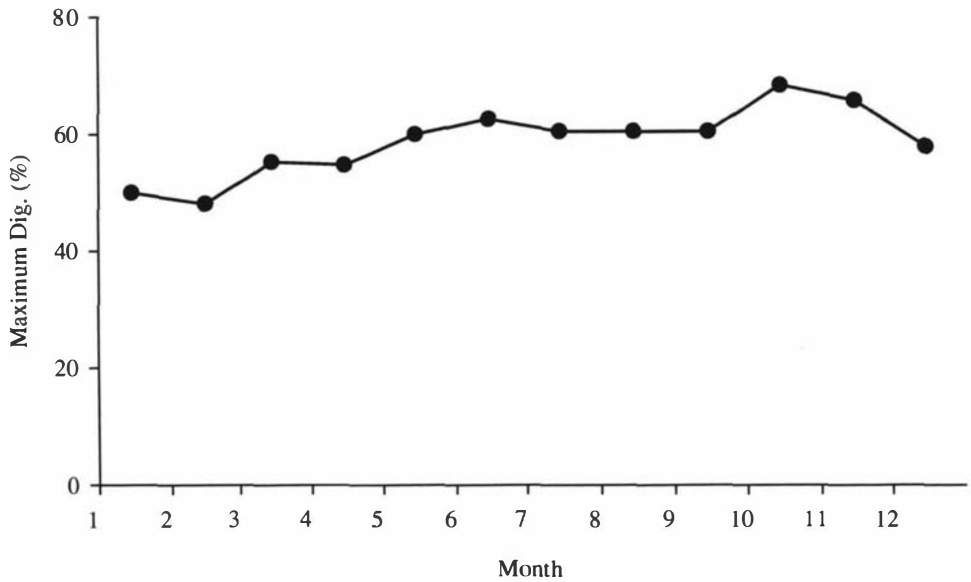

Figure 3.6: Assumed maximum green herbage digestibility in each month.

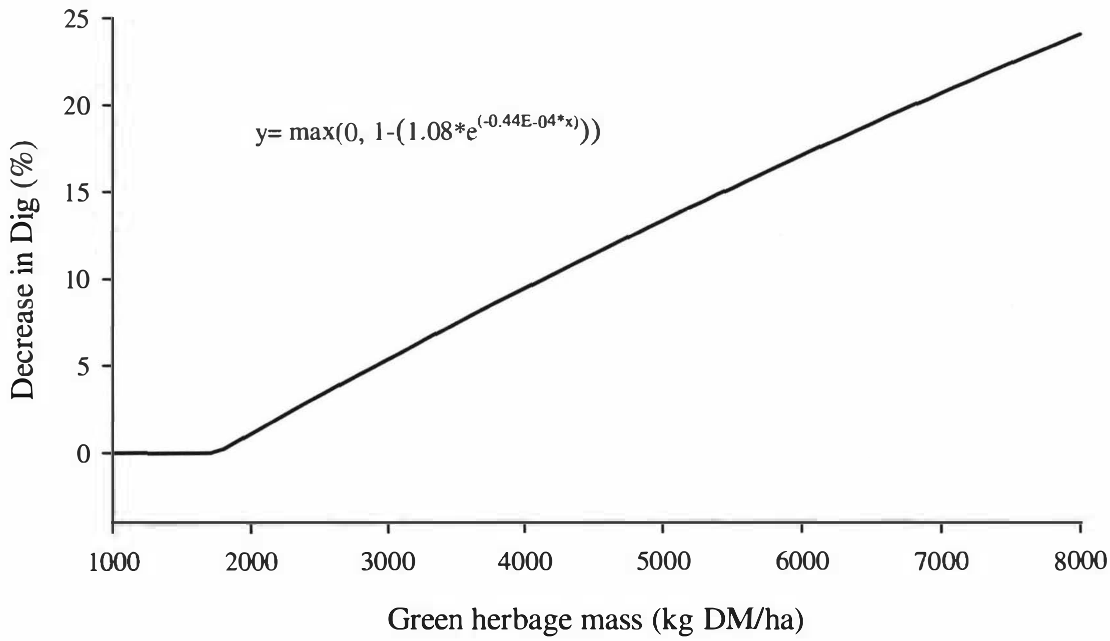

Figure 3.7: Assumed reduction in green herbage digestibility with increasing green herbage mass in reproductive swards (McCall, 1984).

The average herbage digestibility (*ASD*) is calculated assuming the digestibility of the dead material to be 49%. Data from Agropiro (*Thinopyrum ponticum*) pastures (Orbea et al., 1971) were used to estimate this value. As in McCall (1984), the digestibly of the diet selected (*DDS*) is calculated as a function of *ASD*:

$$DDS = 0.7 * ASD + 30$$ **Equation 3.11**

3.4.5. Hay making

When the pasture is harvested for hay a residual of 600 kg DM/ha is assumed. Field dry matter loss at harvesting is considered to be a fixed value of 20%. The digestibility of the hay is reduced by 4% from the average digestibility of the sward at cutting. Values for losses were taken from Barry et al. (1980).

3.5. HAY STORAGE

The class called *HayStorage* maintains the hay stock in kg of DM by accounting for new hay additions, hay consumption, feeding losses and storage losses.

Hay is assumed to be of uniform quality. When new hay is added to the stock, the quality of the whole stock is re-calculated by averaging new and old hay. Only one hay stock is simulated, and no differentiation is made between hay harvested from different paddocks or at different times.

When hay is fed out to the animals, the amount of hay consumed (*CH*, determined by the corresponding decision rules and by the intake capacity of the animals) and the feeding losses (*FL*, 5% Barry et al., 1980) are subtracted from the stock:

$$HR = \frac{CH}{(1 - FL)}$$ **Equation 3.12**

where: HR = hay removed from the stock (kg DM)
CH = hay consumed by all the animal eating hay (see section 3.6.2.2).

Other options are possible, for example storing hay of different quality in separate pools and feeding it back differentially, but these were not investigated at this stage.

A value of 1% per month of the total dry matter stored is assumed for the storage losses (Barry et al., 1980).

3.6. ANIMAL MODEL

The animal components of the farm are represented in the present model by the class *BasicCow*, and its subclasses *Cow* and *Calf*. Keeping the strategy of using published biological models, the animal model from Freer et al. (1997) was used. This publication is very detailed and gives the specifications for a complete animal biology model. Personal communications with M. Freer helped to clarify some points. This animal model was designed for sheep and cattle grazing swards of grasses and other herbaceous plants and contains all the functionality required to develop the animal classes specified in the present model.

This section describes the procedure followed in the animal model. All the equations, including the numerical value of the constants, are taken from Freer et al. (1997). Some changes in the original formulae were necessary and are also explained below.

3.6.1. Normal live weight, relative size and relative body condition

Freer et al. (1997) explain that several functions in their model depend on the stage of development of the animal or on its body condition. Three central concepts in the calculation proposed by these authors are described below, these are the normal weight (N), the relative size (*Z*) and the relative body condition (*BC*). Table 3.3 presents definitions of variables and acronyms used in this section.

Table 3.3: Variables related to weight scaling

Parameter	Description	Units
W	Base weight (Live weight excluding conceptus)	kg
SRW	Standard reference weight: base weight of an animal when skeletal development is complete and condition score is in the middle of the range (SCA, 1990).	kg
N	W of an animal which follows a normal growth curve (Brody, 1945)	kg
N_{fet}	normal foetus weight	kg
Z	degree of maturity = N/*SRW*	kg
BC	Body condition = W/N	-
BW_{fet}	Normal birth weight of the foetus	kg

In all the calculations that follow, base weight (live weight excluding conceptus) is used instead of live weight. N is the normal base weight of an animal at any age (*AGE*: in days), and it is assumed to follow the classical Brody equation (Freer et al., 1997):

$$N = SRW - (SRW - W_{birth}) * \exp\left(\frac{-C_{N1} * AGE}{SRW^{C_{N2}}}\right) \qquad \textbf{Equation 3.13}$$

where: *SRW* = Standard reference weight. Base weight of an animal when skeletal development is complete and condition score is in the middle of the range (SCA, 1990). The value used in this simulation was 400 kg (Mezzadra and Miquel, 1994).

W_{birth} = birth weight (kg)

C_{N1} = growth constant (0.0157 $kg^{0.27}$/day)

C_{N2} = 0.27

The normal base weight change (δN, in kg/day) is:

$$\delta N = \frac{dN}{dAGE} = (SRW - W_{birth}) * \frac{C_{N1}}{SRW^{C_{N2}}} * \exp\left(\frac{C_{N1} * AGE}{SRW^{C_{N2}}}\right)$$ **Equation 3.14**

The normal weight of the foetus at birth (NBW_{fet}) is calculated as a function of the adult base weight:

$$NBW_{fet} = C_{P15} * (1 - C_{P4} * (1 - Z)) * SRW$$ **Equation 3.15**

where: C_{P4} = 0.33

C_{P15} = 0.07

Z = relative size of the mother at calving (see below)

The normal foetus weight (N_{fet}) at any AGE during gestation (AGE_{fet}) is:

$$N_{fet} = BW_{fet} * \exp(C_{P1} - C_{P2} * \exp(-C_{P3} * AGE_{fet}))$$ **Equation 3.16**

where: C_{P1} = 2.21

C_{P2} = 12.91

C_{P3} = 6.2E-3 (day^{-1})

The normal foetus weight gain (δN_{fet}) is a function of the N_{fet} at the corresponding AGE_{fet}:

$$\delta N_{fet} = C_{P2} * C_{P3} * \exp(-C_{P3} * AGE_{fet}) * N_{fet}$$ **Equation 3.17**

Z is the relative weight of the animal and represents the degree of maturity. It is defined as the ratio of the current normal weight to the adult normal weight (N/SRW). Obviously, Z cannot exceed 1.

Finally, BC is the relative body condition and is related to condition score. It is calculated as the ratio of the actual base weight to the normal base weight for the corresponding AGE (W/N).

3.6.2. Intake model

Food intake is predicted as the product of the potential intake for the specified animal and the proportion of that potential (RI: relative intake) that the animal can obtain from the available feed supply (Freer et al., 1997). The intake models of Freer et al. (1997) and McCall (1984) were combined in order to connect the animal model with the pasture model.

3.6.2.1. Potential intake

Potential intake I_{max}, calculated according to Freer et al. (1997), is defined as the amount eaten (kg *DM*/day) when unrestricted access is allowed to a feed with a DM digestibility of at least 80%.

$$I_{max} = 0.025 * SRW * X * (1.7 - X) * TF * LF * YF \qquad \textbf{Equation 3.18}$$

where: $X = \begin{cases} Z & \text{if } Z < 1.0 \\ BC & \text{if } Z = 1.0 \end{cases}$

TF: temperature factor

$$TF = \begin{cases} 1 - C_{I5}(T_{mean} - C_{I6}) & \text{if } T_{mean} > C_{I6} \text{ and } T_{min} > C_{I7} \\ 1 & \text{otherwise} \end{cases}$$

$C_{I5} = 0.02$
$C_{I6} = 25$ °C
$C_{I7} = 22$ °C

LF: lactation factor

$$LF = \begin{cases} 1 + C_{I16} * M_i^{C_{I9}} * \exp(C_{I9} * (1 - M_i)) * LA * LB & \text{if lactating} \\ M_i = \dfrac{AGE_{calf}}{C_{I8}} & \\ 1 & \text{otherwise} \end{cases}$$

$$LA = 1 - C_{I15} + C_{I15} BC_{birth}$$

BC_{birth} = Body condition of the cow at calving
AGE_{calf} = age of the calf : days since calving

$$LB_{(t)} = \begin{cases} LB_{(t-1)} - C_{L15}(LR_t - DR) & \text{if } AGE_{calf} > C_{L14} * C_{L2} \\ LR_{(t-1)} = C_{L16} DR_t + (1 - C_{L16}) LR_{(t-1)} & \\ DR = \dfrac{MP_2}{MP_{max}} & \\ 1 & \text{otherwise} \end{cases}$$

MP_2 and MP_{max} = see section 3.6.5.3.
C_{I8} = Peak intake time after calving (81 days)
C_{I9} = Intake curvature parameter (1.7)
C_{I15} = 0.5
C_{I16} = Peak intake level parameter (0.416)
C_{L2} = Peak milk production time (30 days)

C_{L14} = 0.7
C_{L15} = 0.01
C_{L16} = 0.1

YF: Factor that depresses potential intake in unweaned young to simulate incomplete development of rumen function.

$$YF = \begin{cases} \dfrac{1-\phi_{milk}}{1+\exp(-C_{I3}(AGE - C_{I4}))} & \text{unweaned animals} \\ 1 & \text{other animals} \end{cases}$$ **Equation 3.19**

ϕ_{milk} = Proportion of the diet as milk
C_{I3} = Rumen development parameter 0.22 (day^{-1})
C_{I4} = 60 (day)
AGE = age in days

The potential milk intake in calves ($I_{milk\ max}$) is calculated as:

$$I_{milk\max} = \frac{MC_{\max}}{\mathrm{M/D_{milk}}}$$

where: MC_{max} = maximum milk intake in ME units (Equation 3.39)
M/D_{milk} = ME content in milk

3.6.2.2. *Actual intake*

The actual intake of an individual animal is calculated as the product of the potential intake (I_{max}) and the relative intake (RI):

$$I = I_{max} * RI$$ **Equation 3.20**

RI, which reflects the limitation imposed by the quantity and quality of the food offered to the animal, is estimated using an adaptation of the equation of McCall (1984). If only herbage is being offered to the animal *RI* is calculated as:

$$RI = M * VI_{past}$$ **Equation 3.21**

where: M = a function of herbage mass and herbage allowance.
VI_{past} = a function of herbage energy content.

Thus,

$$M = \begin{cases} A * \exp(-1.016 * \exp(-1.0308 * ALLOW)) & \text{if ALLOW} > 0.8 \\ A * \exp(-1.016 * \exp(-1.0308 * ALLOW)) * \dfrac{ALLOW}{0.8} & \text{otherwise} \end{cases}$$

where: $A = \max(0,\quad 1 - 1.49 * \exp(-0.00198 * GDM))$

ALLOW is herbage allowance as a multiple of potential intake. In the present model, in contrast with McCall (1984), this calculation is done for individual animals, and it is assumed that every animal in a herd has the same opportunity of foraging the offered pasture area. Thus, *ALLOW* took the same value for all the animals in a herd:

$$ALLOW = \frac{GDM * AREA}{I_{max\,herd}} \qquad \textbf{Equation 3.22}$$

where: GDM = green herbage mass in the pasture (kg DM/ha)
$AREA$ = area offered to the herd (ha)
$I_{max\,herd}$ = sum of the I_{max} for all the animals in the herd

The other parameter involved in the calculation of RI is VI_{past}. In McCall (1984) (Fig. 6.6) two relationships between potential intake (VI: kg DM/100 kg LW) and diet quality (MJ ME/kg DM) were used, one for mature and the other for young animals. In the present model, those relationships are modified so that the voluntary intake is expressed in relative terms, that is as a proportion of the maximum potential intake (Figure 3.8).

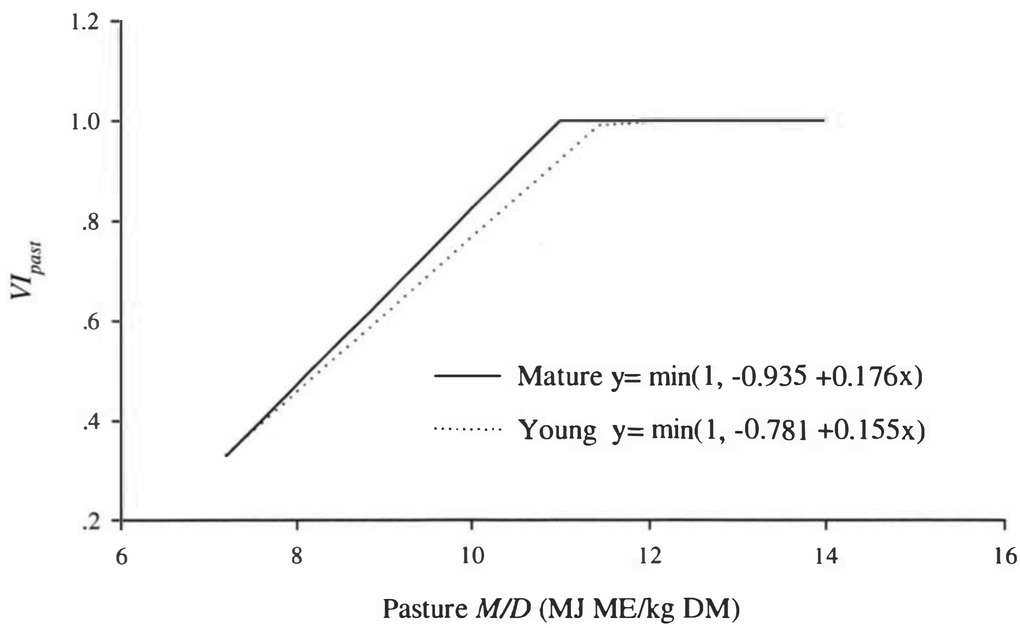

Figure 3.8: Relative potential intake (VI_{past}) as a function of herbage *ME* content (M/D), for young and mature animals. Adapted from McCall (1984, pg. 86).

When the base weight of the animal (W) is less than 60% of the adult weight (SRW) the young animal relationship is used. Between $0.6W$ and SRW, and provided that the animal AGE is less than 16 months, VI is obtained by interpolation between the young and adult relationships. Otherwise the mature relationship is used.

Herbage ME content (M/D_{past}) is estimated as a linear function of the digestibility of the selected diet (DDS_{past}) (AFRC, 1993, p. 42):

$$M/D_{past} = -0.46 + 17 * DDS_{past} \qquad \textbf{Equation 3.23}$$

DDS_{past} is calculated as an attribute of the herbage offered and as a function of average herbage digestibility (see section 3.4.4).

The McCall (1984) model does not consider the use of supplements, and the model of Freer et al. (1997) showed some problems when animals were offered low quality hay (see section 3.7.1). In principle, Freer et al. (1997) can simulate pasture/supplement intake, but it is quite demanding in herbage data. It divides the herbage into 6 pools of fixed digestibility (0.8 – 0.3) that are eaten progressively and assumes that the animal will eat the supplements before it selects herbage of the same or lower quality. Due to the lack of suitable local data, too many assumptions would have been required to use that model under the Salado Region conditions.

At the present stage hay is the only type of supplementation that can be simulated with the model. The following solution was adopted in order to proceed with the project, but it is recognised that this is an area where much more local research is required.

To calculate the potential hay intake, I_{max} is multiplied by an adjustment factor of 1.5. This factor was not included in the original model, but it had to be added in order to produce sensible intake estimates when very low quality hay was fed to the animals (see section 3.7.1). The logic was that animals will be able to eat more feed of equivalent digestibility when it is offered as a supplement than when they have to harvest it by direct grazing. The effect of hay quality on voluntary intake (VI_{hay}) is:

$$VI_{hay} = \min(1, \quad 0.024 + 0.089 * M/D_{hay}) \qquad \textbf{Equation 3.24}$$

where: M/D_{hay} = hay ME content (= $2.67 + 11*D_{hay}+2.67$) (AFRC, 1993)

Faced with the choice between eating hay or pasture, the animal decides which one to consume first according to their relative limitations ($VI_{past}*M$ *vs.* VI_{hay}, for pasture and hay respectively). Once the first food has been consumed the remaining capacity (*ruc* = relative unsatisfied capacity) is calculated which limits the intake of the second food. Figure 3.9 shows a diagrammatic representation of the process followed to simulate selective intake between pasture and hay. This sequence produces acceptable results under the conditions under which the present model has been used. However, it has not been properly validated and there is no guarantee that it would work in conditions different from those under which it has been tested (i.e. medium to low quality hay).

See Table 3.4 for a list of acronyms used in the intake simulation.

Table 3.4: Variables and acronyms used in the calculation of the relative intake (RI).

Parameter	Description	Units
DM	Dry matter	kg
ME	Metabolisable energy	MJ
M/D	ME content	MJ ME/kg DM
M/D_{past}	ME content in consumed herbage	MJ ME/kg DM
M/D_{hay}	ME content in hay	MJ ME/kg DM
M/D_{milk}	ME content in milk	MJ ME/kg DM
D_{green}	Digestibility of green herbage material	-
D_{dead}	Digestibility of dead herbage material	-
D_{past}	Average herbage digestibility	-
DDS_{past}	Digestibility of diet selected from pasture	-
D_{hay}	Digestibility of hay	-
ruc	Relative unsatisfied capacity	-

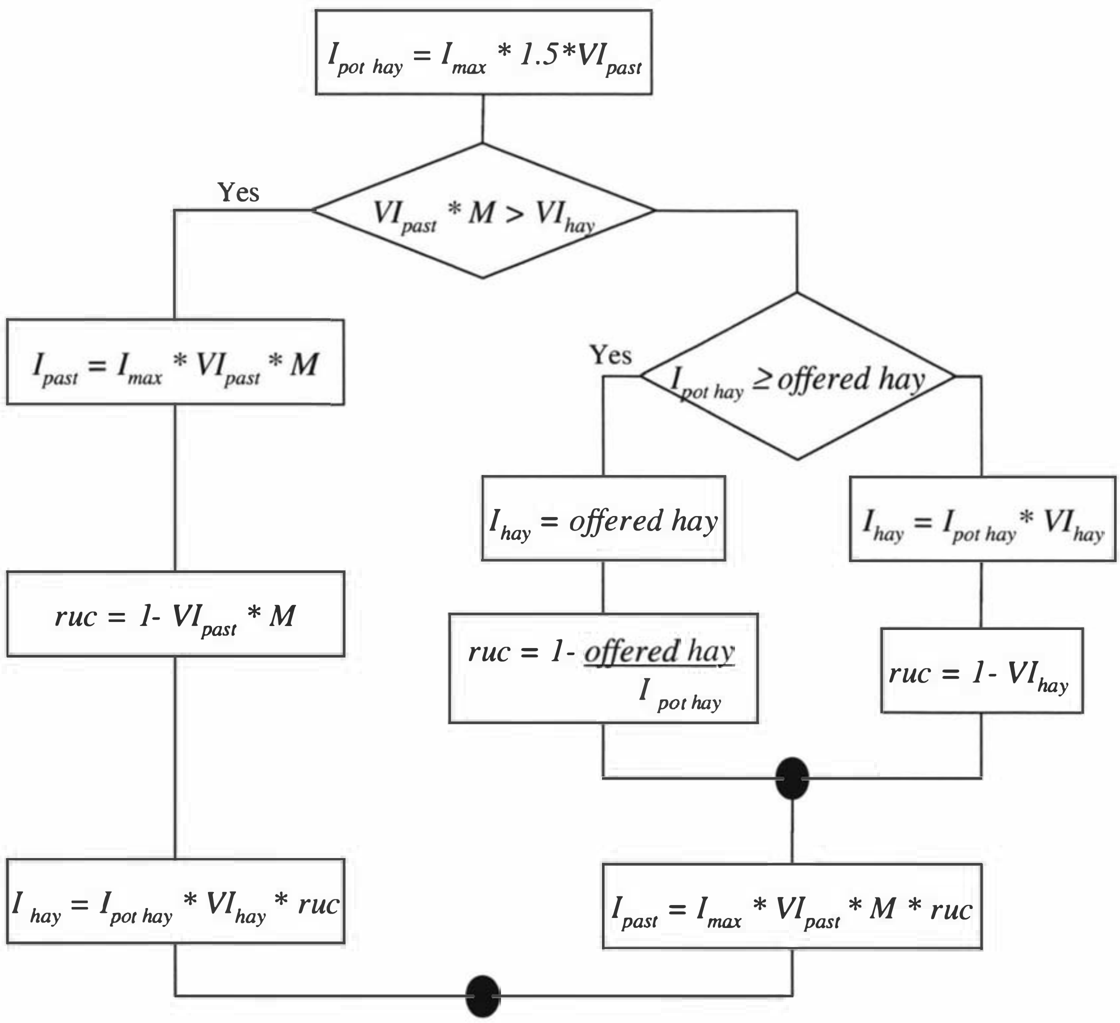

Figure 3.9: Diagrammatic representation of the selective intake between pasture and hay.

Milk intake of a calf (I_{milk}) is calculated as the minimum between milk produced by its mother and its milk intake capacity (Equation 3.39). Note that milk intake is not directly deduced from I_{max}, but through factor YF (Equation 3.19).

Finally, the total amount of metabolisable energy ingested (I_{ME}) is calculated as:

$$I_{ME} = I_{past} * M/D_{past} + I_{hay} * M/D_{hay} + I_{milk} * M/D_{milk}$$ **Equation 3.25**

3.6.3. Reproduction

The present model uses the same relationships as Freer et al. (1997), where the conception rate per cycle depends on the relative size (Z: degree of maturity) and body condition of the cows (Figure 3.10), according to the following equation (Equation 119 in the source):

$$CR = \frac{1}{1+\exp\left(-\left(\frac{2(\ln(0.95)-\ln(0.05))}{b-a}\right)\left(x-\frac{a+b}{2}\right)\right)}$$ **Equation 3.26**

where: $x = Z * BC$
$b = 1$
$a = 0.5$

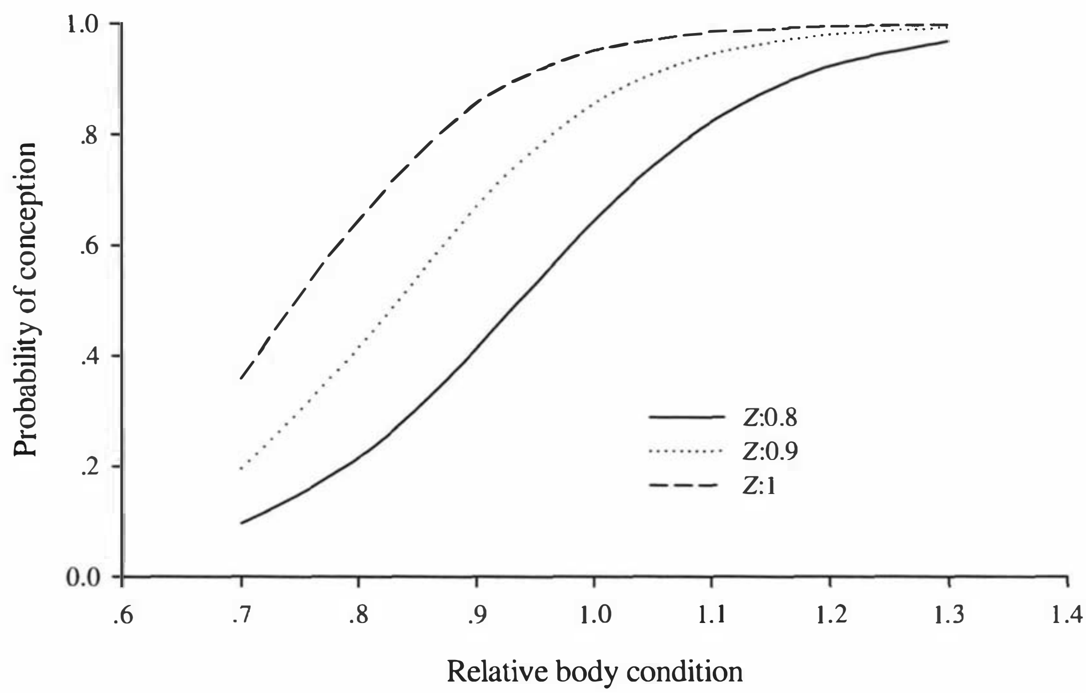

Figure 3.10: Probability of conception in relation to relative size (*Z*) and body condition (*BC*) (Freer et al., 1997).

Cows ovulate exactly every 21 days, and a uniformly distributed random number generator is used on every ovulation event to determine whether the cow conceives or not.

Freer et al. (1997) do not consider any postpartum anoestrous intervals, however periods ranging from 30 to more than 100 days in beef cows have been documented (Morris et al., 1978; Rakestraw et al., 1986; Richards et al., 1986; Warren et al., 1988; Randel, 1990; Wright et al., 1992; Pleasants and McCall, 1993). Analysis of such evidence indicates that the duration of the interval is controlled by the body condition at calving and by the subsequent nutritional level. In the present model it is considered that lactating cows do not start cycling until a minimum body condition (*BC*) is reached. As depicted in Figure 3.11, the *BC* required is assumed to be dependent on the time since calving. The *BC* at the first oestrus is normally not reported in the literature, but it was possible to approximate this value from the information presented in some of the sources consulted (Cantrell et al., 1982; Hanckoc et al., 1985; Wettemann et al., 1986; Wright et al., 1987; Selk et al., 1988; Warren et al., 1988; Houghton et al., 1990; Burges, 2002).

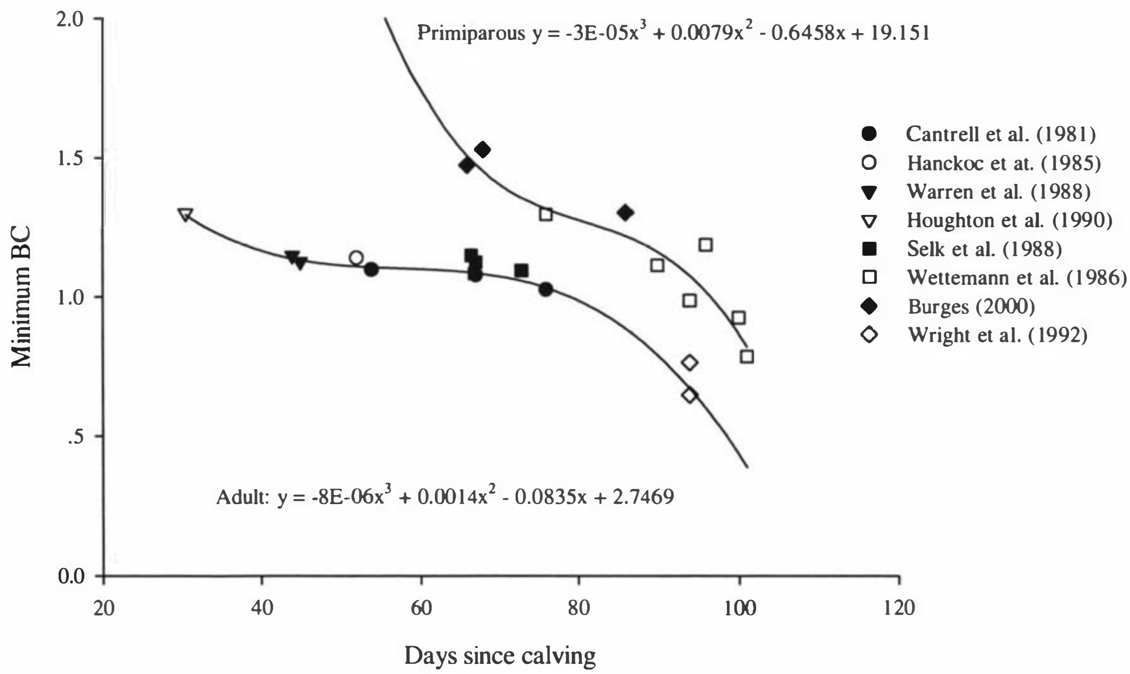

Figure 3.11: Minimum body condition to start cycling as a function of the time since calving. Relationships calculated for adults and primiparous cows using data from the literature.

3.6.4. Mortality

The mortality chance of each animal (*MR*) is calculated according to Freer et al. (1997). *MR* includes a basal rate (C_{D1}) and an additional body condition-dependent component:

$$MR = \begin{cases} C_{D1} + C_{D2} * \max(0, C_{D3} - BC) & \text{if } C_{G13} * EBG < 0.2 * \delta N \\ C_{D1} & \text{otherwise} \end{cases} \qquad \textbf{Equation 3.27}$$

where: C_{D1} = 1.18E-04

C_{D2} = 0.3

C_{D3} = 0.6

C_{G13} = 1.09

BC = relative body condition (see section 3.6.1)

EBG = empty body weight gain (kg/day, see section 3.6.5.4, Equation 3.46)

δN = normal weight gain for the current AGE (see section 3.6.1, Equation 3.14).

The probability MR is calculated and used every day to determine, via a random number generator as described in the previous section, if the animal lives or dies.

3.6.5. Animal state

The animal state is updated daily following Freer et al. (1997). All the equations presented in this section come from this source. Only the partition of the ingested energy (I_{ME}) is considered. Because of the difficulties in obtaining suitable local data, protein and mineral intake and partitioning were ignored.

The total energy ingested (I_{ME}) is partitioned between maintenance, lactation, pregnancy and weight change (gain or loss). The procedure is described below. A list of the central variables associated with the energy partition is showed in Table 3.5.

Table 3.5: Variables, parameters and acronyms used in the calculation of the energy partition.

Parameter	Description	Units
DM	Dry matter	kg
ME	Metabolisable energy	MJ
M/D	ME content in the diet	MJ ME/kg DM
M/D_{past}	ME content in consumed herbage	MJ ME/kg DM
M/D_{hay}	ME content in hay	MJ ME/kg DM
ME_{mant}	ME requirement for maintenance	MJ
ME_{preg}	ME requirement for pregnancy	MJ
ME_{lact}	ME requirement for lactation	MJ
E_{metab}	Basal metabolism	MJ /kg DM
E_{graze}	Energy for grazing	MJ /kg DM
E_{move}	Energy for walking	MJ ME/kg DM
AGE	AGE of the animal	days

3.6.5.1. Maintenance

The energy requirement for maintenance (ME_{mant}, MJ ME/day) includes the basal metabolism (E_{metab}, MJ/day) and the energy requirement for grazing (E_{graze}, MJ/day), and considers the effect of feeding level:

$$ME_{mant} = \frac{E_{metab} + E_{graze}}{k_m} + C_{MI} * I_{ME} \qquad \textbf{Equation 3.28}$$

where: k_m = efficiency of energy use for maintenance
$C_{MI} = 0.09$
I_{ME} = total ME intake (MJ/day)

The parameter k_m is calculated as:

$$k_m = (C_{K1} + C_{K2} * M/D_{solid}) * \phi_{solid} + C_{K3} * \phi_{milk} \qquad \textbf{Equation 3.29}$$

where: M/D_{solid} = ME concentration in the solid diet (MJ/kg, herbage and/or hay)
ϕ_{solid} = proportion of the total DM intake represented by solid fodder.
ϕ_{milk} = proportion of the total DM intake represented by milk

C_{K1} = 0.5
C_{K2} = 0.02
C_{K3} = 0.85

E_{metab} is a function of the metabolic weight ($W^{0.75}$) and the age of the animal (AGE):

$$E_{metab} = C_{M2} * W^{0.75} * \max\left(\exp(-C_{M3} * AGE), C_{M4} * (1 - C_{M5} * \phi_{milk})\right) \qquad \textbf{Equation 3.30}$$

where: C_{M2} = 0.36 (MJ/kg$^{0.75}$)
C_{M3} = 8.0E-5 (d^{-1})
C_{M4} = 0.84
C_{M5} = 0.23
AGE = age in days

E_{graze} has two components: E_{move} which allows for the movements of the animal, and the remaining part related to the digestibility of the forage eaten:

$$E_{graze} = E_{move} + C_{M6} * W * I_{past} * (C_{M7} - DDS) \qquad \textbf{Equation 3.31}$$

where:

$$E_{move} = \begin{cases} \dfrac{W * (1 + \tan(\theta))}{C_{M8} * GDM + C_{M9}} & \text{if GDM} > 100 \\ \dfrac{W * (1 + \tan(\theta))}{C_{M8} * DDM + C_{M9}} & \text{if GDM} < 100 \text{ and DDM} > 100 \\ 0 & \text{otherwise} \end{cases} \qquad \textbf{Equation 3.32}$$

W = base weight (kg)
C_{M6} = 0.006 (MJ/kg^2)
C_{M7} = 0.9
DDS = selected diet digestibility (see section 3.4.4)
C_{M8} = 0.02 (ha/MJ)
C_{M9} = 60 (kg/MJ)
θ = average slope of the grazing area (assumed 0° for the Salado region)
GDM = herbage green dry matter (kg DM/ha)
DDM = herbage dead dry matter (kg DM/ha)

3.6.5.2. *Pregnancy*

The ME requirement for pregnancy (ME_{preg}) is scaled for normal birth weight of the foetus (BW_{fet}, see section 3.6.1) and is a function of the current body condition of the foetus (BC_{fet}) and current age of the foetus (AGE_{fet}):

Equation 3.33

$$ME_{preg} = \frac{BW_{fet} * BC_{fet} * C_{P6} * C_{P7} * \exp(C_{P5} - C_{P7} * AGE_{fet} - C_{P6} * \exp(-C_{P7} * AGE_{fet}))}{k_p}$$

where: $C_{P5} = 345.667$
$C_{P6} = 349.164$
$C_{P7} = 5.76E\text{-}5$
k_p = efficiency of energy use for pregnancy (0.133)
BC_{fet} = foetus body condition (W_{fet}/N_{fet}, see section 3.6.1, Equation 3.1)

The foetus weight increase (δW_{fet}) is obtained by applying a correction factor (CF_{preg}) that accounts for the relative body condition of the mother (BC) to the normal foetus weight increase (δN_{fet}, see section 3.6.1):

$$\delta W_{fet} = \delta N_{fet}(1 + CF_{preg})$$ **Equation 3.34**

where: $CF_{preg} = (BC - 1) * \left(\frac{N_{fet}}{C_{P15} * SRW} \right)$
$C_{P15} = 0.07$

The foetus weight is updated daily:

$$W_{fet(t)} = W_{fet(t-1)} + \delta W_{fet(t)}$$ **Equation 3.35**

3.6.5.3. *Lactation*

The starting point of the calculation of milk production on a particular day of lactation is MP_{max}, which is the potential milk production expressed as the ME value of the milk. The actual milk production is calculated by considering the energy available after accounting for the requirements for maintenance and pregnancy (giving MP_1) and the detrimental effect of a calf not being able to extract all the milk produced (giving MP_2).

$$MP_{max} = C_{L0} * SRW^{0.75} * Z * BC_{birth} * LB * M_m^{C_{L3}} * \exp(C_{L3} * (1 - M_m))$$ **Equation 3.36**

where: SRW = reference adult weight
Z = degree of maturity
BC_{birth} = Body condition of the mother at calving
C_{L0} = peak yield scalar (0.357 MJ/kg$^{-3/4}$)
C_{L3} = shape parameter (0.6)
LB = adjustment factor for previous milk yield (see section 3.6.2.1)
M_m = stage of lactation relative to peak lactation $M_m = \frac{(AGE_{calf} + C_{L1})}{C_{L2}}$

AGE_{calf} = calf's age (lactation day).

C_{L1} = 4 days
C_{L2} = Peak lactation time since calving (30 days)

The amount of energy available for milk production (ME_{xs}) is:

$$ME_{xs} = (I_{ME} - ME_{mant} - ME_{preg}) * C_{L7} * k_l$$ **Equation 3.37**

where: $C_{L7} = 1.17$
k_l = efficiency of energy use for lactation ($k_l = 0.4 + 0.02 * M/D_{solid}$)

The amount of milk (in ME value) that can be produced from ME_{xs} is MP_1:

$$MP_1 = \frac{C_{L7} * MP_{max}}{1 + \exp\left(-C_{L8} * \left(\frac{ME_{xs}}{MP_{max}} - C_{L9}\right)\right)}$$ **Equation 3.38**

where: $C_{L8} = 2.8$
$C_{L9} = 0.5$

The maximum consumption of milk by the calf (MC_{max}) is predicted as a function of metabolic ($W^{0.75}$) weight and age of the calf:

$$MC_{max} = C_{L6} * W_{calf}^{0.75} * (C_{L10} + C_{L11} * \exp(-C_{L12} * AGE_{calf}))$$ **Equation 3.39**

where: $C_{L10} = 0.04$
$C_{L11} = 90$
C_{L12} = 0.42 (kg/kg$^{-3/4}$)

Thus, including the ceiling imposed by the calf's consumption capacity, MP_2 represents the actual yield of milk (as ME for the young):

$$MP_2 = \min(M_{P1}, MC_{max})$$ **Equation 3.40**

The ME used for lactation (ME_{lact}) is obtained by dividing MP_2, which is the gross energy supply, by the metabolizability of the milk (C_{L5}: 0.94) and k_l:

$$ME_{lact} = \frac{MP_2}{C_{L5} * k_l}$$ **Equation 3.41**

Finally, the amount of milk produced in kg of dry matter ($MILK_{DM}$) is:

$$MILK_{DM} = \frac{MP_2}{C_{L5} * C_{L6}}$$ **Equation 3.42**

where: C_{L6} = milk gross energy content (3.1 MJ/kg)

3.6.5.4. *Base weight change*

Base weight change is mainly dependent on the net energy available for this process (NE_g, MJ), the efficiency of energy use for weight gain (k_g), and the energy content of the body weight change (EVG, MJ/kg):

$$NE_g = k_g\left(I_{ME} - \left(ME_{mant} + ME_{preg} + ME_{lact}\right)\right)$$ **Equation 3.43**

In the calculation of k_g (Equation 3.44), the animal state, the diet composition and the amount of metabolisable energy ingested (I_{ME}) are considered. The efficiency for the forage component of the diet (k_{gf}) depends on the day of the year (DOY, through the factor DF) and on its ME content (M/D_{past}). In the original model it also depends on the proportion of legume in the diet, but this is assumed zero in the present model. The efficiency for the supplements (k_{gs}, only hay in this version of the model) is a linear function of its ME content (M/D_{supl}):

Equation 3.44

$$k_g = \begin{cases} k_l/C_{K10} & \text{lactating animals } \& \ I_{ME} < ME_{mant} + ME_{preg} + ME_{lact} \ \text{(i.e. losing W)} \\ C_{K9}k_l & \text{other lactating animals} \\ k_m/C_{K11} & \text{non-lactating animals } \& \ I_{ME} < ME_{mant} + ME_{preg} \ \text{(i.e. losing W)} \\ \phi_{supl}k_{gs} + \phi_{past}k_{gf} + C_{K12}\phi_{milk} & \text{other animals} \end{cases}$$

where: $C_{K9} = 0.95$

$C_{K10} = 0.84$

$C_{K11} = 0.8$

$C_{K12} = 0.7$

ϕ_{supl} = proportion of the total DM intake represented by supplement.

ϕ_{past} = proportion of the total DM intake represented by herbage

ϕ_{milk} = proportion of the total DM intake represented by milk

$k_{gs} = C_{K18}\, M/D_{supl} - C_{K19}$

$C_{K18} = 0.063$ (MJ/kg)

$C_{K19} = 0.308$

$k_{gf} = C_{K13} * \left(C_{K15} * M/D_{past} + C_{K16} * \left(C_{K17} - M/D_{past}\right) * DF\right)$

$C_{K15} = 0.043$ (MJ/kg)

$C_{K16} = 0.01$ (MJ/kg)

$C_{K17} = 15.4$ (MJ/kg)

$C_{K13} = 0.9$

$$DF = \frac{\lambda}{40} * \sin\left(\frac{2 * \pi * DOY}{365}\right) - 1$$

λ = latitude (-38° for Balcarce)

DOY = day of the year (1 Jan = 1)

The energy content of the body weight change (*EVG*) is a function of *Z* (degree of maturity) and relative feeding level in excess of maintenance (*L*):

$$EVG = C_{G6} + 2*(L-1) + \frac{C_{G7} - 2*(L-1)}{1+\exp(-C_{G4}*(Z - C_{G5}))}$$ **Equation 3.45**

where: C_{G4} = 6.0
C_{G5} = 0.4
C_{G6} = 6.7 (MJ/kg)
C_{G7} = 20.3 (MJ/kg)
$$L = \frac{I_{ME}}{ME_{mant}} - 1$$

The empty body weight change (gain or loss) is then calculated as:

$$EBG = \frac{NE_g}{EVG}$$ **Equation 3.46**

In cases where there is a negative energy balance (i.e. $NEg < 0$), *EBG* is negative and the animal loses live weight.

3.7. ISSUES RELATED TO THE BIOLOGICAL MODELS

Several issues were found in implementing the biological models, and these are explained below. The solutions adopted to overcome them are also presented.

3.7.1. Intake model

As was explained in section 3.6.1, order to connect the animal model from Freer et al. (1997) and the pasture model from McCall (1984), an intake model was adapted by combining features from these two sources.

Like many other intake models in the literature (Pittroff and Kothmann, 2001c), Freer et al. (1997) calculate the potential dry matter intake for the animal and then modify it using multipliers to reflect limitations imposed by feed supply. In the present model, the potential intake of the animal (I_{max}, see definition in section 3.6.2.1) is calculated according to Freer et al. (1997), and two multipliers are adapted from McCall (1984).

The formula used to calculate I_{max} (Equation 3.18), is similar to the one recommended by SCA (1990). For a non-lactating adult cow in winter with body condition equal to 1 (i.e. *X*=1, *LF*=1 and *TF*=1) the value of I_{max} would be 0.0175**SRW*. For example, if *SRW* is 400kg (adult weight of the Reserva 6 cows, Mezzadra and Miquel, 1994) then I_{max} would be only 7kg *DM*/day (or 1.75% of *LW*). As a potential intake, 1.75% of *LW* seems rather low as 3% of *LW* is normally regarded as the potential intake for cattle (see for example Campling and Murdoch, 1966; Torres and Boelcke, 1978; DelCurto et al., 1999). The maximum value that I_{max} can reach is 0.0181**SRW* (or 2.1 % of *LW*), at *X* = 0.85.

Furthermore, the multiplicative factors that include the effect of diet quality can only reduce this quantity.

Equation 26 in Freer et al. (1997) estimates the "*relative ingestibility*" (i.e. the proportion of I_{max} that can be achieved) of supplements (RQ_s) as a function of the digestibility of the supplement:

$$RQ_s = 1 - C_{R3} * (C_{R1} - D_s)$$

where: $C_{R3} = 1.7$
$C_{R1} = 0.8$
D_s = digestibility of the supplement.

For more than 30 years in the experimental farm of the Experimental Station INTA Balcarce, pregnant cows have been fed only 6-7 kg DM/day of low quality hay (dry matter digestibility ≈45% and protein content ≈4.9%; J.C. Burges and J. Carrillo, personal communication) from weaning (March) until calving (August – September). During this period, the hay intake rate is about 6 kg DM/day and the cows lose live weight at an approximate rate of 100g per day. According to the Freer equation, RQ_s for this hay would be 0.405. Thus, if I_{max} is 7 kg DM/day then intake would be only 7*0.405 = 2.8 kg DM/day, obviously not enough even for survival. Apparently, 45% digestibility hay is outside the range for which the Freer et al. (1997) model was designed and calibrated. As explained in section 3.6.2.2 (pg 35) a compromise solution had to be adopted, by adding an adjustment factor of 1.5 in the calculation of hay intake in order to increase intake to the levels observed in the Reserva 6 system. It was not possible to determine here where exactly in the intake model the problem laid, so a simple adjustment was applied which does not pretend to be a mechanistic representation of hay intake regulation. Although it produced reasonable results within the range required here, it may not work properly in other cases.

This is just another example of the general low level of development of models for forage intake prediction. Intake regulation of foraging animals is a very complex and unsolved subject. Several reviews have been offered (Ellis, 1978; Weston, 1985; Spalinger and Hobbs, 1992; Gordon and Lascano, 1993; Demment et al., 1995; Ungar, 1996; Galli et al., 1996; Hodgson et al., 1999; Chilibroste, 1999) where it can clearly be seen that a significant lack of scientific agreement exists. A variety of different approaches have been used to try to explain the phenomenon of intake regulation, but none seems to be entirely satisfactory, especially in grazing animals.

A recent series of publications (Pittroff and Kothmann, 2001a,b,c) analysed in detail 19 intake prediction models supposedly designed for practical applications in grazing animals. In comparing the different models, the authors found a remarkably large range of predicted intakes for identical inputs. All the models were severely criticized on the basis of problems with the soundness of the biological and/or mathematical concepts used.

Nonetheless, considering the limitations of the current state of knowledge, it is believed that the intake model used is adequate in the present context, in the sense that it is unlikely to introduce obvious biases in the comparisons. It includes the recognized factors influencing intake (herbage mass, herbage allowance, herbage quality and animal state), and those factors are, in the present model, the result of the interplay between the climate and the management system.

3.7.2. Pregnancy chance model

In the Freer et al. (1997) model no effect of post-partum anoestrus was included because of the difficulty of quantifying it. There is an assumption in the use of that model that the bull(s) will not be put with the cows until about 60 days post-partum, by which time oestrus is usually apparent (Freer, M. personal communication). However, in the Salado region, situations where the bulls are with the cows for periods of 4 to 6 months are still widespread (Rearte, 1998), and in these cases such an assumption would not be valid. For this reason the original model was modified to include an anoestrous period (see Figure 3.11 in section 3.6.3).

Conception rate per oestrous cycle (*CR*), as calculated from Equation 3.26 (see section 3.6.3), can take values near 100%[9]. Normally, the average pregnancy chance per ovulation has been considered to be about 0.6 or 0.7 (Pleasants et al., 1991). It is noteworthy that a *CR* of 0.7 would produce a pregnancy rate of more that 97% in three cycles (i.e. 63 days). The inclusion of an anoestrous period helped to minimize this problem.

3.7.3. Soil saturation and water run-off

In the McCall (1984) model, it is assumed that when the soil moisture is above field capacity all excess water is lost via run-off and deep percolation, and the same is assumed in the present model. However, in the Salado region (also known as the Flooding Pampas), the terrain slopes are almost zero and the soils generally have limited permeability, which means that water may sit on the soil surface for some time (Soriano, 1992). In fact, short term flooding is very common in the area, and substantial floods occur regularly (Sala et al., 1981; Insausti and Soriano, 1987; Taboada and Lavado, 1988; Paruelo and Sala, 1990).

Modelling these aspects of the soil water balance would have required a more sophisticated model, but such a model was not readily available and developing one was beyond the scope of the present project.

[9] The conception rate registered at Reserva 6 for the period 1966 – 1995 was 93.25% on average for a 3-2 month (1966-81 and 1981-95, respectively) mating period (Carrillo et al., 1998)

3.7.4. Pasture model

It is well known that, along with the intake process, an animal also treads and excretes upon the pasture producing different levels of damage (Brown and Evans, 1973). Sheath and Boom (1997), for example, estimated amounts of trodden herbage for a single grazing ranging from 240 to 340 kg DM/ha, depending on the stocking rate and the management used. In the McCall (1984) model, the animals consume a proportion of the pasture, but do not cause any damage to the uneaten herbage. There have been few attempts to model the consequences of animal treading on pasture production, for example the work reported by Finlayson et al. (2002) in New Zealand. The model proposed by these authors could be suitable for incorporation into the present model in the future, but a considerable amount of local data would be required for the necessary calibration. Treading losses were not considered in the present study, which may have produced overestimations of the overall productivity of the system.

While the McCall pasture model included mechanisms to reduce herbage growth after lax grazing (via parameter *CGRF* in Equation 3.8, in pg. 25), this effect disappears after the next hard grazing. The McCall model does not consider the long term degradation effect of repeated under-grazing (on production potential and herbage quality). Overgrazing effects are not taken into account either. Over and under-grazing are both undesirable results of "bad" management strategies. A good grazing management strategy would have a better chance of avoiding or reducing the frequency of these problems. These deficiencies in the model can generate biases in the evaluation of the different policies, for example hiding recognised benefits of forage conservation in maintaining herbage quality (Mayne et al., 2000).

In the calculation of the parameter *LGF*, McCall imposed a maximum limit of 3000kg DM/ha on *PGGC* (post grazing green cover) was used (McCall, 1984, pg 127 footnote 9). The purpose of this limit seems to be to ensure that *GCRF* remains positive. If this is the case, the limit should be 2991kg DM/ha, otherwise *GCRF* can still be negative in vegetative swards. In the current model, a minimum value of zero was imposed on *GCRF* (see Equation 3.8). However, still the model would not behave well in lax grazing, with residuals higher than this values. Note that if, for any reason, a paddock is left with a residual of more that 2991 kg DM/ha, *GCRF* and *LGF* would be zero, therefore there would not be any herbage growth until the next grazing event.

The factor REF in Equation 3.6 is intended to represent seasonal changes in the pasture physiology (Parsons and Chapman, 2000). However it has been demonstrated that management has a profound effect on the amount and in the seasonal pattern of herbage growth (Johnson and Parsons, 1985; Orr et al., 1988). For example, under infrequent cutting (e.g. of paddocks for hay making), gross production of herbage benefits considerably from reproductive development, which may not happen, or may happen to a lesser extent, under more frequent defoliations (e.g. under grazing). As these observations suggest, the approach used by McCall (1984) may not be completely satisfactory in this situations.

3.7.5. Hay losses

Two aspects of haymaking are simplified in the present study: field losses and loss of quality during storage. Because of the lack of appropriate bibliographic information, constant proportional values for both of these, taken from Barry et al. (1980), were used in the current model (see section 3.4.5).

On a real farm, the loss of hay in the field would be related to the prevailing environmental conditions during the drying period. In New Zealand, the period of field drying normally takes 2-5 days, but under adverse conditions it can be as long as 14-20 days (Barry et al., 1980), increasing field losses considerably. The same would be true for the Salado Region. This risk factor reduces the farmer's degree of freedom to decide when to cut the pasture and when to make hay, as the farmer must consider the current and forecast weather conditions. In certain years, bad conditions may impose serious delays on the hay making process, forcing harvest late in the season. The larger the area that is dedicated to haymaking on the farm, the greater is the risk of losses and the lower the chances of harvesting hay of good quality. Apart from lack of published data, another difficulty in simulating field losses is that farmers do not make blind decisions when choosing when to cut pasture. A farmer would not cut when it is raining, a storm is approaching or bad weather is forecast. Therefore, to make a realistic simulation, the model would not only be required to simulate field losses according to weather conditions, but also involve weather forecasting (in the decision making) with the associated probabilities of error.

In the case of hay storage, dry matter and quality losses are affected by the moisture content of the material at baling and by the storage method. If the hay bales are stored outside, as is normally the case in the Salado Region, the climate will also have a strong influence. In systems where high quantities of hay are produced, it may happen that not all the hay harvested in one year is used, and the surplus can be sold or saved for the next year. In these situations an accurate account of the losses would be more critical.

3.7.6. Validation

The pasture model was originally calibrated and tested by its authors using grazed pasture data in New Zealand (McCall and Bishop-Hurley, 2003), but preliminary tests against Argentinean data (see Appendix, section 3.9) permit reasonable confidence that it also approximates the response of pastures to different climatic conditions. It should be noted however that the Argentinean data came from controlled short term (3 to 5 months) cutting trials and the results might not represent the production (and seasonal patterns) of pastures under grazing in the long term (Orr et al., 1988). Also, the model needs to be calibrated for other soil types in the Region.

The farm model as a whole produced reasonable results when compared with a real system. As will be discussed in Chapters 5, the model was used to simulate a real cow-calf farm at the Balcarce Research Station (Reserva 6, introduced in Chapter 1). When using similar stocking rates (i.e. 1.7 cows/ha) and management policies as in Reserva 6 the simulated LW production showed good agreement with real data reported by Carrillo et al. (1998) for the period 1966-1995 (271±40 vs. 272±31 kg LW/ha/year, real and simulated respectively). The maximum stocking rate achieved in the Reserva 6 system was 2.54 cows/ha, with a liveweight production of 360 kg/ha/year (Burges et al., 1998), and this level was sustained for 3 years (1997-2000). For such a stocking rate, the model would predict a production level of about 370kg LW/ha/year, indicating a good agreement (less that 3% overestimation).

Validation is often strictly regarded as evaluating a model in its ability to predict observational data (Oreskes et al., 1994). However, it is generally impossible to validate a complex dynamic models in this strict sense due to the limited observation of the system dynamics (Reynolds and Ford, 1999). The model produced results that were in line with some historical informations available, but this would never be considered enough if this was an absolute prerequisite to use the model. Furthermore, one of the main aims in farm-system models is to simulate scenarios that have never been observed in reality before (e.g. a new management strategy, possible climate change). Validity is seen here in a broader sense as usefulness for purpose (Barlas, 1996). That is, validation is the process of showing that the model is justifiable and appropriate for its purpose (Rykiel, 1996). Being a research model, not intended to be used for decision making, such usefulness has to do with the ability of the model to simulate a broad range of management strategies and generate meaningful information in terms of the long term dynamics of cow-calf systems. Building confidence in the usefulness of a model is a gradual process (Barlas, 1996), and has been a continuous focus throughout this research.

3.8. DISCUSSION

The objective of this project is to study different production strategies at the whole farm level. A model was built with the main emphasis on the simulation of the farm management. The required bio-physical models, as described in this chapter, were taken from the literature and modifications were only introduced when absolutely necessary.

The issues discussed in section 3.7 are not easy to resolve, and it was necessary to progress to the following stages of the project by adopting ad-hoc solutions in most cases. It was not possible to seriously improve any of these aspects in the models with the available published information in time available.

3.9. APPENDIX: PASTURE MODEL TESTING

The pasture model was tested against data from several experiments carried out in the Experimental Research Station, Balcarce-INTA with *Thinopiron ponticum* pastures. The experiment reported by Fernández Greco et al. (1998) was conducted in autumn, and the other experiments in spring (Orbea and Villar, 1972; Fernández Greco et al., 1996; Fernández Greco et al., 1997; Piaggio et al., 1998).

In all the other cases, except Orbea and Villar (1972), the trials were conducted following the Anslow and Green (1967) method involving sequential cutting. The cutting dates were not reported, so simulated experiments were created with 5 paddocks cut every 21 days in staggered sequence for the purpose of comparison. In the case of Orbea and Villar (1972) the pasture was cut on 20/9/1971 and then allowed to grow for 91 days. As the exact cutting days were provided, the model was set to imitate this. As Figure A 3.1 shows, there was close agreement between the observed and the predicted data in terms of total accumulation of dry matter. The experimental data used in the comparison correspond to treatments without nitrogen fertilization. Real weather data for the corresponding periods, collected at the Balcarce-INTA weather station 2 kilometres away from the experimental sites, where used for the simulation.

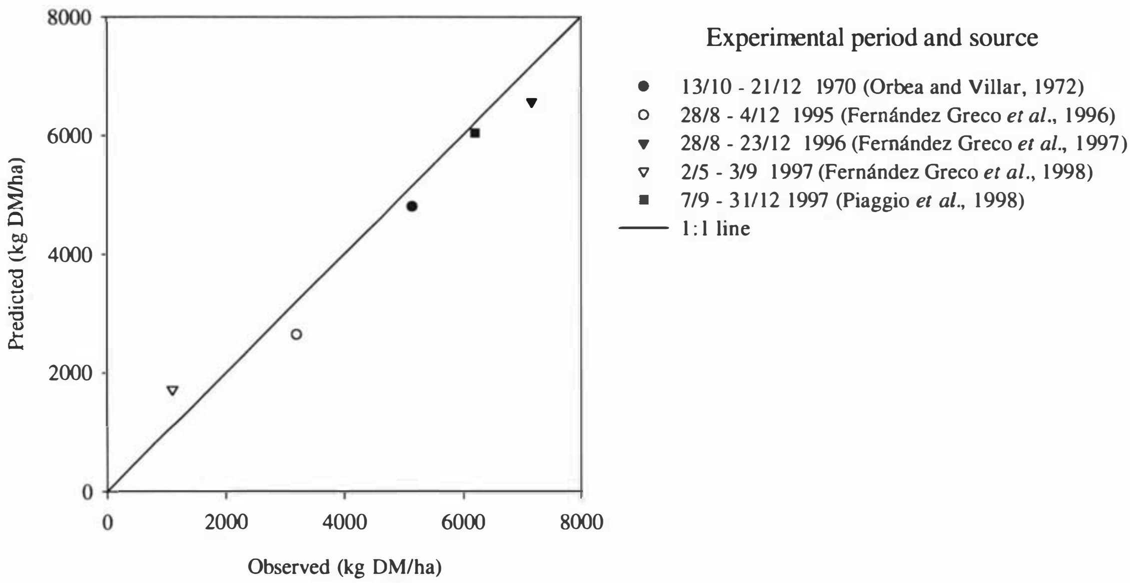

Figure A 3.1: Observed vs. simulated herbage dry matter accumulation for different periods. The field data were obtained from cutting trials following the Anslow and Green (1967) method at the Research Station of INTA Balcarce, Argentina (37° 58′ South). In all cases, the observed value correspond to agropiro (*Thinopirum ponticum*) swards fertilized with phosphorus only.

CHAPTER 4

PRELIMINARY EXPERIMENTS

4.1. INTRODUCTION

Improving system understanding is a frequently stipulated reason for building simulation models. Understanding the system (and the model outputs) is a prerequisite before engaging in policy analysis, thus testing and experimenting with a model constitute key elements in the modelling process (Sterman, 2000).

Preliminary experiments are a way of testing a model. By using the model under different circumstances, it is possible to gain confidence that the model is correctly implemented (internal validity, as described by Rykiel, 1996). Within this project, the third party models used to represent the bio-physical components of the farm were mostly not modified. For this reason, during the preliminary experimentation stage, attention was mainly concentrated on testing the specific components of the model, for consistency of the rules and reasonableness of the result. Also, some programming errors may only appear when using the model to simulate a variety of situations (Rykiel, 1996; Sterman, 2000).

This chapter describes three preliminary experiments performed with the model, which provided particularly valuable experience for designing the final round of experiments that will be described in chapters 5 and 6. The experiments presented next served three purposes, 1) to build confidence in the model by studying its behaviour under varied conditions, 2) to gain a better understanding of pastoral cow-calf systems and 3) to explore possibilities for improvements in the model and ways of analysing model outputs.

4.2. EXPERIMENT 1: SIMULATION OF THE EFFECT OF CHANGING CALVING DATE IN COW-CALF SYSTEMS OF THE SALADO REGION (BUENOS AIRES PROVINCE)[10].

A dynamic simulation model is being developed with the objective of studying a variety of management questions in beef suckler systems of the Salado Region. Preliminary results of a particular study with the model are presented to illustrate the potential use of the model. The simulation adjusts the state of each paddock daily, based on the climate, the state of the paddock at the start of the day and grazing during that day. Pasture growth, senescence and decay are driven by daily net radiation, air temperature and soil moisture. Similarly, each animal's state is updated daily in response to its initial state, animal's potential, energy intake and management rules. Herbage intake is calculated from herbage mass and green/dead ratio and is affected by the quality and quantity of the hay offered. Management strategies are specified using decision rules entered by the user. Animals are grouped into herds, and paddocks are grouped into blocks and most management rules are specified at herd or block level. These rules are checked every day and can trigger a variety of management actions: sell cows; wean cows; feed hay; move a herd to a new paddock; mate a herd; close paddocks; release paddocks; make hay; assign cows to herds. There are also rules to reassign paddocks to the different herds. Those actions represent the most important control points that a manager can use to operate the farm. Simulating performance at the level of individual animals and paddocks, but specifying management rules at the herd and block levels allows simulations of farms of different sizes and the representation of multiple alternatives for grazing management. Because management rules are not embedded in the code, but are specified through a user interface, a wide range of management strategies can be simulated and compared. The model was used to study the possible impact of changes to the mating period in a winter calving herd. As a base for the comparisons, a simulated farm was created that approximately imitates the management and general structure of the experimental cow-calf farm of INTA-Balcarce (Reserva 6) ("A"). The effect of delaying the breeding season 15 ("B") and 30 ("C") days was analysed. In B and C, the date for weaning and culling were delayed by the same amount of time (Table 4.1).

Table 4.1: Dates for mating, calving, weaning and culling for the three alternatives.

	A	B	C
Mating	1/Nov-31/Dec	15/Nov-15/Jan	1/Dec-31/Jan
Expected calving	13/Aug-12/Oct	27/Aug-27/Oct	12/Sep-12/Nov
Weaning and Culling [1]	1/Mar	15/Mar	31/Mar

[1] Old, non-pregnant and dry cows.

A 100ha operation with 40 paddocks was simulated. The model was run over 40 consecutive years for each scenario. During the first 10 years the average climatic year was used to initialise the system. For the remaining 30 years, real weather data (series

[10] This section has been published in its entirety as: Romera, A. J., Hodgson, J., Morris, S. T., Stirling, W. D., and Woodward, S. J. R., 2002. Simulation of the effect of changing calving date in cow-calf systems of the Salado region (Buenos Aires Province). Revista Argentina de Producción Animal 22:341-342.

1970-2000) from INTA-Balcarce were used. Only the last 30 years were considered for the comparisons. In all the cases, 35 replacement heifers were retained each year and the target cow number was 170 head (cows plus heifers) at the beginning of autumn. Neither animals nor fodder were imported to the farm. The differences observed between the alternatives were very small (Table 4.2), not being greater than 3% in any of the variables analysed. The variability between years was also not affected. Conclusions were essentially the same at stocking rates 10% and 20% higher than the original.

Table 4.2: Means (±SD between years) and 95% confidence interval for the differences (CI) of the simulated outcomes for the three alternatives.

	A	B	C	CI(B–A)	CI(C–A)
Pregnancy rate cows	0.956±0.020	0.957±0.018	0.959±0.015	-0.008 to 0.010	-0.006 to 0.011
Pregnancy rate heifers	0.958±0.035	0.946±0.051	0.929±0.180	-0.035 to 0.010	-0.096 to 0.037
Weaning weight (kg)	164.1±9.8	163.2±9.1	160.8±9.8	-3.23 to 1.41	-6.39 to -0.36
Total sales (head/year)	126.3±6.0	126.6±6.3	125.0±14.7	-1.42 to 2.02	-6.12 to 3.52
Live weight Production (kg/ha/year)	289.4±32.3	289.3±32.2	284.1±44.4	-5.98 to 5.80	-16.37 to 5.73

Under the present conditions, the results suggest that when the appropriate management variables (i.e. weaning and sale dates) are adjusted accordingly, changing the calving period, even by as much as a month, would have little effect on the productivity of a cow-calf system.

4.3. EXPERIMENT 2: MODELLING THE CONSEQUENCES OF DIFFERENT REPLACEMENT POLICIES ON THE LONG TERM PRODUCTION VARIABILITY IN COW-CALF SYSTEMS [11].

Abstract

In cow-calf systems, the replacement policy is an important part of management since it shapes the age structure of the herd. This section explores the dynamic consequences of different replacement policies on the production outcomes of pastoral cow-calf systems. Three different replacement policies were analysed using a simulation model of a cow-calf farm. The model is dynamic, mechanistic and climatically driven, and implements management strategies with flexible rules. Different cow replacement policies can produce different patterns of oscillation in key farm outputs as a result of cyclical behaviour in the age structure of the herd. Consequently, variations observed in the productivity of cow-calf systems may not only be the result of environmental influences but can also be caused by the interaction between management strategy and the evolving state of the system. Complex interactions between the environment and the management strategy can also be present, and the differences between strategies were shown to be dependent on the environmental variability being simulated.

4.3.1. Introduction

The productive life of a cow can range from one to more than fifteen years, depending on the conditions under which the animal was reared, and as a result herds usually contain a wide distribution of ages. This means that replacement and culling policies shape the age structure and hence the long term stability and productivity of the herd. Furthermore, as with many other agricultural decisions, the consequences of replacement and culling decisions may be felt for several years, so analysis of these policies is a dynamic problem (Monti et al., 1999), and cannot be understood by static analysis.

Stable herds with constant numbers of cows and age compositions have been examined (Azzam and Azzam, 1991; Tess and Kosltad, 2000; Smeaton and Vivanco, 2001), but this stability is rarely observed on real farms. For example, external influences such as climatic and economic fluctuations, or particular management decisions, can result in changes to the herd's size or age structure that have consequences over several years. Although there has been considerable interest in replacement policies (e.g. Smith, 1973; Gartner, 1982; Kristensen, 1992), their dynamic aspects have largely been ignored. In

[11] This section has been submitted in its entirety as a paper to Agricultural Systems.

Acknowledgments: Many of the ideas presented in this section were discussed in a workshop held at Massey University on 14 March, 2002. Many thanks to the participants: Gavin Sheath and Duncan Smeaton (AgResearch Limited); Kevin MacDonald (Dexcel Limited) and Tony Bywater (Lincoln University).

particular, results from consecutive years are usually averaged out, obscuring potentially valuable insights into system dynamics and variability.

The study of dynamically complex problems requires observation of the system over long time horizons. According to Sterman (2000), the time horizon should be long enough to capture the delayed and indirect effect of the potential policies. The same author notes the human tendency to think of cause and effect as being local and immediate, but points out that often cause and effect are distant in time and space. Furthermore, most unintended effects of decisions are the result of feedbacks with long delays, so that the effects are far removed from the original problem symptom or point of decision.

The objective of the study reported here was to explore the long term dynamic consequences of different replacement policies. In particular, the study aimed to estimate the time horizon over which significant biological and economic differences due to alterative polices become evident, and to determine whether particular kinds of decision rules produce more or less severe oscillations in year to year farm performance. This section shows how these simulations gave better understanding of the dynamics of the system, and improved a specific part of the management modelling.

4.3.2. Materials and methods

A simulation model was used to assess the long-term variability of animal numbers and farm production under different replacement policies. In a self-replacing herd, the replacement policy involves two different components, the culling of adult cows and the retention of new heifers as replacements. Culling can take place for many reasons such as disease, low productivity, reproductive failure or age (Gartner and Herbert, 1979; Monti et al., 1999). In order to focus attention on the strategic aspects of the problem, only reproductive failure and age were considered in the present study.

4.3.2.1. Model

The model used to simulate the cow-calf farms has been described in detail by Romera et al. (2004). The model is defined and programmed in an object-oriented (OO) manner (Coad and Yourdon, 1991). In an OO model, program "classes" represent different types of real-world entities. There may be several instances of each class called "objects", each with its own "attributes" that describe individual characteristics.

The biophysical components of the model are represented by the *cow*, *pasture* and *soil* objects (Sherlock et al., 1997). The cow submodel was adapted from Freer et al. (1997), while the pasture submodel was based on McCall (1984). Herbage intake was calculated using an adaptation of McCall (1984) that allowed the estimation of the intake for individual cows in a herd, and the soil submodel was based on Allen et al. (1998). Comprehensive details of the bio-physical models are presented in the original publications (and also in Chapter 3), but note that animal performance is dependent on nutrition; and herbage growth (and senescence) is dependent on weather conditions, soil water content and current green herbage mass (which determines how much of the incident light is intercepted).

The model represents the organization of the farm as a number of herds (groups of cows), paddocks (areas of land with a pasture and a soil) and blocks (group of paddocks to be used by a particular herd). To simulate a farm system with the model, the user must specify:

1. *The structure of the farm.* Total area of the farm, total number of paddocks, names of the herds and the number of paddocks assigned to each herd. The simulations described in this section are based on a farm with a total area of 100 ha divided into 40 paddocks of equal size and three herds (see section 4.3.2.2 below).

2. *Initial state of the farm.* The model can assume a default initial farm state from the number of cows per herd, maximum and minimum herbage mass, maximum and minimum proportion of green material and soil water content entered by the user. Alternatively, a saved farm state from another simulation can be used to initialise the program.

3. *The weather data.* The weather is specified as the mean air temperature, minimum and maximum air temperature, rain, global radiation and wind speed for each day during the simulation. Actual weather records can be used or weather can be randomly generated by selecting years at random from a pool of such weather records.

4. *The management strategy.* Farm management is represented by a set of decision rules entered by the user to simulate the desired type of management. The management rules take the form: "**if** a certain condition is true **then** a specific action is taken". The rules can trigger different types of actions, as explained in Romera et al. (2004), and are applied daily during the simulation.

The state of the model is updated daily during the simulation. Other than weather, the only stochastic components in the model (in the class *Cow*) are conception and deaths. In each reproductive cycle during the mating season each cow has the chance of conceiving, and death can occur at any time. The probabilities are age and body condition dependent and are calculated according to Freer et al. 1997 (details are given in Chapter 3) Apart from this, the model is completely deterministic, so that its outputs are primarily the result of the initial farm conditions, weather inputs during the simulation sequence, and the farm management strategy.

4.3.2.2. Farm management strategy

A "base" management strategy was created, which defines the decisions rules common to all simulations. This strategy represents the management currently applied in an experimental farm operating at the INTA-Balcarce Research Station ("Reserva 6"), improvement of which was one the objectives of the project. Various strategies were then defined by modifying the replacement policy rules relative to this base strategy. The complete set of decision rules is detailed in Appendix (Table A 4.1, section 4.6). The simulated farm contained three herds:

Herd 1: heifers from weaning to first pregnancy evaluation in March.

Herd 2: grazing cows from first pregnancy on.

Herd 3: adult cows (after first weaning) on hay only. The cows were maintained in this herd from weaning until calving, until 1 October, or until the farm run out of hay, whichever occurred first.

Ten paddocks were initially assigned to herd 1, 29 to herd 2 and one to herd 3, but these numbers could dynamically change during the simulation as a result of management actions.

All adult non-pregnant cows (from the second mating onwards) and old cows (cows over 11-12 years old) were culled from the farm at the beginning of the autumn (in March). There were also rules to sell cows when "emergencies" arose, that is, at very low average farm pasture covers or at low body condition scores (see Table A 4.1 in Appendix, section 4.6: rules R 5, R 6, R 12, R 19 and R 25). The system produced its own replacements and there were no purchases of animals from outside the farm.

4.3.3. Replacement policy analysis

This study (section 4.3) analyses how a herd adjusts the cow number when the actual number is below the desired target. There are two aspects in this adjustment: a) it takes several years for cow numbers to increase to near the target number, and b) even after the target cow number is achieved, the age distribution of the herd will be affected for several further years, with consequent longer-term impact on farm outputs. Both aspects are influenced by the replacement strategy. The study particularly examines the longer-term consequences of the replacement strategy.

4.3.3.1. Replacement Policy A: Variable number of replacements

Under the first replacement policy tested, cows were culled in March after 9 calvings (10 breeding seasons, i.e. 11-12 years old), the age at which the teeth of many cows in the Salado region have become visibly worn as a result of feeding low quality forages. In order to increase the number of breeding cows as quickly as possible from any shortfall, enough replacement heifers were retained each year to reach the target cow number (170 adult cows and heifers at 1 July). That is, the number of replacement heifers is calculated as:

$$R = T-N$$

Where N is the actual cow number (cows plus heifers) left after reproductive and age-culling in March, and T is the target number.

Applying systems dynamics analysis (Sterman, 2000), herd dynamics can be modelled as shown in Figure 4.1. In such a model, the replacement policy of a beef cow herd is viewed as an inventory control system, where the total cow number is the "inventory" to be controlled. In the case of Policy A (as described above), the cow number is adjusted by a feedback loop (RE) to the number of heifers retained as replacement each year. That is, the inventory is controlled through the inflow of heifers. Because of the delay between a heifer entering the herd and the same animal becoming old, this system would be expected to produce oscillations, especially after an increase in the target cow number.

This strategy tries to increase the herd size as quickly as possible. The large number of replacement heifers in the initial years will result in large numbers of cows culled and replaced by new heifers ten years later. Although the herd size will recover quickly, the age distribution may therefore be unstable for a period afterwards.

4.3.3.2. Replacement Policy B: Constant number of replacements

Under this policy, a constant number of heifers ($\underline{R}$) is kept each year. With Policy A, a large number of replacement heifers retained in one year results in a large number of culled cows and hence a large number of replacement heifers ten years later. The resulting cycles might be expected to be damped if a constant number of heifers were retained, rather that a varying number to match any deficit in herd size.

In a stable herd with $\underline{T}$ cows, that retains $\underline{R}$ new heifers each year and eliminates old cows after $\underline{n}$ mating seasons (10 in this case) or after a reproductive failure, the expected outflow of cows (O) should be:

$$O = \underbrace{(T - R) * (1 - k)}_{\text{Open cows}} + \underbrace{R * k^{n-1} * (1 - d)^n}_{\text{Old cows}} + \underbrace{T * d}_{\text{Deaths}} \tag{1}$$

where $\underline{k}$ is the rate of reproductive success (expected pregnancy rate), and $\underline{d}$ is the expected death probability in cows. In a stable herd, $\underline{O}$ must be equal to $\underline{R}$ (i.e., the inflow to the pool of cows), so equation 1 can be solved for $\underline{R}$:

$$R = \frac{T * (1 - k + d)}{-(k^{n-1} * (1 - d)^n) - k + 2} \tag{2}$$

Policy B then keeps $\underline{R}$ heifers each year (e.g., $\underline{R}_{(k=0.95,d=0.03,T=170)} \cong 23$ or $R_{(0.95,0,170)} \cong 20$) and culls non pregnant and old cows as described for Policy A.

Using the inventory control analogy (Figure 4.1) the deficiencies of this policy become clear. In order to avoid oscillations, a feedback loop (RE) was eliminated, reducing the adaptability of the system. Herd size will obviously take longer to recover with this strategy, but it should result in a stable age distribution after 10 years.

4.3.3.3. *Replacement Policy C: Limited age-cullings*

Another cause of cyclical behaviour in Policy A was the fixed age for culling cows; if they are culled at age $\underline{n}$, there will be an n-year cycle. A second possible way to dampen oscillations is therefore to control the outflow of cows, by limiting culling in order to avoid peaks in the number of culled cows $\underline{n}$ years after any peak in the number of replacements. Policy C placed no limit on the number of replacements, but restricted the number of age-culled cows to a number not greater than $\underline{AC}$, which is the number of age-culled cows that a stable herd would have each year:

$$AC = \underbrace{R * k^{n-1} * (1-d)^n}_{\text{Old cows}} = \frac{T * (1-k+d)}{2-k-(k^{n-1} * (1-d)^n)} * k^{n-1} * (1-d)^n$$

This value (e.g. $\underline{AC}_{(0.95,0.03,170)} \cong 11$ or $\underline{AC}_{(0.95,0,170)} \cong 13$) was used as a restriction for the number of cows culled in any year, with any excess cows of age $\underline{n}$ or higher being allowed to stay at least one additional year.

One advantage of Policy C over Policy B is that the herd size builds up more quickly if the initial cow number is small, since more replacement heifers can be retained in the initial years.

In this policy the second feedback loop (CU, Figure 4.1) to the outflow of cows is improved by incorporating a limit (AC) to the number of age-culled cows. With this strategy, the herd size should recover as quickly as with strategy A, but without the sudden increase in age-culling after 10 years.

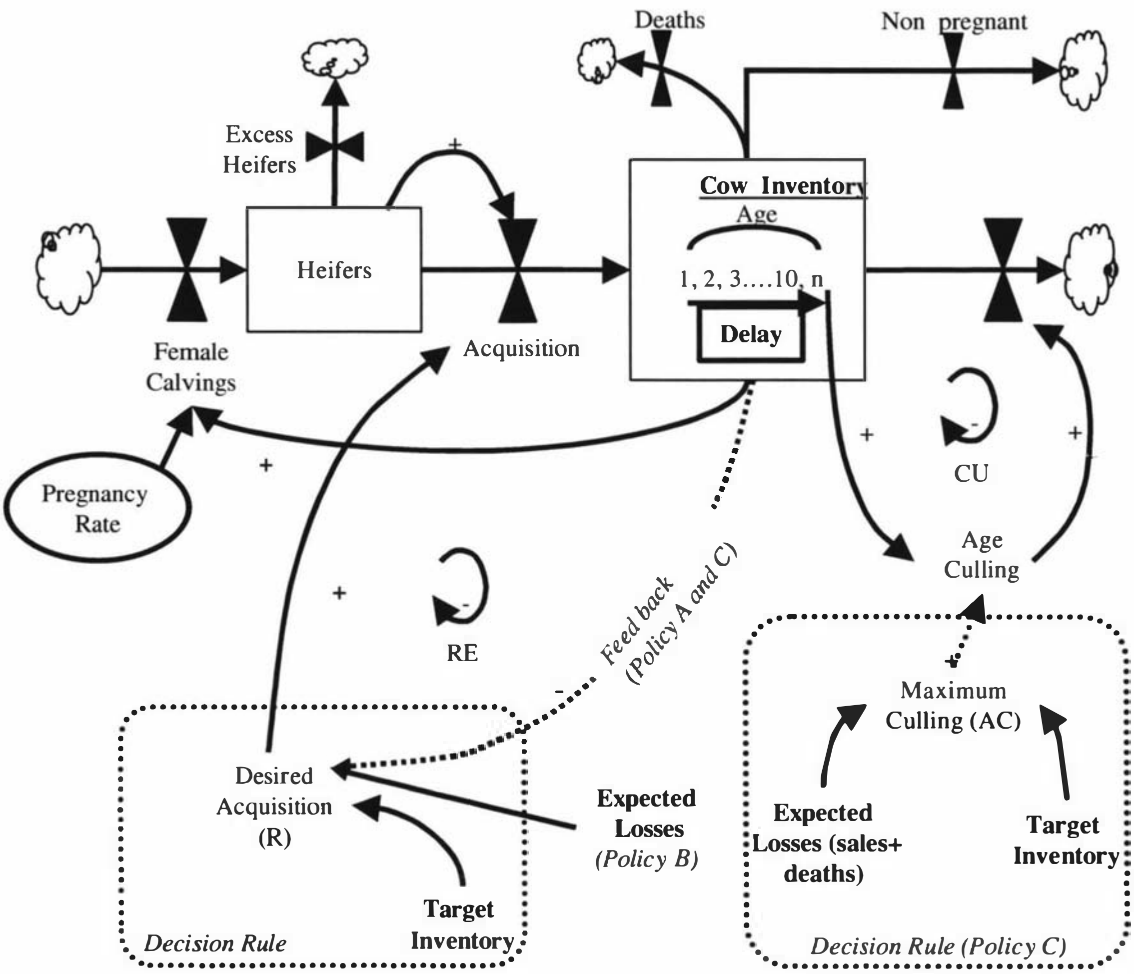

Figure 4.1: Stock and flow diagram for the control of the cow number in the herd.

4.3.4. Policy illustration

To illustrate the effects that the use of the different replacement policies would have on the system, the model was run for 50 years, repeating an average climatic year. This reduced random variation and focused attention on the non-stochastic dynamic behaviour of the system. As initial conditions, the simulation started with 100 cows (70 cows below the target cow number) with ages ranging from 1 to 10 years (Figure 4.2). It was also assumed that there were no deaths in the herd. Figure 4.3 shows the period of stock build up for the three strategies. Strategy A and C were, as expected, much quicker in reaching the target cow number than C (Figure 4.3 a), by retaining a larger number of heifers during the first years (Figure 4.3c). Note, however, the sudden increase in policy A in the number of age-culled cows, from year 12 onwards (Figure 4.3b). Policy A, and to a lesser extent Policy C, generated unbalanced age structures in the herd Figure 4.4). The observed oscillations can be ascribed to the structure of the replacement policy rules, particularly in Policy A, the forced culling of animals at age 10 years.

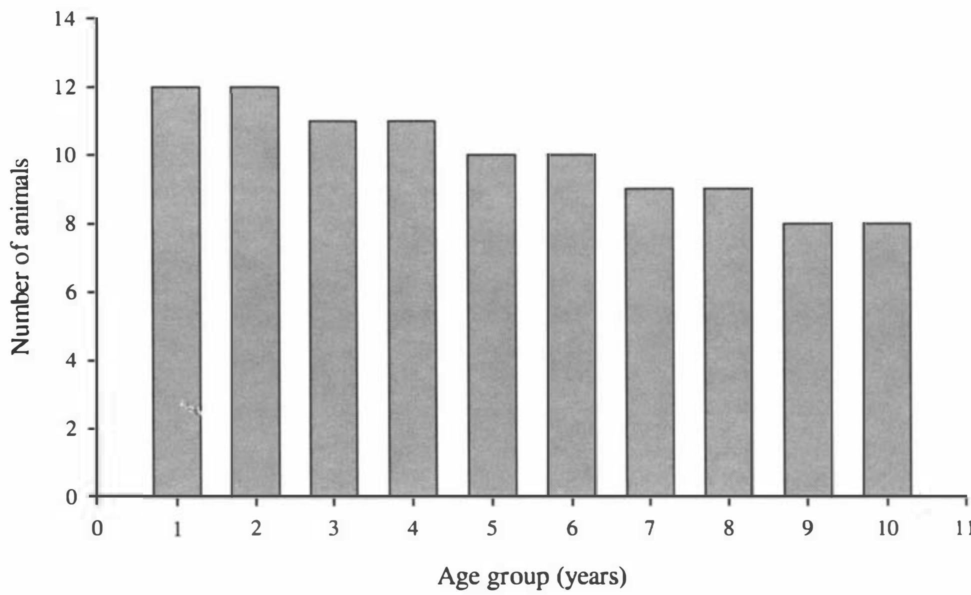

Figure 4.2: Cow age distribution in the initial herd.

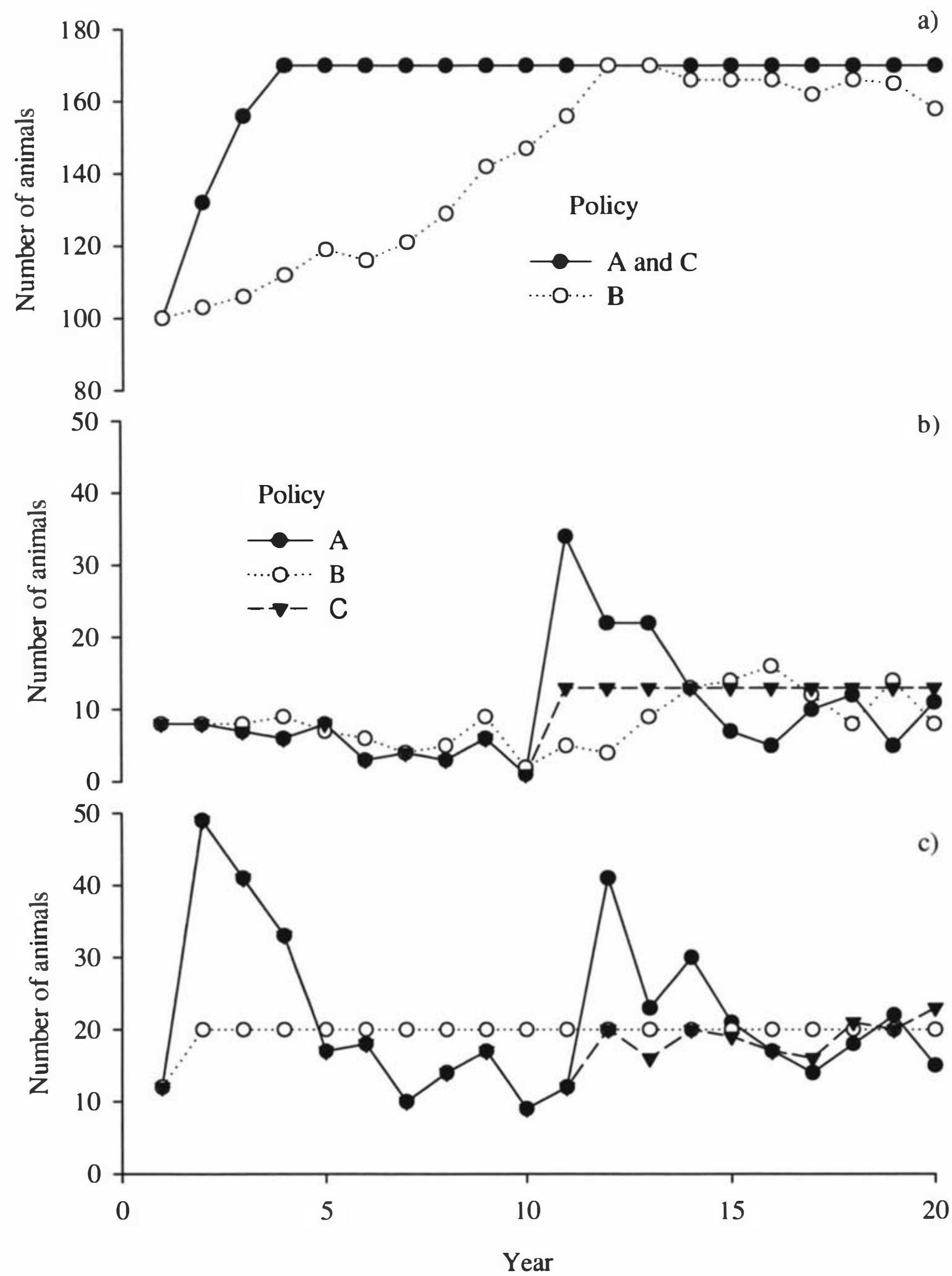

Figure 4.3: Total cow number (a), number of age-culled cows (b), and number of replacement heifers (c) for policies A, B and C. Using average weather data and starting from a low cow number.

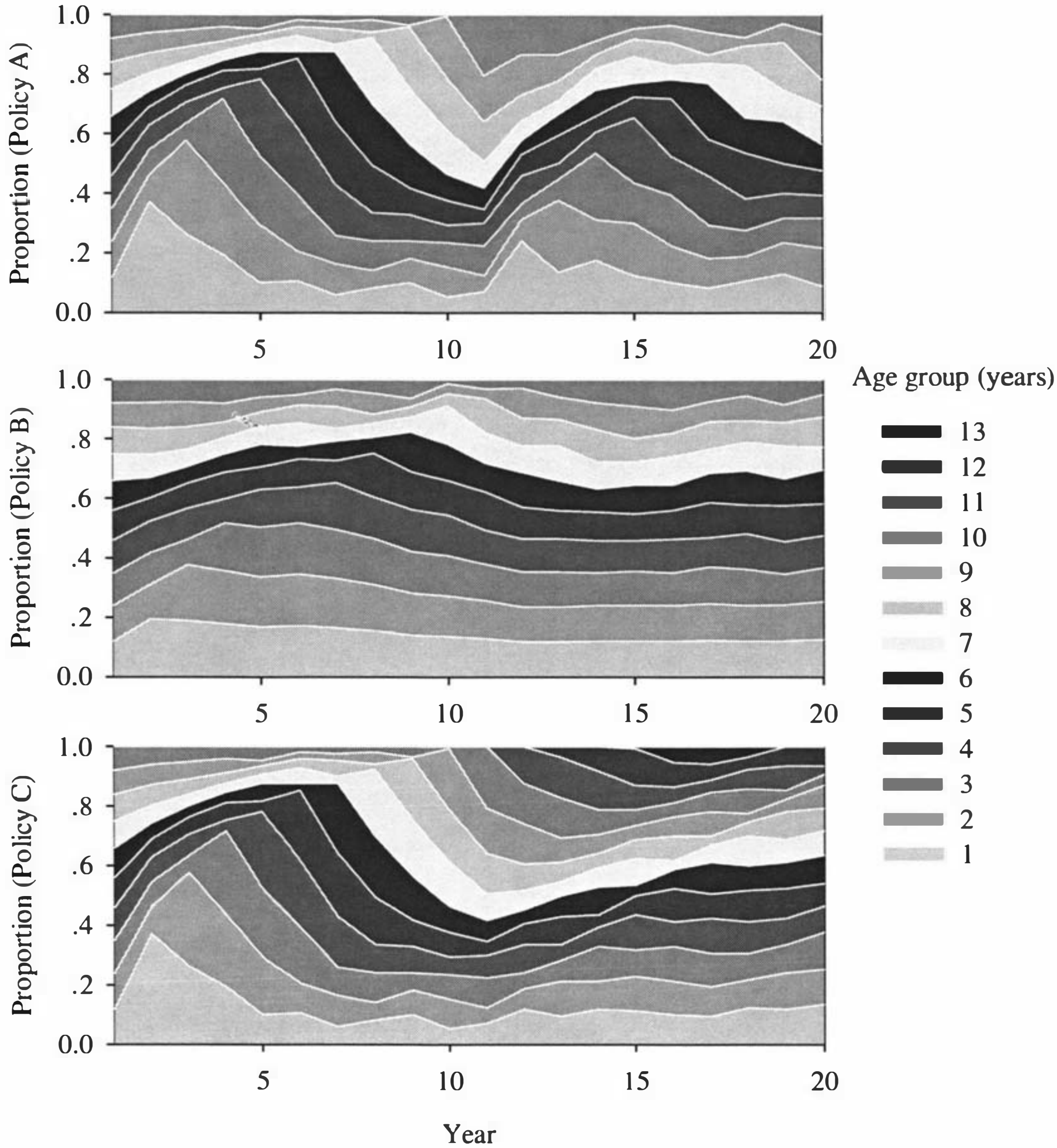

Figure 4.4: Cow age distribution for policies A, B and C. Using average weather data and starting from a low cow number.

The three strategies generated quite different dynamics in the long run in terms of liveweight production and number of animals sold each year (Figure 4.5). Despite the use of uniform weather inputs for the simulations, all the policies showed oscillations. Since the pregnancy rate was stable between years (Table 4.3), the oscillation could not be entirely attributed to the random component of the model (i.e. conception). Furthermore, the oscillations would not disappear even if this component was eliminated (all cows conceiving each year). In fact, the smaller the effect of random factors removing cows from the system before reaching the culling age (i.e., reproductive failures, deaths and sales in response to climatic emergencies), the more persistent and pronounced these oscillations became. The averages for both variables in Figure 4.5 were similar between policies, but Policy C, generated significantly less variation than the others (Table 4.3).

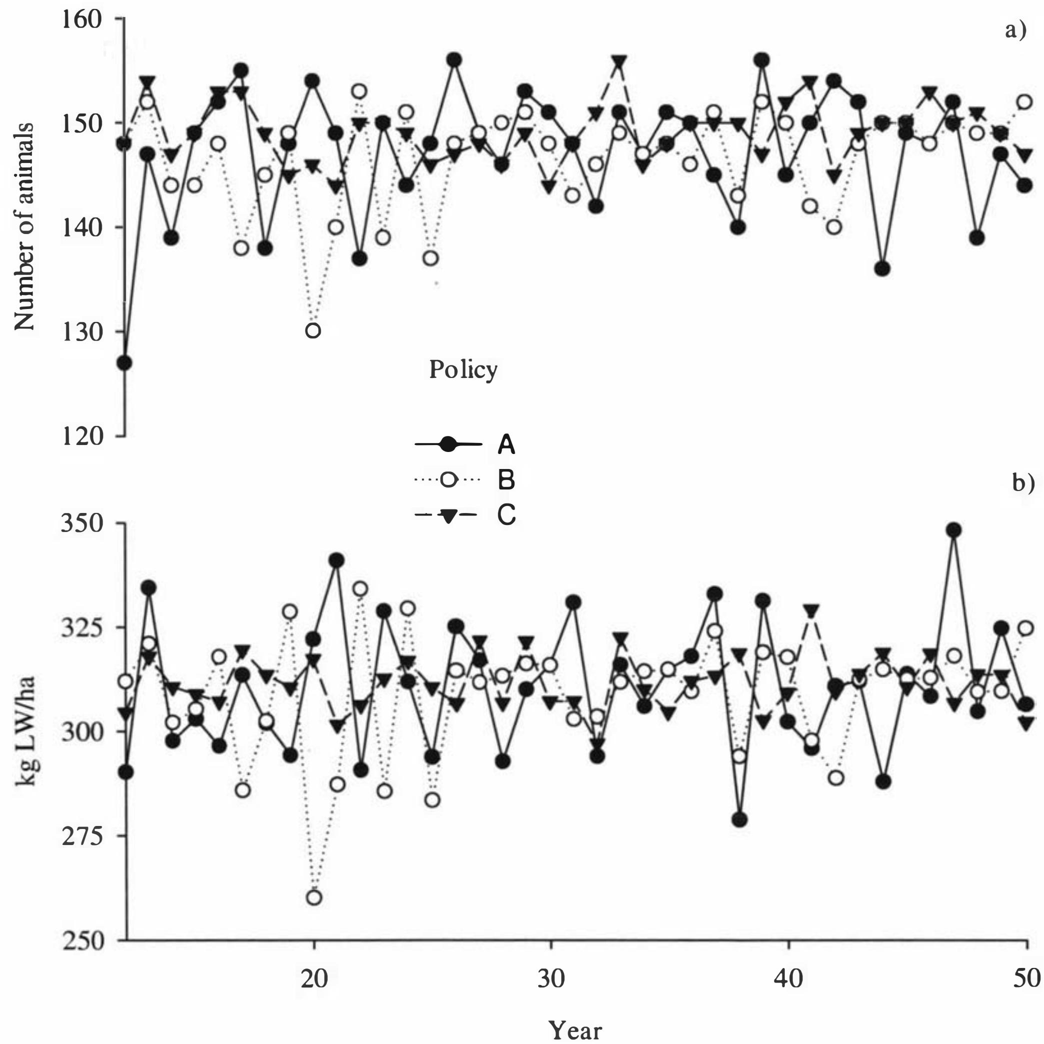

Figure 4.5: Total annual sales in number of animals (a) and liveweight sold (b). Using average weather data and starting from a low cow number (years 10 to 50).

Table 4.3: Mean and standard deviation for production indicators for policies A, B and C, using average weather data and considering only the period from the point when the target cow number was reached (years 10 to 40).

	Policy		
	A	B	C
Replacement heifers (animal/year)	21±6	20±0	19±3
Age culls (animal/year)	14±6	11±3	12±1
Pregnancy rate (Primiparous)	94±6	93±5	93±6
Pregnancy rate (Multiparous)	95±2	95±2	95±2
Sold animals (animal/year, cows plus calves)	147±6	145±9	149±3
Liveweight sold (kg/ha/year, cows plus calves)	313±20	306±22	312±7

4.3.5. Policy comparison

The almost deterministic results presented in the previous section showed the expected behaviour from the strategies. When most of the exogenous variation between years was eliminated and the random elements of the model were reduced, a strong source of year-to-year oscillations in farm production arising endogenously from the farm management rules was identified, and its consequences were then obvious. Would the benefits of the improved management policy (C) be retained when a more realistic situation is simulated? And also, do the effects of an unbalanced initial age distribution persist in the long-run with random weather? To investigate these questions a second series of simulations was run, where random weather and death (see Chapter 3) were incorporated.

To produce a better discrimination between the strategies, 20 artificial sets of 50 years of weather data were generated by selecting years at random from the original 30 years data from the INTA-Balcarce research station, Argentina from 1970 to 2000. Three different initial conditions (INI) were tested, in all the cases with the target cow number (170):

1. Starting from the conditions that each strategy generated after the building up period described in the previous section (BU);
2. Starting with an age distribution with too many young cows (YNG, only ages from 1 to 4 years); and
3. Starting with an even age distribution (EVEN), that is, the expected numbers in a stable herd with 95% survival rate between successive age groups.

The means and standard deviations for different performance indicators were statistically compared by considering each of the 20 simulations of 50 years as an independent replicate. The GLM procedure of SAS (1999) was used, the statistical model being:

$$y_{ijk} = \mu + S_i + INI_j + (S*INI)_{ij} + R_k + e_{ijk}$$

(for i= $A, B, C,$; $j = BU, YNG, EVEN$ and k=1 to 20)

where: y_{ij} = ij-th observation

μ = general mean

S_i = i-th strategy

INI_j = j-th initial state

R_k = k-th replicate (run of 50 years)

e_{ijk} = error term for the ijk-th observation

Table 4.4 shows the results of the ANOVAs for liveweight and number of animals sold for the twenty replicates. Despite the introduction of random weather and deaths, the effect of the replacement policy was highly significant in all cases, explaining a large proportion of the total variation. On the other hand, the importance of the initial conditions (and their interaction with policy) as source of variation in the long run was notably smaller. The number of deaths was similar for all treatments (5.2±2.3 and 5.2±6.2 animal/year, for cows and calves, respectively).

Table 4.4: Analysis of variance for the mean and standard deviation (SD) within replicate for sale of cows plus calves: liveweight (kg/ha/year) and number (animal/year).

		Sold LW[2] (Mean)		Sold LW[2] (SD[1])		Sold animals[3] (Mean)		Sold animals[2] (SD[1])	
Source	DF	SS	Pr > F	SS	Pr > F	SS	Pr > F	SS	Pr > F
Policy	2	5729	<.0001	1435	<.0001	1788	<.0001	61	<.0001
INI	2	175	0.0007	36	0.1842	2	0.644	18	0.0147
REP	19	5021	<.0001	1968	<.0001	781	<.0001	1006	<.0001
Policy *INI	4	155	0.0116	13	0.8673	28	0.0329	14	0.1476
Error	152	1760		1600		389		317	
Total	179	12842		5052		2989		1416	
R^2		0.86		0.68		0.87		0.78	

[1]Average of 20 within-replicate SDs.
[2]See text

The differences between the average values for the different performance indicators were statically significant, although the value of the differences were small. The differences in standard deviation were more important, with Policy C being the most stable (Table 4.5). Policy C reduced the variability in liveweight and animals sold by 7 and 12%, respectively, in comparison with Policy A. Counter to its objective, Policy B produced the most variable results, which is a consequence of its lower capacity to adjust for deviations from the desired cow number in the face of variable weather. Note that Policy B, on average, maintained a smaller cow number than policies A and C.

Table 4.5: Means and standard deviations for different performance indicators for policies *A*, *B* and *C* and starting conditions (*BU, YNG, EVEN*) (see text for details). Values between parenthesis in the last column represent confidence intervals (95%) for the ratio of standard deviations of each policy (*B* or *C*) over *A*.

		Initial state				
	Policy	BU	YNG	EVEN	Mean	SD_i/SD_A[1]
Sold animals[3] (animal/year)	A	124±15[2]	124±14	125±13	124±14	
	B	118±15	119±14	119±15	119±15	1.05(1.01 to 1.09)*
	C	126±14	125±13	126±12	126±13	0.93(0.91 to 0.96)*
Liveweight sold[3] (kg/ha/year)	A	270±36	267±35	270±34	269±35	
	B	256±38	257±37	258±37	257±37	1.09(1.05 to 1.12)*
	C	270±31	266±31	269±30	269±31	0.88(0.86 to 0.91)*
Total Cow number	A	167±3	167±2	167±2	167±2	
	B	158±8	160±8	159±7	159±8	3.93(3.52 to 4.35)*
	C	167±2	167±2	167±2	167±2	1.05(0.98 to 1.12)
Replacement heifers (animal/year)	A	24±8	24±8	24±7	24±8	
	B	23±1	23±1	23±1	23±1	0.08(0.07 to 0.09)*
	C	23±6	23±6	23±6	23±6	0.77(0.75 to 0.8)*

[1] Average and 95% confidence interval for ratio of the SD for policy i (B or C) over SD for Policy A.
[2] Average of 20 within-replicate SDs
[3] Cows plus calves
* Significant difference (P < 0.05)

4.3.6. Discussion

Livestock farms are open dynamic systems which can be conceptualised as cybernetic systems, where production is managed by human activities regulating controllable factors in order to maintain the system in line with its overall purposes (Sørensen and Kristensen, 1992). Thus, the dynamic behaviour of open systems (i.e. systems interacting with their environment) is only partially determined by factors from the environment. Systems also generate their own internal dynamics, regardless of their environment, as the state variables influence system evolution, generating system-characteristic eigendynamics (von Bertalanffy, 1969; Bossel, 1994; Skittner, 2001). The fact that deterministic dynamic systems might generate their own variability, as was shown in this study, has also been well demonstrated in many other types of systems (Forrester, 1961; Coyle, 1978; Robinson and Freebairn, 2001). Results reported, but not discussed, by Gartner and Herbert (1979) when comparing simulated replacement policies in dairy herds, showed different types of oscillations despite the fact that their model was completely deterministic and without any kind of external influences. In the context of this study, the inference is that the weather is not the only source of variability in cow-calf systems; and at least a proportion of their variability might be generated by the internal structure of the system itself.

The results of this study indicated that, even with no environmental differences between consecutive years, the system generated complex dynamic behaviour. According to the system dynamics theory, oscillations can arise when there are significant delays in a negative feedback loop (Sterman, 2000). In our case, the system was trying to eliminate a discrepancy between the current cow number and a target by changing the number of replacement heifers, with two mayor delays, the time taken for a heifer to become a productive cow (weaning to first calving) and the time taken for a cow to become old (i.e. being culled). Thus, replacement policy *per se* proved to have a disproportionate influence on the dynamic behaviour of this type of system. Similarly, the dynamic consequences of other decision rules (e.g., grazing management, forage conservation, supplementation) could also be analysed to get a better understanding of the system behaviour, which is a necessary step in improving any particular strategy (Coyle, 1978). These experiments are the subject of subsequent research presented in the following chapters.

When the same climatic year was repeated 40 times, in order to simulate a long time period without the interference produced by weather variations, the internal sources of variability in the system were magnified. Under this artificially stable environment all the policies exhibited similar average performance, but Policy C was much more stable that the others. Policy B was obviously too rigid and required much longer to reach the target cow number compared with policies A and C, and counterintuitively it was not more stable than A even after the target cow number was reached (year 10 to 40). However, when real climatic sequences were used in the simulations, the advantages of Policy C became less pronounced (in this case Policy A was only 8-14% more variable that C). This indicates that comparing production strategies under average weather conditions gives incomplete information; it can be misleading and can only be done for specific purposes. In this case, it helped to identify a pattern in the data, leading to the clarification of a cause of oscillatory behaviour.

Sørensen et al. (1992) treated the culling policy problem in a different way, by breeding all the female calves and keeping them until one week prior to calving. A heifer due to calve is retained if required to replace a culled cow or to increase the size of the herd if required. Thus, culling and replacement are more closely connected in time, helping to reduce problems. Another option would have been to purchase pregnant heifers when required. In the case of the cow-calf system being simulated in this study, these were not practically feasible options, since calves are sold immediately after weaning. Hence it was necessary to treat culling and replacement as separated events.

Understanding the internal dynamic of the system is an important step in the modelling process. The oscillations explored here are only evident over long periods of time, so they are unlikely to be noticed in field experiments or in real farms. However, from the modelling point of view the question is totally different. In the case of a model designed to do long term simulations and to study alternatives for system control under environmental uncertainty, it is necessary to understand the elements in the structure of the system that contribute to its variability. In this context, replacement policy in itself was the cause of a significant amount of variation.

4.3.7. Conclusions

Simple replacement rules can result in cow-calf systems that generate long-term oscillations or that are slow to accommodate to changes such as the decision to increase the desired cow number on a farm. Improved replacement rules can reduce these problems without adversely affecting long-term production. As shown in the present study, the year to year variations normally observed in the productivity of pastoral systems may not only be the result of external influences, but can also be unexpected consequences of the management policies followed by the farmer. Interactions between the environment and the management strategy can also be present, the differences between strategies being dependent on the environmental variability being simulated. This makes short term or unreplicated comparison of farming strategies problematic.

4.4. EXPERIMENT 3: ALTERNATIVE HAY USE POLICIES[12]

Livestock systems in the Salado region are characterized by their complete reliance on pasture production. However, the marked seasonality of pasture growth results in imbalances between animal requirements and food supply. Forage conservation can be used to collect pasture surpluses during the spring-summer and feed them back during the winter, when pasture growth can be almost zero. Technical advisers (official and private) have promoted the use of this technology for many years, but with limited success. One of the reasons for this could be the difficulties in demonstrating the expected benefits of forage conservation on the total farm system.

The model was therefore used to assess the impact of haymaking and hay usage strategies, by analysing four different management strategies in a cow-calf farm, three of which involved different policies for hay use during the autumn-winter period and a control strategy in which no hay was harvested or used. The four strategies were otherwise as similar as possible and were defined by the rules in Table A 4.2 (Appendix, section 4.6). This base system was an approximate representation of the experimental cow-calf farm at the INTA-Balcarce research station (Carrillo, 1997; Carrillo et al., 1998).

4.4.1. Base system

The base system consisted of a cow-calf farm with a total area of 100 ha, subdivided into 40 paddocks (2.5ha each).

Three herds were defined, “1”, “2” and “3”; to which 10, 29 and 1 paddocks were initially assigned respectively. Herd 1 contained the heifers from weaning to first pregnancy scanning (March) at 18-20 months of age. Herd 2 and 3 held the adult cows. Herd 3 only existed during the period of hay feeding, and contained non-lactating cows with more than one calving, being fed hay and with restricted access to pasture. When no hay was being fed, all the adult cows were in herd 2, which received a freer access to pasture than herd 3.

Cows were mated in November and December (calving from 13 August to 12 October) and weaning was planned for 1 March. The calves not retained as replacements were sold at 1 March, along with old and reproductively failed cows. There were several rules that sold animals to correct or minimize deviations from the desired state in the system, e.g. low average pasture cover or low cow body condition (rules 6, 7, 22, 30 and 31 in Table A 4.2. Appendix, section 4.6). Those sales were referred to as “emergency sales”. The target cow number was 170 breeding animals (cows + heifers) at 1 March, which

[12] Experiment included in the paper Romera, A. J., Morris, S. T., Hodgson, J., Stirling, W. D., and Woodward, S. J. R., 2004. A model for simulating rule-based management of cow-calf systems. Computers and Electronics in Agriculture 42: 67-86.

was regulated by the rules controlling sales. Thirty five heifers were retained each year as replacements.

For those strategies using hay, every year, from 1 October, 30% of the total area (12 paddocks = 30ha) was closed for the purpose of making hay. The paddocks were released to grazing after the hay was harvested. Paddocks were cut when the total herbage mass was greater that 4000kg dry matter /ha, or not later than 1 March. The total quantity of hay produced was therefore partially dependent on the climatic conditions during the spring-summer period.

4.4.2. Alternative hay-use policies

Hay could be used from 1 April to the end of calving (15 October). The three strategies using hay also had differences in the assignment of the cows to herds 2 and 3, which were required in order to implement the hay feeding strategies. The specific rules for each strategy are shown in Table A 4.3 (Appendix, section 4.6).

The principle in the strategies was to feed the hay back during autumn-winter (after weaning), whilst restricting the access of the cows to the pastures and saving standing pasture for the onset of the calving season.

The four strategies were:

Strategy "NoHay": the base strategy was simulated without including any of the rules to make and feed hay.

Strategy "A": offered 8 kg dry matter of hay per cow per day (in herd 3) in the last part of the autumn-winter, starting from the date when the hay stocks were enough to feed the cows until the end of calving. Only one paddock was allocated for use by herd 3. Once calving started (and the calved cows moved from herd 3 to herd 2) hay was offered *ad-libitum* to herds 2 and 3.

Strategy "B": offered 8 kg dry matter of hay per cow per day (in herd 3) in the first part of the autumn-winter, from weaning until when all the hay was eaten. As in strategy A, only one paddock was allocated for use by herd 3.

Strategy "C": offered 6 kg dry matter of hay per cow per day in herd 2, from weaning until when all the hay available was used. In this strategy, no cows were assigned to herd 3 and the cows remained in the herd 2 all year round.

4.4.3. Simulations

The model was initially run for each strategy for 10 years to initialise the system, starting from the default initial state (100 non-lactating, non-pregnant cows with ages ranging from 2 to 8 years; and paddocks with a range of herbage mass from 0.5 to 2.5 t DM/ha and from 90% to 50% green matter) and using an average climatic year. The final state of the system was saved to a file to re-initialise the model in the subsequent simulations.

In the first simulation, the model was run over 30 consecutive years using real weather data from the INTA-Balcarce research station, Argentina from 1970 to 2000. There were indications that strategies using hay had greater stability (Figure 4.6). The coefficient of variation for total sales produced by the farm (LWS, kg live weight/ha/year) for *NoHay* was 14%, compared with 7%, 8% and 7% for *A*, *B* and *C* respectively.

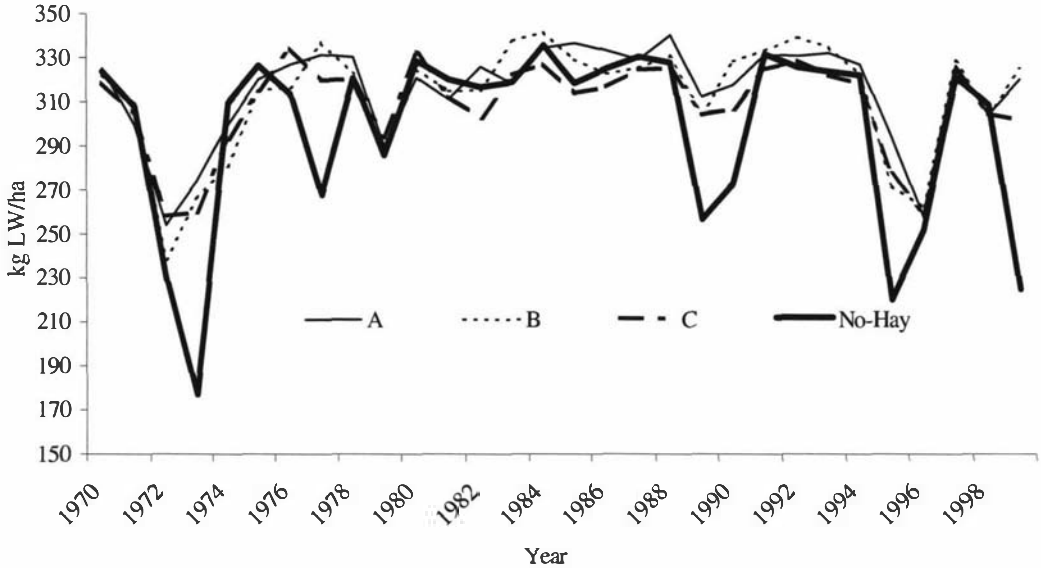

Figure 4.6: Animal live weight sold (kg/ha/year) for the strategies A, B, C and NoHay (see text for details). Simulation with real weather data.

In order to produce a better discrimination between the strategies, 20 artificial sets of 50 years of weather data were generated by selecting years at random from the original 30 years' data. The means and standard deviations for different performance indicators were statistically compared by considering each of the 20 simulations of 50 years as an independent replicate. The GLM procedure of SAS (1999) was used, the statistical model being:

$y_{ij} = \mu + S_i + R_j + e_{ij}$ (for i= *NoHay, A, B, C* and j=1 to 20)

where: yij = ij-th observation

μ = general mean

S_i = i-th strategy

R_j = j-th repetition (run of 50 years)

e_{ij} = error term for the ij-th observation

The three hay-making strategies had significantly different means from *NoHay* for several output variables (Table 4.6 and Table 4.7), though the differences were of limited magnitude. The differences in number of heads and live weight sold were due to differences in calf sales, which were explained by a greater proportion of years with heifers failing to attain the appropriate live weight for mating, and emergency sales, in the *NoHay* strategy compared to the rest. In general, differences between the means for the hay-making strategies were very small, though in some cases the differences were statistically significant.

Table 4.6: Means and standard errors (n = 20, see text for details) for different performance indicators for strategies *NoHay, A, B* and *C*.

Output variable	SEM*	Strategy			
		NoHay	A	B	C
Hay harvested (t dry matter /year)	0.2	-	82	81	81
Mean cow calving weight (kg)	1	377^{c}	371^{a}	374^{b}	370^{a}
Mean cow live weight at 1/Nov (kg)	1	372^{d}	369^{b}	371^{c}	367^{a}
Mean cow weaning weight (kg)	1	430^{c}	429^{b}	430^{c}	428^{a}
Mean calf weaning weight (kg)	1	176^{b}	178^{c}	178^{c}	173^{a}
Pregnancy rate in Cows (%)	0.1	94.9	95.1	95.0	95.0
Pregnancy rate in Heifers (%)	0.1	95.5^{b}	95.5^{b}	95.1^{a}	95.3^{ab}

a, b, c Different letters in the same row indicate significant difference (Duncan's test, $p < 0.05$).
* Pooled standard error of the means.

Table 4.7: Means and standard errors (n = 20, see text for details) for different performance indicators for strategies *NoHay, A, B* and *C*. Values in parenthesis represent confidence intervals (95%) for the differences in means of each hay-making strategy (*A, B* or *C*) minus *NoHay*.

Output variable	SEM*	Strategy			
		NoHay	A	B	C
Sales (head/year)					
Total	0.5	119.7^{a}	124.2^{b}	124.1^{b}	123.8^{b}
			(3.5 — 5.3)	(3.5 — 5.1)	(3.3 — 4.9)
Cows	0.1	35.0	35.1	35.0	35.0
			(0.03 — 0.2)	(-0.1 — 0.1)	(-0.1 — 0.1)
Calves	0.5	84.7^{a}	89.1^{b}	89.5^{b}	88.8^{b}
			(4.4 — 5.3)	(3.5 — 5.1)	(3.3 — 4.8)
Live weight sold (kg/ha/year)					
Total	2	297^{a}	307^{c}	307^{c}	302^{b}
			(8.4 — 13.0)	(8.3 — 12.2)	(3.3 — 7.6)
Cows	1	146	146	147	146
			(-0.7 — 1.4)	(-0.4 — 1.4)	(-1.0 — 1.1)
Calves	1	150^{a}	161^{c}	160^{c}	156^{b}
			(8.7 — 12.0)	(8.4 — 11.2)	(3.9 — 7.0)

a, b, c Different letters in the same row indicate significant difference (Duncan's test, $p < 0.05$).
* Pooled standard error of the means.

The standard deviations were significantly smaller for the strategies using hay than for the *NoHay* strategy, with reduction in the order of 16 to 22% in LWS and 20 to 26% in calf live weight sold (Table 4.8). The differences in standard deviations between strategies *A*, *B* and *C* were mostly non significant.

Table 4.8: Means and standard errors (n = 20, see text for details) for the standard deviation of different performance indicators for strategies *NoHay*, *A*, *B* and *C*. Values in parenthesis represent confidence intervals (95%) for the ratio of standard deviations of each hay-making strategy (*A*, *B* or *C*) over *NoHay*.

Output variable	SEM*	*Strategy*			
		NoHay	*A*	*B*	*C*
Sales (head/year)					
Total	1.1	17.6[b]	13.3[a] (0.6 — 0.8)	13.2[a] (0.64 — 0.81)	13.3[a] (0.65 — 0.83)
Cows	0.9	5.9	5.7 (0.7 — 1.1)	5.3 (0.6 — 1.1)	5.6 (0. 6 — 1.1)
Calves	0.7	15.1b	10.3a (0.6 — 0.7)	10.7a (0.6 — 0.8)	10.6a (0.6 — 0.8)
Live weight sold (kg/ha/year)					
Total	3	48[b]	40[a] (0.7 — 0.9)	41[a] (0.7 — 0.9	39[a] (0.7 — 0.9)
Cows	2	21	19 (0.7 — 1.0)	20 (0.8 — 1.1)	20 (0.7 — 1.1)
Calves	1	33[c]	25[ab] (0.7 — 0.8)	26[b] (0.7 — 0.9)	24[a] (0.7 — 0.8)

[a, b, c] Different letters in the same row indicate significant difference (Duncan's test, $p < 0.05$).
* Pooled standard error of the means.

The use of hay reduced significantly the frequency of "problem years". Figure 4.7 shows the proportion of years with emergency sales (i.e., sales forced by low pasture cover or low body condition in the cows), failure to attain the appropriate live weight at mating in heifers, and liveweight sold under 250 kg/ha/year. This suggests that the effect of using hay was mainly achieved by mitigating the consequences of "poor" climatic years.

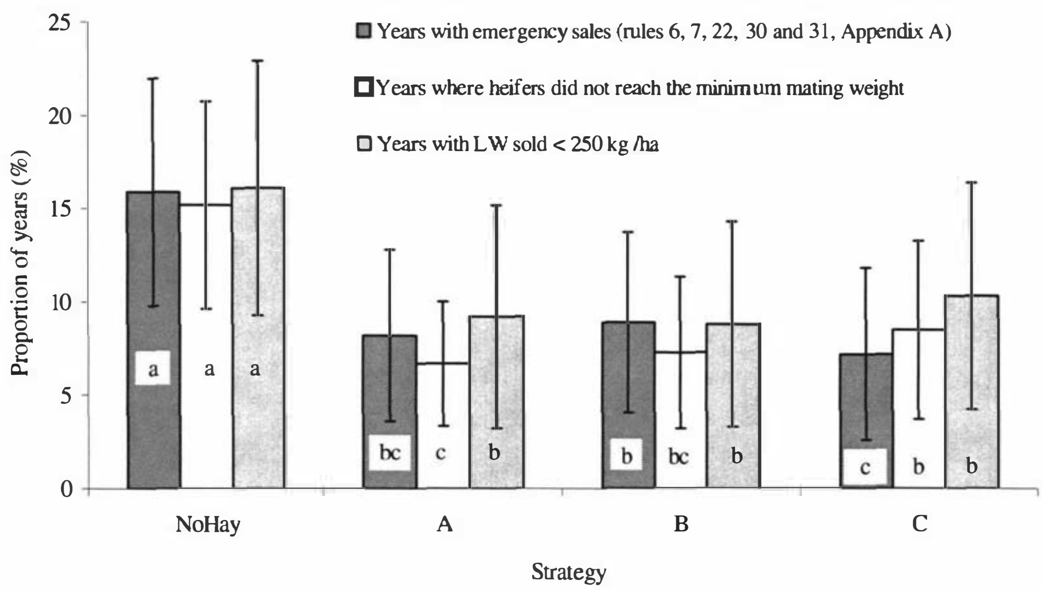

Figure 4.7: Proportion of years with major difficulties for the strategies A, B, C and NoHay (see text for details). Vertical lines represent SD, different letters indicate significant difference (Duncan's test p<0.05). Estimates from 20 runs of 50 years.

The quantitative predictions from the simulations indicate that the use of hay in cow-calf systems of this kind would moderately improve average productivity. Note that the increase in average in liveweight production would not justify haymaking on its own in economical terms. But more importantly, it would give more production stability to the farm. The results suggest that, provided hay is utilized on the farm, the pattern of use does not make much difference to production.

In this study, only the rules directly related to hay harvesting and hay use changed between strategies, and the full expression of eventual advantages of forage conservation on cow-calf farms may require further changes in system management. Further studies were be conducted to explore this question (Chapters 5 to 7).

4.5. METHODOLOGICAL CONSIDERATIONS

Through this chapter, some of the well-known characteristics of complex dynamic systems, and specifically livestock systems, emerged. In order to effectively use a model like the one developed in this project it was necessary to properly consider those dynamic aspects.

The second experiment presented in this chapter provided an illustration of the complex dynamic behaviour that a system can exhibit even without the influence of external factors. The long term consequences of management decisions were also highlighted. Sterman (2000) warns against selecting time horizons that are too short in the study of dynamic systems.

As in a real system, a dynamic model produced auto-correlated time series of outputs. The results produced one year are affected not only by the environmental conditions in that particular years, but also by the history of the system. The current state of the system represents a "memory" of the past. This means that common statistical tests, relying on the assumption of sample independence, may be not appropriate to compare alternative management policies.

Weather variability is another important feature of pastoral systems. It has been demonstrated that using deterministic weather leads to overestimation of system productivity and can introduce serious biases in the comparisons of alternative managements (Cacho et al., 1995; Cacho et al., 1999). But not only that, the particular weather sequence taken can modify the relative behaviour of different alternatives being compared (Robinson and Freebairn, 2001). Confirming this, it was shown in Experiment 3 that sampling the same sequence of actual climatic data in different random order significantly affects the outputs of the system.

In a cow-calf system, there are multiple management factors that could be analysed when looking for improved management strategies. The number of possible options at each decision point are numerous, and the possibility of interactions can not be ruled out without investigation. The model presented here was designed to maximize the flexibility to create different management strategies by combining any number of decision rules. Having said that, adequate reflection and planning are required when experimenting with a simulation model, and unsystematic trial and error exercises should be kept to a minimum[13]. It is important to use care in choosing the simulation runs that are going to be conducted. Simulation involves experimentation, and experimentation requires appropriate design and analysis if reliable results are desired (Kleijnen, 1995). Poorly planned simulation runs can result in significant loss of information, or worse, misleading results (Barton, 2002).

Taking all these considerations into account, the following aspects appear as requirements when planning simulation studies:

- Long term simulations
- More that one weather sequence
- Independent replicates
- Systematic approach

The experimental protocol used in the following chapters, which is similar to the one used by Cacho et al. (1999), tried to address those issues. A block design in factorial arrangement. Different random weather sequences were considered as blocks, and different management factors levels were combined in a factorial arrangement. At this point, a new class called *Strategy* was added to the model. In an experiment to examine the effect of several decision rules, each of which having more than one version, the *Strategy* class has the responsibility of creating simulations with all possible combinations of the rules. Thus, for example, if among a set of decision rules the user enters two rules with four versions each, an object of the *Strategy* class will automatically create all sixteen combinations.

[13] According to Sterman (2000, pg 36) this is very common among modellers, he calls it the "*videogame syndrome*", in which people "*play too much and think too little*".

4.6. APPENDIX

Table A 4.1: Experiment 2. Decision rules to implement Policy A, B and C. (see rules number R 8 and R 20).

Applied to/condition	Action
Herd: 2 (Mature cows)	
R 0 SA[month] = 11 OR SA[month] = 12	join
R 1 SA[month] = 3 AND SA[day] = 2 AND CA[2,pregnant] = false AND CA[2,numberOfMatings] > 0 AND HA[2,pregnancyRate] > 0.8	sell cow
R 2 SA[month] = 3 AND (SA[day] = 31 AND CA[2,numberOfMatings] GE 15	sell cow
R 3 SA[month] = 3 AND SA[day] = 1 AND CA[2,lactating] = false	wean cow
R 4 SA[dayOfTheYear] > 225 AND SA[dayOfTheYear] < 285	feedHay, amount: 10
R 5 SA[pastureCover[14]] < 1000 AND SA[day] = 1 AND (CA[2,positionBcRank] / HA[2,numberOfCow]) > 0.9	sell cow (Sell the 10% thinnest cows)
R 6 CA[2,bodyCondition[15]] < 0.6	sell cow
R 7 SA[month] = 2 AND HA[2,meanBodyCondition] < 1	wean cow
R 8 **A**. SA[month] = 3 AND SA[day] = 3 AND CA[2,numberOfMatings] > 9 **B**. SA[month] = 3 AND SA[day] = 3 AND CA[2,numberOfMatings] > 9 **C**. SA[month] = 3 AND SA[day] = 3 AND CA[2,numberOfMatings] > 9 AND CA[2,positionAgeRank] LE 9	sell cow This rule controls the culling of old cows and it has 3 versions. The same version as in R 20 is always selected to control the cow number.
R 9 SA[pastureCover] < 1000 AND GP[2,greenHerbage] < 500	changePaddock
R 10 SA[pastureCover]> 1000 AND GP[2,greenHerbage]<1000	changePaddock
R 11 SA[dayOfTheYear] < 225 OR SA[dayOfTheYear] > 285	feedHay, amount: 0
R 12 SA[pastureCover]<1600 AND CA[2,positionBcRank]> 130	sell cows (cut off the cow number to 130)
Block: 2, nPaddocks=29	
R 13 ((BA[2,pastureCover] < 2000 AND HA[2,numberOfCow] > 0) AND (BA[1,numberOfPaddocks] GE 10 OR (HA[1,numberOfCow] = 0 OR BA[inOffer,numberOfPaddocks] > 0)))	withdrawPaddock
R 14 ((BA[2,pastureCover] > 2500 AND (PA[2,grazingDay] = 0 AND (PA[2.firstInRank] = true AND	withdrawPaddock

[14] PastureCover: average herbage mass on the farm
[15] bodyCondition: scale used by Freer et al. (1997), 1 is equivalent to 5 in the 1 to 9 scale.

Applied to/condition	Action
HA[1,numberOfCow] > 0))) AND BA[inOffer,numberOfPaddocks] = 0)	
R 15 HA[2,numberOfCow] > 0 AND HA[2,meanBodyCondition] < 1 AND (BA[1,numberOfPaddocks] GE 10 OR HA[1,numberOfCow] = 0)	withdrawPaddock
R 16 BA[2,numberOfPaddocks] LE 30 AND SA[day] = 1	withdrawPaddock
R 17 HA[1,numberOfCow] > 0 AND BA[1,pastureCover] < BA[2,pastureCover] AND BA[inOffer,numberOfPaddocks] LE 1 AND PA[2,firstInRank] = true AND BA[1,numberOfPaddocks] LE 10	depositPaddock
Herd: 1 (Replacement heifers)	
R 18 GP[1,greenHerbage] < 2500	changePaddock
R 19 CA[1,bodyCondition] < 0.6	sell cow
R 20 **A.** SA[month] = 3 AND SA[day] = 4 AND CA[1,positionInRank] > (170 - HA[2,numberOfCow] - HA[3,numberOfCow]) **B.** SA[month] = 3 AND SA[day] = 4 AND CA[1,positionInRank] > 20 **C.** SA[month] = 3 AND SA[day] = 4 AND CA[1,positionInRank] > (170 - HA[2,numberOfCow] - HA[3,numberOfCow])	sell cow This rule controls the sales of weaned heifer and it has 3 versions. The same version as in R 8 is always selected to control the cow number.
R 21 SA[dayOfTheYear] = 305 AND (HA[1,meanBodyCondition] > 0.95 OR (SA[dayOfTheYear] > 305 AND HA[1,isJoined] = true)	join
Block: 1, nPaddocks=10	
R 22 BA[1,pastureCover] < BA[2,pastureCover] AND HA[1,numberOfCow] > 0	withdrawPaddock
R 23 BA[inOffer,numberOfPaddocks] > 1 AND BA[1,numberOfPaddocks] LE 10	withdrawPaddock
R 24 PA[1,lastInRank] = true AND BA[1,numberOfPaddocks] > 10	depositPaddock
Herd: 3 (Mature cows on hay)	
R 25 SA[pastureCover] < 1000 AND (SA[day] = 1 OR SA[day] = 15) AND (CA[3,positionBcRank] / HA[3,numberOfCow]) < 0.1)	sell cow
R 26 CA[3,bodyCondition] < 0.6	sell cow
R 27 HA[3,numberOfCow] > 0 AND SA[dayOfTheYear] < 225	feedHay , amount: SA[hayStock] / (HA[3,numberOfCow] * (225 - SA[dayOfTheYear]))
R 28 HA[3,numberOfCow] = 0	feedHay , amount: 0
R 29 SA[dayOfTheYear] > 225 AND HA[3,numberOfCow] > 0	feedHay, amount: 10
R 30 CA[3,lactating] = false AND HA[2,numberOfCalves] =	sell cow

Applied to/condition	Action
0 AND CA[3,positionAgeRank] LE SA[numberOfCows] – 170	
Block: 3, nPaddocks=1	
R 31 HA[3,numberOfCow] = 0	depositPaddock
R 32 HA[3,numberOfCow] > 0 AND BA[3,numberOfPaddocks] = 0	withdrawPaddock
R 33 BA[3,numberOfPaddocks] > 1 AND (PA[3,lastInRank] = true AND PA[3,onGrazing] = false	depositPaddock
HerdOrganizer (Class in charge of assigning the cows to the herds)	
R 34 CA[age] < (791 - CA[DOYOfBirth]) AND CA[gender] = 2	toHerd: 1
R 35 SA[dayOfTheYear] GE 93 AND SA[dayOfTheYear] LE 284 AND (CA[age] > 800 AND CA[lactating] = false AND SA[hayStock] > 0 AND (SA[hayStock] GE COUNT[CAC[2,age] > 800] * (1797.5 - (8 * SA[dayOfTheYear])) OR HA[3,numberOfCow] > 0)	toHerd: 3
R 36 CA[age] GE (791 - CA[DOYOfBirth]) AND CA[gender] = 2	toHerd: 2
PaddockBank	
R 37 PA[closed] = true AND PA[totalHerbage] > 5000 OR SA[dayOfTheYear] = 1	makeHay
R 38 (BA[closed,surface] + SA[areaCut]) < 30 AND SA[month] > 9 AND PA[restingDays] = 1 AND SA[pastureCover] > 1500)	closePaddock
R 39 PA[wasCut] = true	releasePaddock
R 40 SA[dayOfTheYear] = 90 AND PA[closed] = true	makeHay
R 41 (BA[1,numberOfPaddocks] < 7 AND HA[1,numberOfCow] > 0	releasePaddock
WeanerPool (Auxiliary herd containing weaners until sold or assigned to a herd)	
R 42 CA[weaners,gender] = 1	sell cow
R 43 (SA[month] = 1 OR SA[month] = 2) AND CA[weaners,positionInRank] > 40	sell cow

Table A 4.2: Experiment 3. Rules composing the base strategy

Applied to / condition	Action
Herd: '2'	
R 0 GP[2,greenHerbage] < 500	changePaddock
R 1 SA[totalHerbageMass] > 1000 AND GP[2,greenHerbage] < 1000	changePaddock
R 2 SA[month] = 11 OR SA[month] = 12	join
R 3 SA[month] = 3 AND SA[day] = 2 AND CA[2,pregnancyDay] = 0	sell cow
R 4 SA[month] = 3 AND SA[day] = 31 AND CA[2,numberOfMatings] GE 15	sell cow
R 5 SA[totalHerbageMass] < 1000 AND (SA[day] = 1 OR SA[day] = 15) AND (CA[2,positionBcRank] / HA[2,numberOfCow]) > 0.95)	sell cow
R 6 CA[2,bodyCondition] < 0.6	sell cow
R 7 SA[month] = 3 AND SA[day] = 3 AND CA[2,positionAgeRank] < (SA[numberOfCows] - 170)	sell cow
R 8 SA[month] = 2 AND SA[day] = 28 AND CA[2,lostCalf] = true AND CA[2,numberOfCalvings] > 0 AND HA[2,numberOfCalves] > 0	sell cow
R 9 SA[month] = 11 AND SA[day] = 1 AND CA[2,lactationDay] = 0 AND CA[2,numberOfCalvings] > 0 AND SA[numberOfCows] > 150	sell cow
R 10 SA[month] = 2 AND HA[2,meanBodyCondition]<1	wean cow
R 11 SA[month] = 3 AND SA[day] = 1 AND CA[2,lactationDay]>0	wean cow
R 12 Depends on the strategy	**feed hay**
Block: '2'	
R 13 SA[month] = 3 AND BA[2,totalHerbageMass] > 7000 AND PA[2,firstInRank] = true AND PA[2,closed] = false	cleanPasture
R 14 BA[2,totalHerbageMass] > 2500 AND PA[2,grazingDay] = 0 AND PA[2,firstInRank] = true AND HA[1,numberOfCow] > 0 AND BA[inOffer,numberOfPaddocks] = 0	depositPaddock
R 15 HA[1,numberOfCow] > 0 AND BA[1,totalHerbageMass] < BA[2,totalHerbageMass] AND BA[inOffer,numberOfPaddocks] = 0 AND PA[2,firstInRank] = true AND BA[1,numberOfPaddocks] LE 10	depositPaddock
R 16 (BA[2,totalHerbageMass] < 2000 AND HA[2,numberOfCow] > 0) AND (BA[1,numberOfPaddocks] GE 10 OR HA[1,numberOfCow] = 0 OR BA[inOffer,numberOfPaddocks] > 0)	withdrawPaddock

Applied to / condition	Action
R 17 (HA[2,numberOfCow] > 0 AND HA[2,meanBodyCondition] < 1) AND (BA[1,numberOfPaddocks] GE 10 OR HA[1,numberOfCow] = 0)	withdrawPaddock
R 18 BA[inOffer,numberOfPaddocks] > 1 AND BA[2,numberOfPaddocks] LE 30	withdrawPaddock
Herd: '1'	
R 19 GP[1,greenHerbage] < 2500	changePaddock
R 20 (SA[dayOfTheYear] = 305 AND HA[1,meanWeight] > 247) OR (SA[dayOfTheYear] > 305 AND HA[1,isJoined] = true)	join
R 21 CA[1,bodyCondition] < 0.6	sell cow
R 22 SA[month] = 3 AND SA[day] = 2 AND	sell cow
R 23 CA[1,positionInRank] > (35 + COUNT[CA[1,age] > 365])	
R 24 SA[month] = 3 AND SA[day] = 2 AND CA[1,numberOfMatings] > 0 AND CA[1,pregnancyDay] = 0	sell cow
Block: '1'	
R 25 SA[year] = 4 AND BA[1,totalHerbageMass] > 7000 AND PA[1,grazingDay] = 0 AND PA[1,firstInRank] = true	cleanPasture
R 26 BA[1,totalHerbageMass] > 2500 AND PA[1,grazingDay] = 0 AND PA[1,firstInRank] = true AND BA[1,numberOfPaddocks] > 2 AND BA[inOffer,numberOfPaddocks] = 0	depositPaddock
R 27 BA[1,totalHerbageMass] < 2000 AND HA[1,numberOfCow] > 0	withdrawPaddock
R 28 BA[inOffer,numberOfPaddocks] > 1 AND BA[1,numberOfPaddocks] LE 10	withdrawPaddock
Herd: '3 (only in strategies A and B)	
R 29 (SA[month] = 3 AND SA[day] = 3) AND CA[3,positionAgeRank] < (SA[numberOfCows] - 170)	sell cow
R 30 (SA[day] = 1 OR SA[day] = 15) AND SA[totalHerbageMass] < 1000 AND (CA[3,positionBcRank] / HA[3,numberOfCow]) > 0.95	sell cow
R 31 CA[3,bodyCondition] < 0.6	sell cow
R 32 Depends on the strategy	feed hay
Block: '3' (only in strategies A and B)	
R 33 HA[3,numberOfCow] = 0	depositPaddock
R 34 HA[3,numberOfCow] > 0 AND BA[3,numberOfPaddocks] = 0	withdrawPaddock
HerdOrganizer	

	Applied to / condition	**Action**
R 35	CA[age] < 600 AND CA[gender] = 2	toHerd: 1
R 36	Depends on the strategy	toHerd: 2
R 37	Depends on the strategy (only in A and B)	toHerd: 3
	PaddockBank	
R 38	(BA[closed,surface] + SA[areaCut]) < 30 AND SA[month] > 9 AND PA[restingDays] =1	closePaddock
R 39	PA[closed] = true AND PA[totalHerbage] > 4000	makeHay
R 40	SA[dayOfTheYear] = 90 AND PA[closed] = true	makeHay
R 41	PA[wasCut] = true	releasePaddock
	WeanerPool (Herd temporarily containing the calves immediately after weaning)	
R 42	CA[weaners,gender] = 1	sell
R 43	(SA[month] = 1 OR SA[month] = 2) AND CA[weaners,positionInRank] > 40	sell

Table A 4.3: Experiment 3. Specific rules for strategies A, B and C.

Strategy A

if SA[dayOfTheYear] GE 93 AND SA[dayOfTheYear] LE 284 AND CA[age] > 800 AND CA[lactating] = false AND SA[hayStock] > 0 AND SA[hayStock] GE COUNT[CA[age] > 800] * (260 + 7.5 *(205-SA[dayOfTheYear]))
then toHerd: 3

if (CA[age] > 600 AND CA[gender] = 2) AND (SA[dayOfTheYear] GE 284 OR SA[dayOfTheYear] < 93 OR
(SA[hayStock] = 0 OR CA[age] < 800 OR CA[lactating] = true OR SA[hayStock] < (COUNT[CA[age] > 800] * (260 + 7.5 *(205-SA[dayOfTheYear])))
then toHerd: 2

if HA[3,numberOfCow] > 0 AND SA[dayOfTheYear] < 225
then Herd 3: feedHay , amount: 8

if SA[dayOfTheYear] > 225 AND HA[3,numberOfCow] > 0
then Herd 3: feedHay , amount: 10

if SA[dayOfTheYear] > 225 AND SA[dayOfTheYear] < 285
then Herd 2: feedHay , amount: 10

Strategy B

if (CA[age] > 600 AND CA[gender] = 2) AND
(SA[dayOfTheYear] GE 284 OR SA[dayOfTheYear] < 93 OR SA[hayStock] = 0 OR CA[lactationDay] > 0 OR CA[age] < 800)
then toHerd: 2

if SA[dayOfTheYear] GE 93 AND SA[dayOfTheYear] LE 284 AND CA[age] > 800 AND CA[lactationDay] = 0 AND SA[hayStock] > 0
then toHerd: 3

if HA[3,numberOfCow] > 0 AND SA[dayOfTheYear] < 225
then Herd 3: feedHay, amount: 8

if HA[3,numberOfCow] > 0 AND SA[dayOfTheYear] GE 225
then Herd 3: feedHay, amount: 10

if SA[dayOfTheYear] > 225 AND SA[dayOfTheYear] < 285
then Herd 2: feedHay, amount: 10

Strategy C

if CA[age] > 600 AND CA[gender] = 2
then toHerd: 2

if SA[dayOfTheYear] > 93 AND SA[dayOfTheYear] < 285
then Herd 2: feedHay, amount: 6

CHAPTER 5

COMPARISON OF HAYMAKING STRATEGIES USING THE "RESERVA 6" APPROACH

Abstract

This study uses a cow-calf farm simulation model to compare the long term performance of a range of hay quantity-quality combinations. In the simulation farm management is based on Reserva 6, an experimental cow-calf farm established in 1966 at INTA-Balcarce Experimental Station where different technologies, including haymaking, were adapted and applied in order to improve the farm systems in the Salado Region of Argentina. The study found that the benefit of using hay and the contrast between the effects of different haymaking strategies on animal outputs increased as the stocking rate increased. The analysis also suggested that the liveweight production of cow-calf farms, under a rather rigid haymaking policy like Reserva 6, would be maximized by harvesting 40-50% (but not more) of the total farm area and aiming to harvest hay at medium herbage mass (therefore medium quality). The results therefore indicate that the policy currently followed in Reserva 6 of allocating 30% of the farm to haymaking is not excessive, but its physical productivity could be increased by making hay at lower herbage mass.

5.1. INTRODUCTION

The Salado region (or Pampeana Depression) of Buenos Aires Province, Argentina, is an area of approximately 9 million hectares (Soriano, 1992). The region has soil limitations for growing crops, and about 90% of the land is dedicated to cow-calf production (Carrillo and Shiersmann, 1992; Carrillo et al., 1998). The low productivity attained by average commercial farms relative to the region's potential, however has been of concern for some time (Rearte, 1998).

In 1966 an experimental cow-calf farm was established at the INTA-Balcarce Experimental Station where different technologies could be adapted and applied in order to improve the systems in the area, increasing productivity and stability. Primarily, the objective of this farm was to estimate the production potential of the cow-calf systems of the Salado Region by optimally using the technology available to commercial farmers in the area (Carrillo et al., 1998). The system is known as "Reserva 6" and is still in operation, consistently producing much more than the average farm (270 vs. the average 60-70kg of liveweight/ha/year) through the use of cultivated pastures, subdivision, regular fertilization, planned animal health control, a restricted mating season (2 months), early weaning (5-7 months of age) and forage conservation. Reserva 6 has been not just an experimental farm, but a way of promoting a particular technological package to farmers.

Reserva 6 follows a strict haymaking program, closing paddocks at the beginning of spring (normally early October), after one spring grazing. Every year, thirty percent of the area is devoted to making low quality hay (digestibility ≅ 45%) by cutting at high herbage masses, most of which is destined to provide maintenance feed for pregnant adult cows in the following winter. Cows are kept on a small paddock from weaning (March) to calving (August-September), receiving 6-9kg DM of hay per day and losing about 10% of their initial liveweight over this period. After calving, cows and calves are moved to paddocks that have not been grazed since early autumn. Both the amount of hay produced and its quality have been matters of controversy among local farmers, consultants and researchers.

The objective of this study was to compare the long term performance of a wide range of hay quantity-quality combinations using Reserva 6 as a base system. Trying to compare different strategies by using a classical experimental approach of testing several combinations in the field for several years would not be feasible, so the question is addressed through a simulation study.

5.2. MATERIAL AND METHODS

A cow-calf farm model was used for the simulations, as described in detail in Chapters 2 and 3. The management of the farm is represented by rules entered by the user (see Table A 5.1 for the complete list of rules used for this particular case. Appendix, section 5.6) and the simulation time step was one day. The biological components of the model were simulated using legacy models (Neil et al., 1997), described by Freer et al. (1997) for the animals, McCall and Bishop-Hurley (2003) for the pastures and Allen et al. (1998) for the soil water balance.

Details of these models are given in the publications mentioned, but it is important to note that the pasture model is climatically driven (by incident solar radiation, air temperature and soil water content) and actual climatic data from Balcarce was used to assess the long term differences between alternative management strategies. The herbage accumulation predicted by the pasture model was compared with actual data from several years of herbage cutting trials carried out at the INTA-Balcarce Experimental Station, and the agreement between observed and predicted data was acceptable (see Chapter 3), bearing in mind that cutting trials tend to produce more pasture than grazing trials. However, no herbage growth data were available from grazing trial in the region.

Based on the management scheme used in the Reserva 6, a computer-based experiment was designed and implemented on a simulated 100ha cow-calf farm. The simulations described in this paper are based on a farm with 40 paddocks of equal size, and three different herds:

- Herd 1: heifers from weaning to first pregnancy diagnosis in March.

- Herd 2: grazing cows from first pregnancy on. The cows in this group are offered hay *ad-libitum*, but only during the calving period.

- Herd 3: mature cows (after first weaning) on hay only. The cows are moved to this group after weaning, starting from the date when the hay stocks are enough to feed at least 8 kg dry matter of hay per cow per day until the end of calving. The cows are moved to herd 2 at calving, at 1 October, or when the farm runs out of hay, whichever occurs first. Once calving starts, hay is offered *ad-libitum*. Only one paddock is allocated for use by herd 3. This description corresponds to the policy A in Experiment 3 (Chapter 4).

Most of the animal sales occur in autumn, namely weaned calves not retained as replacements, non-pregnant cows and those cows that have lost their calf. Ten paddocks were initially assigned to Herd 1, 29 to the Herd 2 and one to Herd 3, but these numbers can dynamically change during the simulation through management rules. Reserva 6 is managed following a fairly strict and stable scheme, so it was relatively straightforward to represent its management strategy in the form of decision rules (Table A 5.1 lists the 44 decision rules that are used. Appendix, section 5.6).

Cow-calf systems in general, and Reserva 6 in particular, have several built-in points of flexibility including animal sales, weaning date and cow body condition targets. Any of these elements can be managed according to the current circumstances, giving adaptability to the system. These elements were incorporated in the decision rules used for the simulations. Animals are normally sold in autumn, but sales can occur at any time if the average herbage mass of the farm, or the body condition of the cows, are too low. Similarly, weaning is planned for 1 March, but it could be initiated from 1 February if the body condition of the cows is lower than 1 (equivalent to 5 in a scale 1-9, Freer et al., 1997). In this way the model, like a real farm, has the capacity for self-correction in the pursuit of the production goals implicitly embedded in the management strategy.

Two management variables related to the haymaking policy of the farm were varied in the simulations: the area closed for hay making in spring (AREA: ha) and the target herbage mass at which hay is harvested (MASS: t DM/ha) (see Table 5.1). If the target herbage mass for cutting is not reached, the closed paddocks are cut at a final cutting date, in which case the actual cutting herbage mass could be lower than the target. Paddocks are only cut once in a season, and then released to grazing. The variable AREA directly affects the total amount of hay produced on the farm. The variable MASS, on the other hand, not only affects the quantity of hay but also its quality. The different haymaking policies were simulated across a wide range of target cow numbers (SR: total number of cows on the 100ha-farm after the autumn sales). Note that the actual cow numbers may be lower than the target, since "emergency" animal sales might take place in years where there is very low average herbage mass on the farm or low animal body condition (rules R 5, R 6, R 14, R 20, R 27 and R 28 in Table A 5.1. Appendix, section 5.6).

The three factors (AREA, MASS and SR) were combined in an experimental design following a factorial arrangement. Such a procedure has been used by others in similar circumstances (Cacho et al., 1999) and is one of the most commonly used types of designs (Barton, 2002). Table 5.1 shows details of the levels of treatment considered.

Table 5.1: Management variables analysed in the study.

Variable	Levels						
Target cow number: SR (cows + heifers)	**170**[2]	200	230	260	290	320	350
Area closed for haymaking: AREA (ha)	20	**30**[2]	40	50	60		
Target herbage mass for cutting: MASS (t DM/ha)	3 (1/Jan)[1]	4 (20/Jan)	5 (10/Feb)	**6 (1/Mar)**[2]			

[1] Dates in parenthesis indicate the date when hay is made regardless of the herbage mass in the closed paddocks. [2] Policy approximately applied in the Experimental farm of INTA-Balcarce, Argentina.

The complete list of decision rules, including those with more than one version (rules R 8, R 14 and R 21 for SR; R 38 for MASS and R 39 for AREA), were entered and the corresponding 140 combinations (5 * 4 * 7 levels of AREA, MASS and SR, respectively) were then automatically generated by the model. As a control treatment, a strategy without hay was included (NoHay) and tested for the same range of cow numbers. Similarly to Cacho et al. (1999), the model was initially run for 10 years to initialise the system, starting from a common initial state (100 non-lactating, non-pregnant cows with ages ranging from 2 to 8 years; and paddocks with a range of herbage mass from 0.5 to 2.5 t DM/ha and from 90% to 50% green matter) using an average climatic year[16]. This initialisation enabled the target cow numbers to be reached and the appropriate age structure in the herds to be generated. The value of all the state variables of the system at the end of this initialisation period was saved to a file for use in reinitialising the model in subsequent simulations.

Twenty artificial sets of 50 years of daily weather data were generated by selecting years at random from an actual series of data recorded at the Balcarce Research Station of INTA (37° 58′ South), close to Reserva 6, from 1970 to 2000. All the 147 strategies were simulated using the same 20 series of 50-year weather data, reinitialising the model each time, which gave a total of 2940 simulations. The intention was not to simulate systems actually lasting 50 years, but to study the dynamic responses of the system to changing environmental conditions and so to permit a more accurate comparison between strategies in terms of their long term productivity and stability.

The study used a dynamic model in which any year's farm state had a strong effect on outputs in the following year, so annual outputs take the form of auto-correlated time series. However the experimental design ensures that the separate 50-year series of data are independent, simplifying statistical analysis. The means and coefficients of variation

[16] The average climate year was generated by averaging the original 30 years of records, for each day of the year and for all the climatic variables

for different performance indicators were statistically compared by considering each of the 20 simulations of 50 years to be an independent replicate. The GLM procedure of SAS (1999) was used, the statistical model being:

$$y_{ijkl} = \mu + SR_i + AREA_j + MASS_k + (SR\ AREA)_{ij} + (SR\ MASS)_{ik} + (AREA\ MASS)_{jk} + (SR\ AREA\ MASS)_{ijk} + R_l + e_{ijkl}$$

$$\begin{cases} i = 170, 200, 230, 260, 290, 320, 350 \\ j = 20, 30, 40, 50, 60 \\ k = 3, 4, 5, 6 \\ l = 1, 2, \ldots, 20 \end{cases}$$

where: y_{ijkl} = ijkl-th observation (the mean or coefficient of variation of some output variable over the ijkl-th 50-year simulation run)
μ = general mean
SR_i = i-th cow number target
$AREA_j$ = j-th area policy (i.e. area in hectares closed for hay making)
$MASS_k$ = k-th target cutting herbage mass policy (i.e. mass at which cutting is decided)
R_l = l-th replicate (i.e. 50 year simulation)
e_{ijkl} = error corresponding to the ijkl-th observation

5.3. RESULTS

The quantity and quality of the hay produced differed between strategies (Table 5.2) as anticipated. Cutting at greater herbage mass produced more hay but with lower digestibility. The range in total hay produced was almost six fold between minimum and maximum.

Table 5.2: Hay produced per year and digestibility.

	Target cutting herbage mass policy (t DM/ha)			
Area harvested (ha)	3	4	5	6
20	39.2±1.1[a]	54.4±2.8[b]	68.2±7.3[c]	81.2±12.5[d]
30	58.8±2[a]	81.5±4.5[b]	102.4±10.7[c]	121.9±18.9[c]
40	78.7±2.8[a]	108.6±6.2[b]	136.2±14.9[c]	162.4±25.4[c]
50	98.8±4.7[a]	135.5±8.5[b]	169.6±19.1[c]	202.2±32.1[c]
60	119±6.7[a]	161.7±11.1[b]	201.8±24[c]	240.3±39.7[c]
	Hay dry matter digestibility (%)			
Mean	53±0.4[a]	49.9±0.8[b]	48.1±1.5[c]	46.8±1.8[d]

[abcd] Means in the same row followed by different letters are significantly different ($p<0.05$), t pairwise test.

Not all the hay produced was actually consumed, depending on the amount of hay harvested relative to cow numbers (Figure 5.1). The effect of cutting mass is noteworthy; apart from its direct effect on the amount of hay produced it also influenced animal intake capacity via hay quality (see Chapter 3 for details of the daily intake calculation). When hay was made at low mass (3 or 4t DM/ha), it was mostly consumed (Figure 5.1), even at the maximum value of area harvested. This was not the case when hay was cut at high mass (5 or 6t DM/ha).

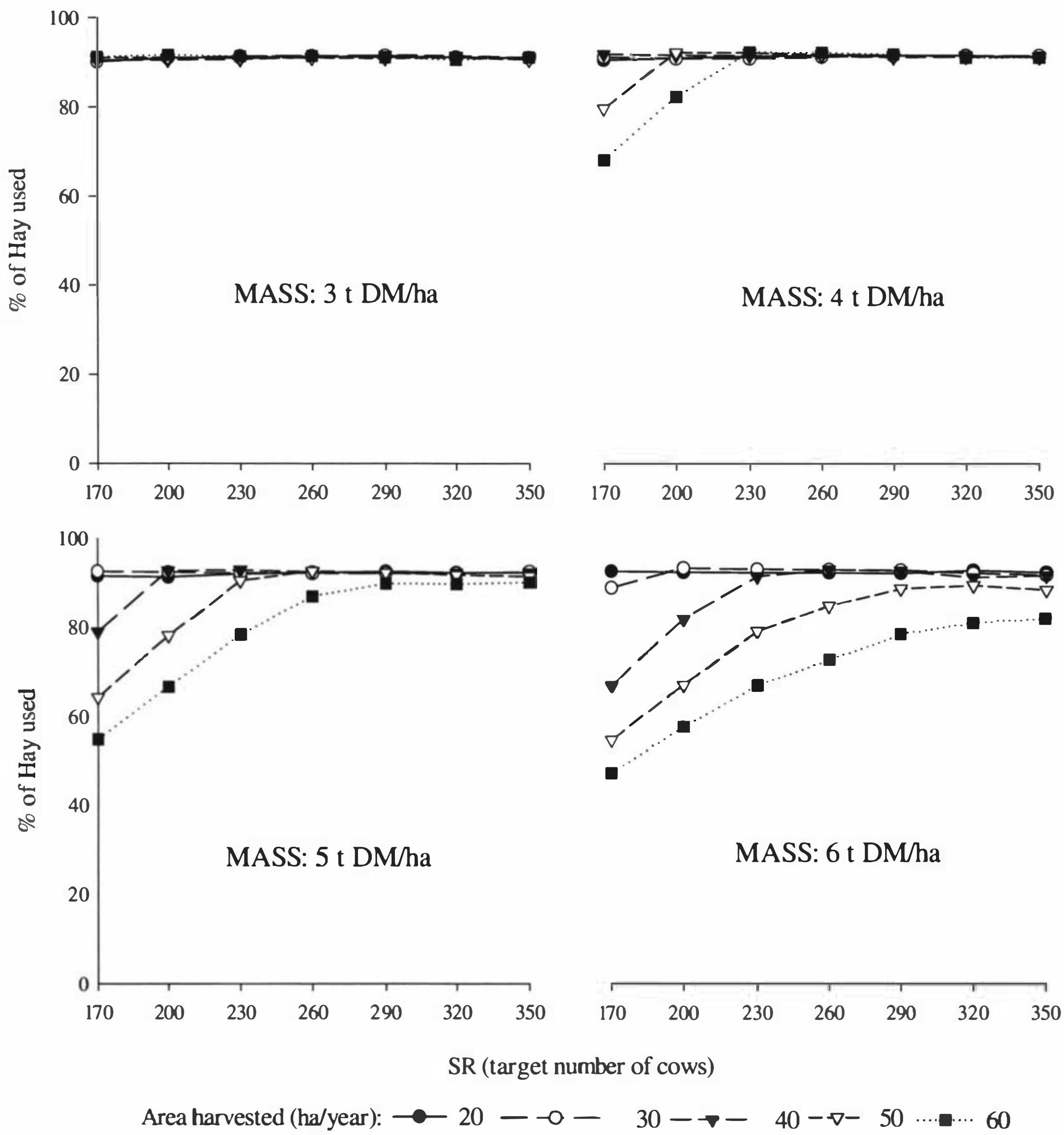

Figure 5.1: Proportion of the hay produced used in the following winter on average for each cow number (SR: target number of cows), area closed for haymaking and cutting mass policy (MASS: target herbage mass to decide making hay, 3 to 6 t DM/ha).

The haymaking policy had a major impact on the nutrition of the animals. Figure 5.2 shows the liveweight of the cows at calving and at weaning. The differences between the strategies are a result of differences in winter nutrition with lower quality hay (as a result of harvesting at high herbage mass), also the more hay was produced the more time the cows spent confined to a small paddock (without access to pastures). Both elements resulting in lower cow liveweight at calving. The difference was slightly lower by weaning time, but still significant. The liveweight of cows fed hay was consistently lower than when no hay was fed, the difference increasing progressively with increase in herbage mass at harvesting and area harvested.

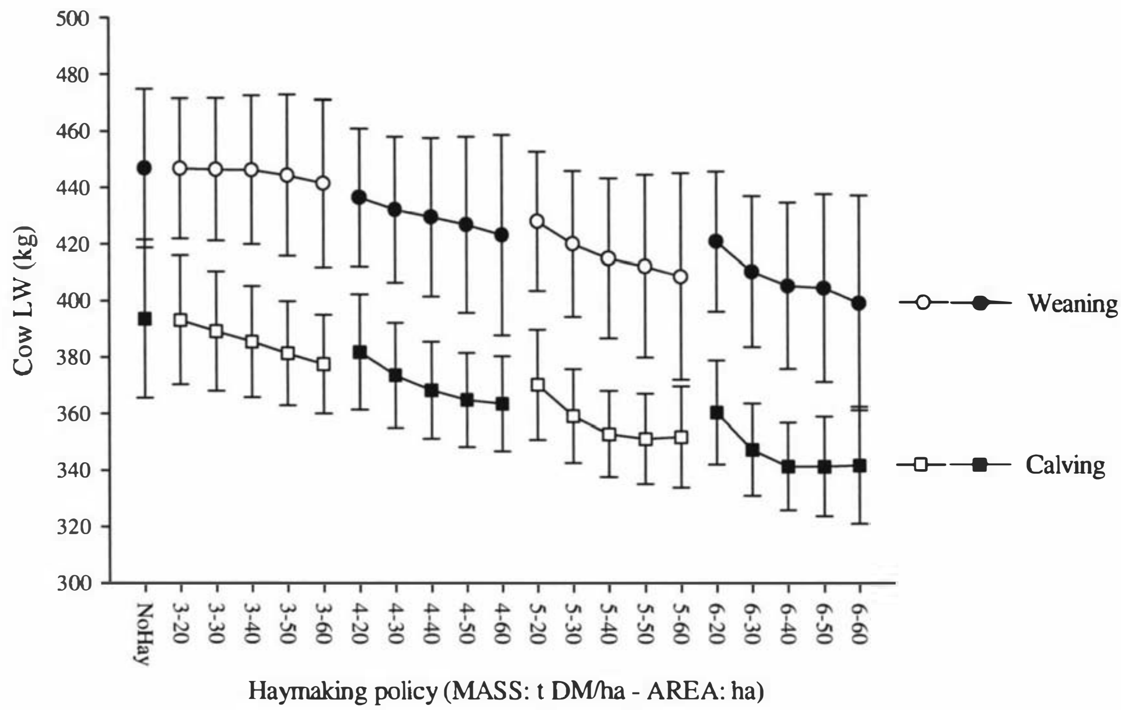

Figure 5.2: Cow LW after calving and at weaning for each hay making policy. AREA = area closed for hay making (20 to 60 ha) and MASS = target herbage mass to decide cutting (3 to 6 t DM/ha). Combinations such as AREA=20 and MASS=3 are denoted by "20-3" on the axes. Vertical lines indicate standard deviation.

The results presented this chapter focus mainly on the total amount of liveweight (LW) sold from the farm (kg LW/ha/year) and, within that, the amount of calf liveweight sold (kg LW/ha/year), as indicators of the animal production of the system. Aspects related to herbage dry matter fluxes and a simple economic risk analysis will be discussed in Chapter 7. The three main effects of AREA, MASS and SR and their interactions were all significant ($p<0.001$) for both response variables (ANOVAs in Table A 5.2 and Table A 5.3. Appendix, section 5.6). However, target cow number was the most important source of variation in both cases, explaining more that 60% of the total variation. Replicate was the second most important explanatory variable (12%), followed by MASS (7%) and AREA (1%). The mean and standard deviation for every combination simulated in the experiment are given in the Appendix (Table A 5.5 and Table A 5.6. Section 5.6).

To help illustrate different features of the results, the information is also presented graphically. Figure 5.3 shows the combined effect of the variables AREA and MASS on calf LW sold for the different cow numbers. The contour map representations at the top of Figure 5.3 show that the "favourable region" (lightest shading) moves downwards on the area harvested axes as cutting herbage mass increases. That is, the higher the cutting herbage mass the lower the optimum area for haymaking (approximately 46, 39, 34 and 22 ha for 3, 4, 5 and 6 t DM/ha, respectively). The lower panel of Figure 5.3 shows how each strategy (including NoHay) reacts to the increase in cow numbers. Note that the effect of using hay tended to be maximum at the intermediate levels of cow numbers. Figure 5.3 also indicates that the advantages of using hay were less clear at the highest cutting herbage mass policy, and even disappeared when more that 50ha were allocated to haymaking. The difference among the haymaking policies increased with cow numbers, especially at high cutting herbage masses. The figures indicate that the highest advantage was gained by making hay at low to medium herbage mass and cutting about 40-50ha.

The effect of strategy on the variability of the system outputs was also explored using ANOVA on the coefficients of variation (CV). Replicate (i.e. 50-year simulation runs), the main effects and their interactions were all significant (Table A 5.4. Appendix, section 5.6) (analysis for SD instead of CV gave similar results, not reported). Again, target cow number explained more of the differences in the CV than other factors (Figure 5.4).. The coefficient of variation increases with the cow number, and appears to be an optimum (i.e. lowest CV) at AREA=40 and MASS=4-5 (see Figure 5.4). Cutting more that 50ha appears to be counterproductive, increasing the variability without any benefit in the average calf liveweight production (Figure 5.4). The NoHay strategy showed the highest variability across the range cow numbers (bold dots in Figure 5.4).

To help visualization and to summarize the effects of the different strategies in terms of average production level and variability, Figure 5.5 shows both elements combined in one graph for each strategy (mean ± SD). This shows the expected curvilinear response in average calf LW production, with a maximum point at approximately 290 cows, and indicates the increase in the variability of the system outputs as cow numbers increase.

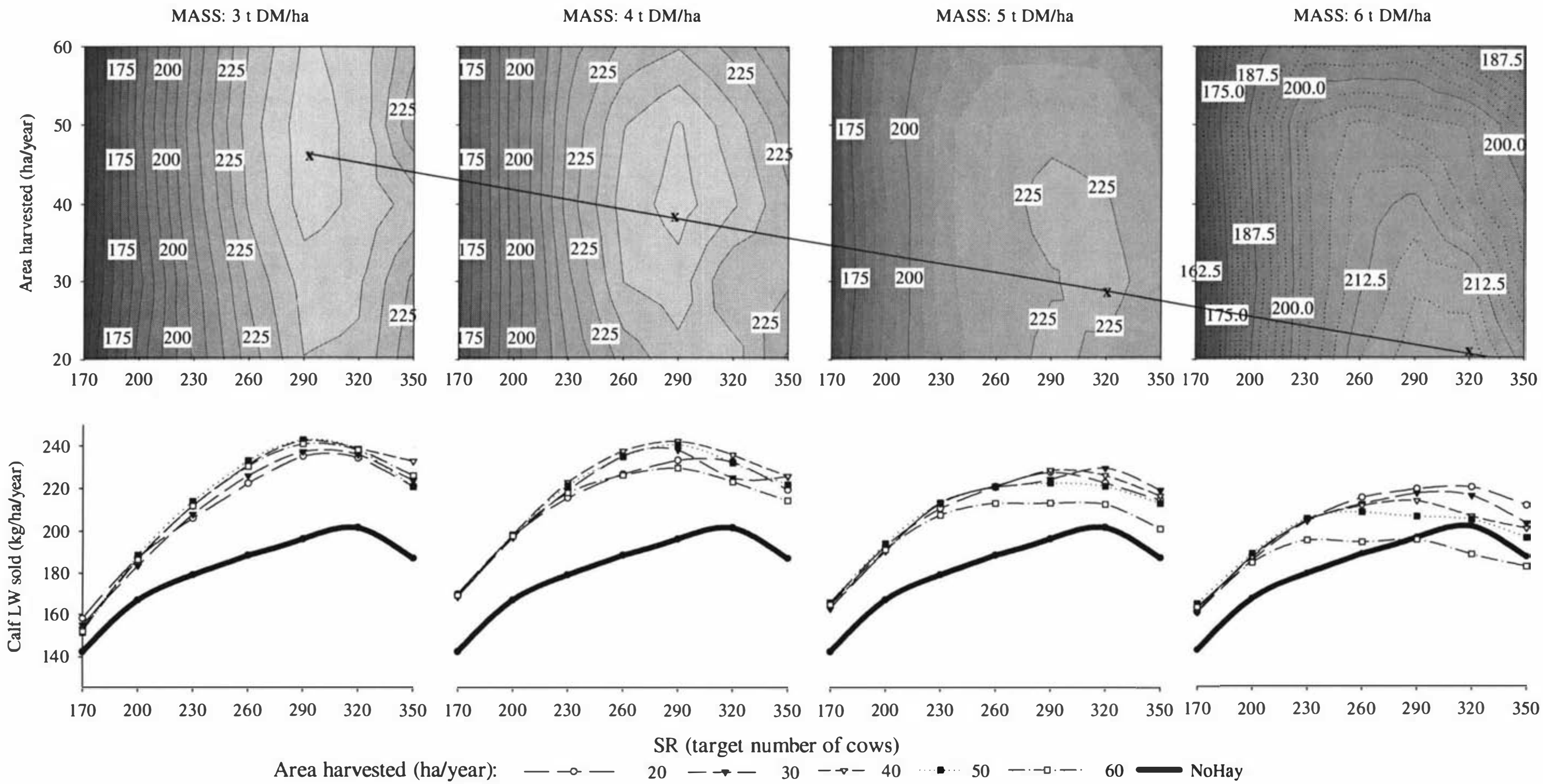

Figure 5.3: Response of calf LW sold to target number of cows on the farm (SR) for each level of area closed for haymaking and cutting mass policy (MASS: target herbage mass to decide making hay, 3 to 6 t DM/ba). Xs in contour graphs indicate the approximate location of the maximum points.

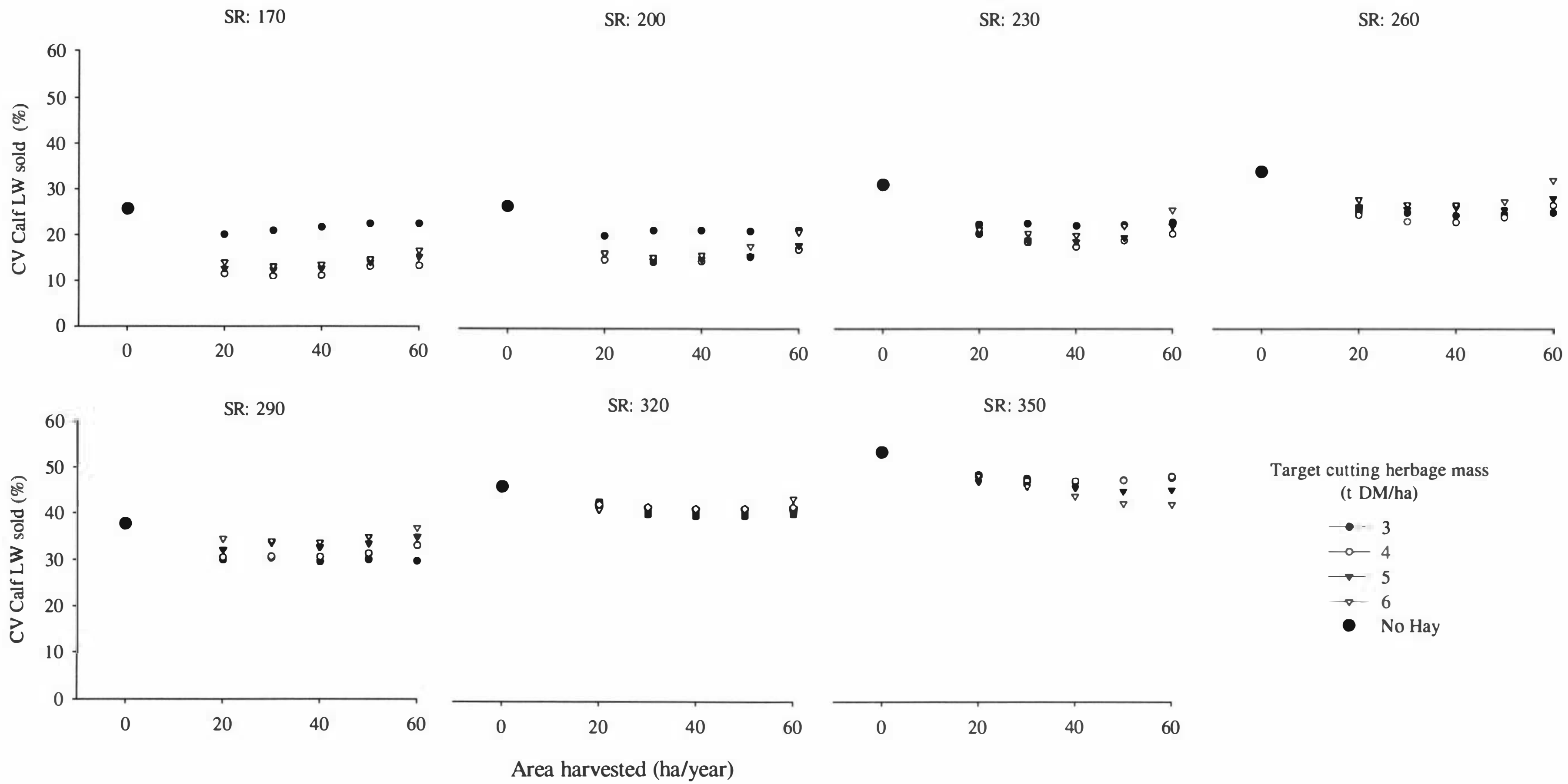

Figure 5.4: Influence of the area closed for haymaking and cutting mass policy (target herbage mass to decide making hay, 3 to 6 t DM/ha) on the coefficient of variation of calf LW sold (average of 20 within-replicate CVs) for each target number of cows in the farm (SR).

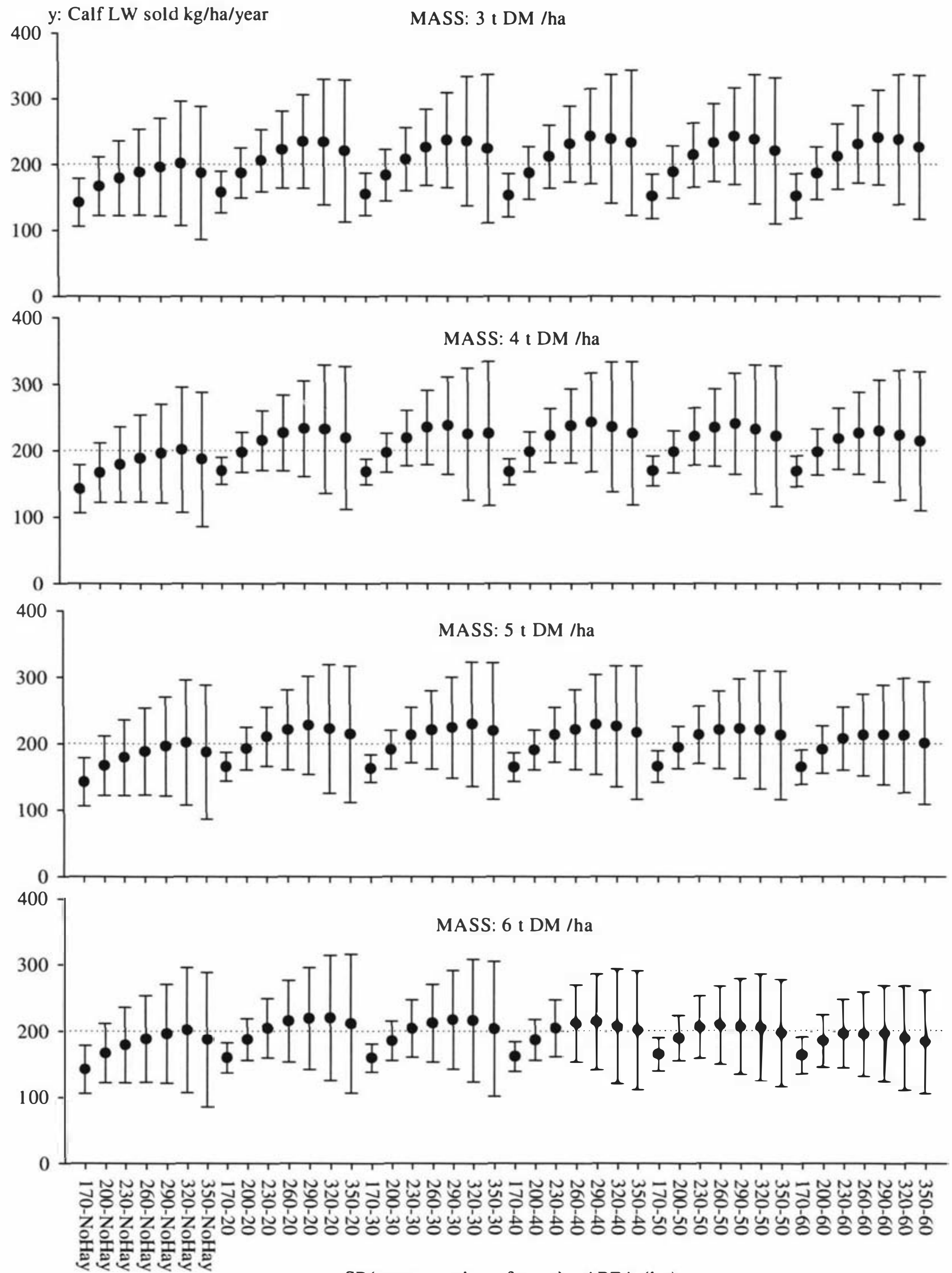

Figure 5.5: Response of calf LW sold to the target number of cows in the farm (SR) for each level of area closed for hay making (AREA, 20 to 60 ha) and cutting herbage mass policy (MASS: target herbage mass to decide making hay, 3 to 6 t DM/ha). Combinations such as SR=170 and AREA=20 are denoted by "170-20" on the horizontal axes. Vertical lines indicate standard deviation.

Within each target cow number (except at the highest level), there was an inverse relationship between the average production of the system and its variability (Figure 5.6), indicating that less productive strategies delivered more variable outputs. Note that, in the figure, the points corresponding to NoHay are predominantly above (i.e. greater variability for the same SR) and to the left of the others (i.e. less productivity for the same SR). This means that the NoHay combinations were more variable for a similar level of average production, or less productive at similar level of variability. However, this relationship disappeared when the cow number was too high, and some of the haymaking strategies were not unequivocally better than NoHay.

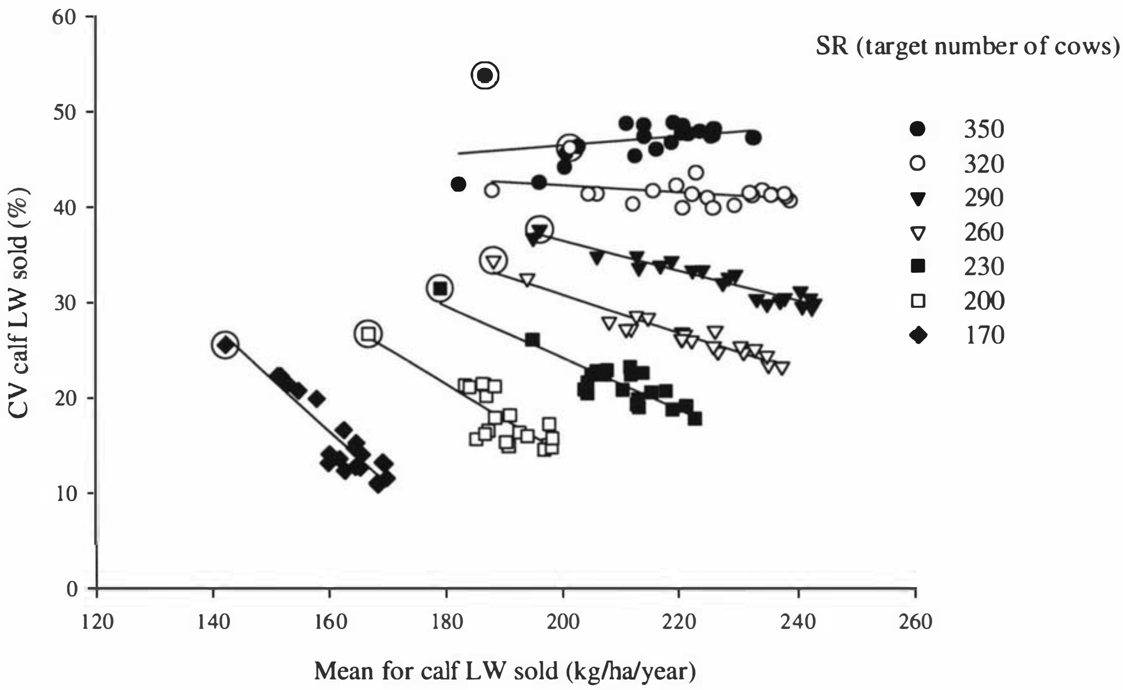

Figure 5.6: Relationship between coefficient of variation (CV) and mean calf liveweight sold (calfLW) for each target cow number (SR). The circled points are from the NoHay strategy.

The main reason for the lower calf LW sold from the NoHay strategy is the smaller proportion of years where the heifers reach adequate liveweight for first mating at 15 months of age (Figure 5.7). On average across all target cow numbers, early mating of heifers was only possible in 24.6 ± 3.2 years out of 50 (i.e. 49% of the years) for the NoHay strategy, while in the best strategy (AREA: 40ha, MASS: 4t DM/ha) it was possible in 43.1± 4.1 years (i.e. 86% of the years). A low proportion of years with heifers meeting the desired liveweight at mating time was also noted in the haymaking policy cutting at the lowest mass (i.e. at 3t DM/ha), and this was especially evident at low cow numbers.

It was hypothesized that this was partially the result of an important pasture clean up effect produced by making hay, but only if the pastures were not mowed too early in spring. To test this, one of the most productive haymaking strategies (AREA= 50ha, MASS=4t DM/ha) was simulated as before, but without feeding the hay back to the animals. In terms of heifer feeding, this combination performed as well as the equivalent normal hay-using strategy (Table A 5.5 and Table A 5.6. Appendix, section 5.6). In relation to this, the heavier cow liveweight on NoHay (Figure 5.2) reflects a diversion of forage from heifers to cows.

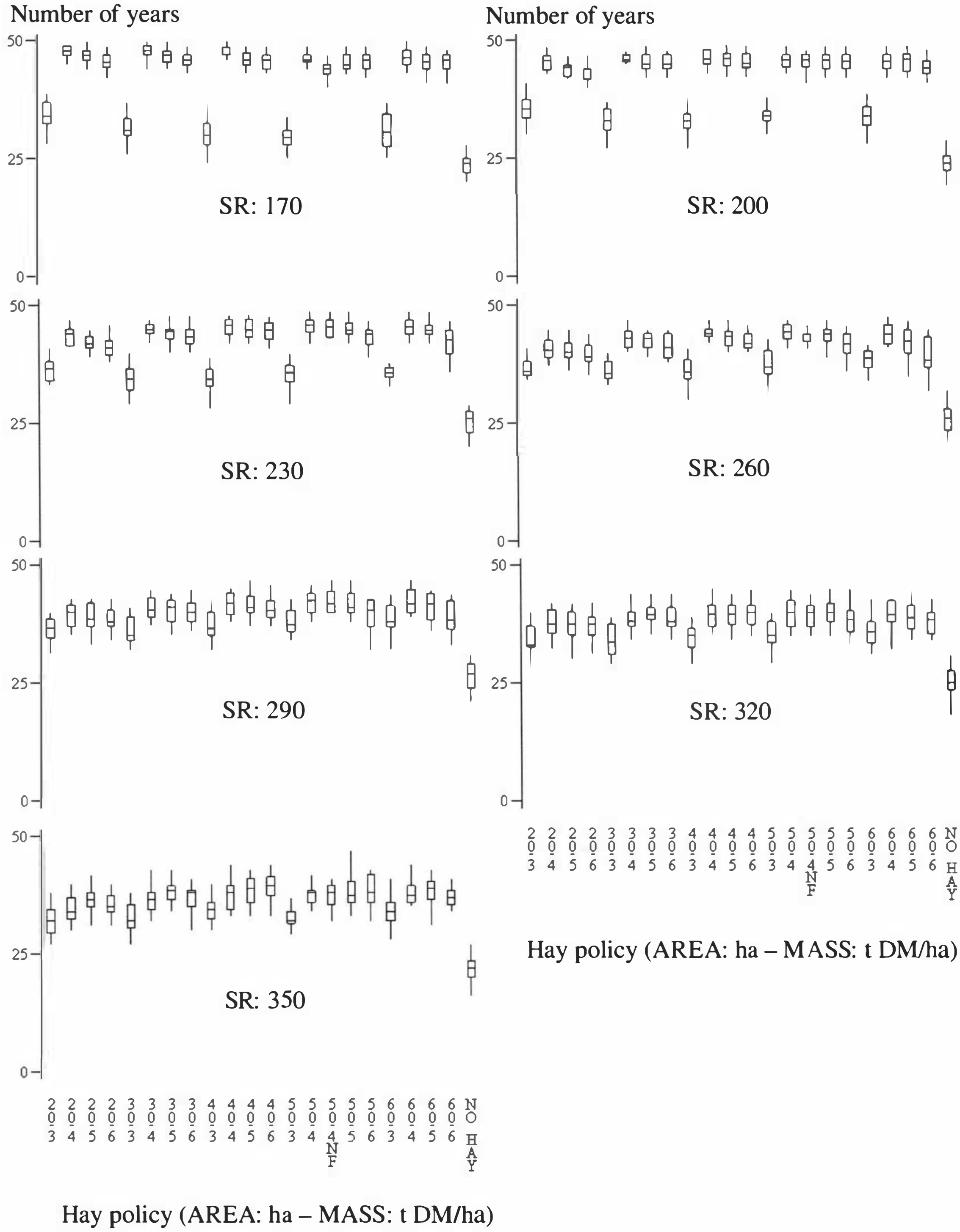

Figure 5.7: Boxplot representation for the number of years within each 50-year replicate in which 15-month heifers mating was possible for each target cow number (SR) and hay making policy. AREA = area closed for hay making (20 to 60 ha) and MASS = target herbage mass to decide cutting (3 to 6 t DM/ha), and combinations such as AREA=20 and MASS=3 are denoted by "20-3" on the axes. NF indicates a combination where hay was not fed back to the cows (see text for details). Whiskers correspond to replicates (50-year runs) in which this proportion was maximum and minimum.

Another of the characteristics of the less productive and less stable strategies (especially 60-5, 60-6 and NoHay), was their relative inability to sustain high cow numbers, because of recurrent "emergency sales". This partially explains their lower performance. Figure

5.8 shows the relationship between target cow numbers (SR) and the actual cow number for each strategy.

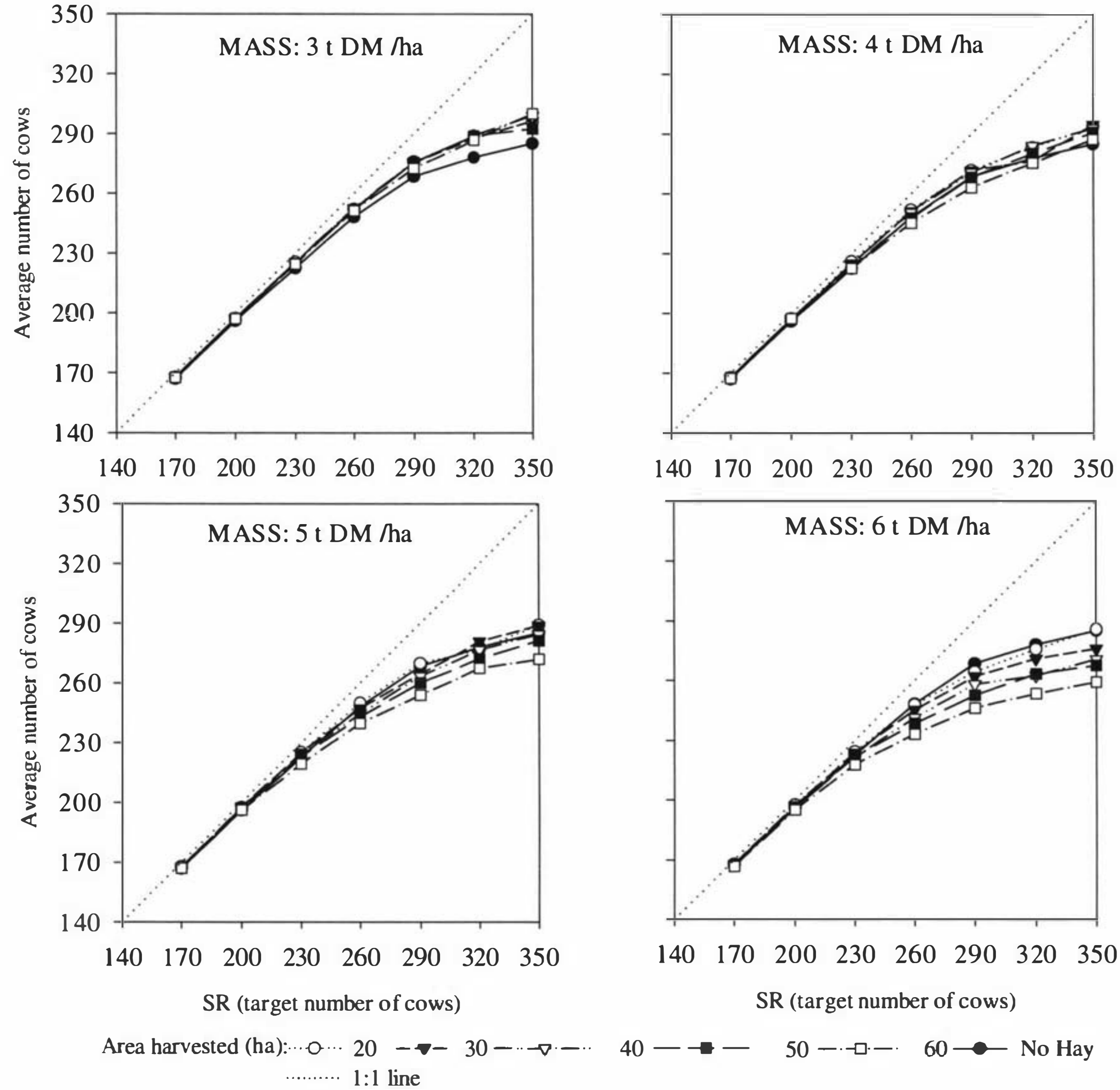

Figure 5.8: Relationship between target and actual number of cows for each combination of target number of cows (SR) for each combination of area closed for haymaking and cutting mass policy (MASS: target herbage mass to decide making hay, 3 to 6 t DM/ha)

5.4. DISCUSSION

Bishop-Hurley and Nuthall (1994) noted that most of the research on forage conservation and supplementation has been concerned with the effect of supplementation on individual animal production and performance, rather than on the integration of conservation into management systems. The objective of this study was to explore the effects of different haymaking policies at a strategic level by modelling a cow-calf farm. The results presented by Blaxter and Wilson (1963) relating to the optimal time to cut hay indicated that a single recommendation could not be made. According to those authors, any choice must depend on the type of animal production envisaged. In the case of Reserva 6, the hay is intended to maintain dry cows, a very flexible category of animals able to cope with the broadest range of food qualities. The conclusions drawn from this study should be considered in such a context.

Choosing between alternative haymaking strategies in a real farm represents a multicriteria problem, which in general cannot be solved by maximizing any single variable. The cost of haymaking, labour availability and many other variables are dependent on a particular farmer's situation and goals (Valentine et al., 1993). In line with the approach proposed by Cacho et al. (1999), instead of management recommendations, studies of this type provide information about system response patterns that decision makers can use according to their particular needs.

An important simplification was made, in order to concentrate attention on the strategic side of the problem (as opposed to operational day to day decisions). It was assumed in the simulations that cutting hay was always possible, regardless of the weather conditions. In a real situation, the weather conditions and outlook must be considered. To give an idea of how complicated it could be to formulate a realistic representation, Bishop-Hurley and Nuthall (1994) needed 350 rules for an expert system dealing only with surplus feed allocation for sheep farms.

The pasture model was originally calibrated and tested by its authors using grazed pasture data in New Zealand (McCall and Bishop-Hurley, 2003), but preliminary tests against Argentinean data (Chapter 3) permit reasonable confidence that it represents the response of actual pastures to different climatic conditions (i.e. variation between years). It should be noted however that the Argentinean data came from controlled short term (3 to 5 months) cutting trials and the results might not represent the production (and seasonal patterns) of pastures under grazing in the long term (Orr et al., 1988). When compared with Reserva 6 at similar stocking rate (i.e. 1.7 cows/ha) and haymaking policy (30% of the area allocated to haymaking and cutting at 6 t DM/ha) the simulated LW production showed good agreement with real data reported by Carrillo et al. (1998) for the period 1966-1995 (271±40 vs. 272±31 kg LW/ha/year, real and simulated respectively). However, the simulated system was able to sustain higher stocking rates than have been managed in real situations so far. The actual productivity of pastures under grazing is unknown, hence, in order to gain more confidence in the comparison between strategies, a range of stocking rates was used. The assumption behind this was that, in terms of strategy comparisons, a range of stocking rates would have more or less a similar effect as a range of pasture productivity. A strategy that performs better than the rest across a wide range of stocking rates in the model would have a good chance of performing well in the field. Therefore, the results produced by the model are not to be considered in absolute terms; rather the interest is in the relative behaviour of the different strategies, in which it is possible to have much greater confidence. According to Fu (2002) "*it is generally easier to compare solutions and find relative ordering among them that it is to estimate them precisely*".

Both the mean and variance of outputs from a management policy can be important criteria in decision making (Pleasants et al., 1995). Pasture conservation has been proposed as an option to make systems more resistant to drought (McMillan, 1989). In the present study, the strategy that did not use hay was consistently less productive and less stable than most of the combinations using hay. The differences however depended on cow numbers, being greatest at the intermediate levels of cow numbers. In Experiment 3, in Chapter 4, the variability of the system was significantly reduced by using hay, but the improvement in average production was moderate. This low impact can now be explained by the fact that, in that experiment, only the lowest level of stocking rate was used. It was also noted that the advantages of the haymaking strategies were more important when calf liveweight sold, rather than total liveweight sold, was considered. This reflects the effect of haymaking on improving the proportion of years with heifers reaching the target weight for mating at fifteen months.

The merits of using hay in pastoral systems are not universal. Taylor and Scales (1985) found no beneficial effect of using hay in terms of carcass weight gain per hectare in a series of farmlet studies, but those trials used young growing cattle and the farmlets were irrigated. Scattini (1984), working with tropical grass pastures, found small benefits from making and feeding hay, but again the experiments only included weaner steers and heifers grazing in winter and spring (May-November). In general, hay is not a particularly appropriate food for finishing stock. In such cases the main advantage would only come from the pasture-conditioning effect of haymaking (topping) by removing accumulated dead material in summer (Scattini, 1984). In contrast, breeding beef cows are well suited to eating low quality roughages during periods of feed restriction (Pleasants et al., 1994; McCall, 1994). In a three year farmlet study, Thomson et al. (1989) found little benefit of pasture conservation in dairy systems, though only 17-33% of the area was closed. The possible benefits of hay are highly dependent on the type of farming system being considered (e.g. finishing vs. cow-calf farms). An important part of the advantage of making hay lies in the reduction of system variability. Therefore the advantage will be larger the more inconsistent the climate of the region, and, in general, long term studies are required to capture effects of this type. In summary, the benefits of making and using hay will depend on the particular type of operation, the environmental conditions of the area under study (and to certain extent on the length of the study period) and on the way haymaking is managed, (i.e. the decisions of closing and mowing paddocks). All these elements make generalizations difficult.

The simulated results obtained here indicate that dedicating 40-50% of the total area of the farm to haymaking, and cutting at approximately at 4t DM/ha (therefore harvesting medium quality hay) would allow high stocking rates to be sustained and therefore give a more productive system. However, assigning too much area to haymaking, especially if the hay is made at a high mass, produced the worst performance among the haymaking policies across all the stocking rate range. The most extreme haymaking strategies did not perform better than the strategy without hay, and clearly cutting 60% of the area would be too much, since detrimental effects (i.e. lower productivity and greater variability) started to appear in relation to more moderate strategies.

Another observation that emerged from the results is that cow numbers affected the relative behaviour of the different strategies, both in average production and variability. The benefits of haymaking were more important at the intermediate cow numbers tested.

It seems that making hay at too high herbage mass is detrimental to the system. The effect on cow liveweight (Figure 5.2) indicates that this is likely to be due to the lower quality of the hay, although the longer period of time when the paddocks remain closed (while waiting for the herbage mass to accumulate) can also be part of the explanation. Another possibility could be that cutting hay late does not leave enough time for pasture to re-grow before winter. When hay is made early (3 – 4t DM/ha), it is possible to harvest up to 40-50% of the whole area of the farm and sustain very high cow numbers. Cutting at a low herbage mass (therefore early in the spring) on the other hand, reduces the possibilities of using haymaking as a pasture topping tool, which is an additional, but important, benefit. Therefore, with this scheme of closing a fixed area at a more or less fixed date, the optimum combination seems to be cutting at medium herbage mass and a rather large proportion of the farm (around 50%).

Among the strategies compared in the present study, that most similar to the haymaking policy applied in the Experimental Farm of INTA-Balcarce is the combination: 30ha, cutting at 6t DM/ha. According to the results obtained in the present study, this combination was in the mid-low part of the range, both in expected production and stability. At least when physical production is considered, and provided hay is made at medium herbage mass, more that 30% of the farm area could be harvested. The results also suggest that Reserva 6 could be improved by cutting at relatively lower herbage mass, and is apparently not currently allocating too much area to haymaking. Making approximately the same amount of hay per year, but moderately increasing its quality could lead Reserva 6 to increases in both productivity and stability.

Harvesting excessive amounts of hay by cutting at high herbage masses (and producing low quality hay) and harvesting more that 50% of the area, does not seem to be a useful alternative. However, making more hay that required for immediate needs could be beneficial if a more flexible haymaking policy were adopted, allowing the production of higher quantities of good quality hay, perhaps leading to more productivity and stability. In this case, hay surpluses could be carried to the next year and used as a buffer for the system, or be traded if the market conditions allowed it. Certain rigidity was observed in the Reserva 6 haymaking policy, in the sense that paddocks are closed on a calendar basis and closed paddocks are only released for grazing once the hay is made. A more flexible strategy that takes into account simple pasture budgeting to decide closing and harvesting of pastures is the subject of the next chapter.

5.5. CONCLUSIONS

The benefit of making hay, and the contrast between the effects of different haymaking strategies on animal outputs, depend on the stocking rate, being maximum around the stocking rate levels that delivers the maximum production. The long term liveweight production of cow-calf farms, under a rather rigid haymaking policy like the one explored here, would be maximized by harvesting 40-50% of the total farm area and aiming to harvest hay of medium quality.

The results obtained here indicate that the policy currently followed in Reserva 6 of allocating 30% of the farm to haymaking is not excessive, and suggest productivity could be increased by making hay at lower herbage mass, improving the quality of the hay produced.

5.6. APPENDIX

Table A 5.1: List of decision rules used in the simulations (see chapter 2 for details on the syntax used)

Applied to/condition	Action
Herd: 2 (Mature cows)	
R 0 SA[month] = 11 OR SA[month] = 12	join
R 1 SA[month] = 3 AND SA[day] = 2 AND CA[2,pregnant] = false AND CA[2,numberOfMatings] > 0 AND HA[2,pregnancyRate] > 0.8	sell cow
R 2 SA[month] = 3 AND (SA[day] = 31 AND CA[2,numberOfMatings] GE 15	sell cow
R 3 SA[month] = 3 AND SA[day] = 1 AND CA[2,lactating] = false	wean cow
R 4 SA[dayOfTheYear] > 225 AND SA[dayOfTheYear] < 285	feedHay, amount: 10
R 5 SA[pastureCover[17]] < 1000 AND SA[day] = 1 AND (CA[2,positionAgeRank] / HA[2,numberOfCow]) < 0.05	sell cow
R 6 CA[2,bodyCondition[18]] < 0.6	sell cow
R 7 SA[month] = 2 AND HA[2,meanBodyCondition] < 1	wean cow
R 8 **A**. SA[month] = 3 AND SA[day] = 3 AND CA[2,positionAgeRank[19]] < (SA[numberOfCows] - 170) **B**. SA[month] = 3 AND SA[day] = 3 AND CA[2,positionAgeRank] < (SA[numberOfCows] - 200) **C**. SA[month] = 3 AND SA[day] = 3 AND CA[2,positionAgeRank] < (SA[numberOfCows] - 230) **D**. SA[month] = 3 AND SA[day] = 3 AND CA[2,positionAgeRank] < (SA[numberOfCows] - 260) **E**. SA[month] = 3 AND SA[day] = 3 AND CA[2,positionAgeRank] < (SA[numberOfCows] - 290)	sell cow This rule controls the culling of old cows and it has 5 versions. The same version as in R 21 is always selected to control the cow number.
R 9 SA[month] = 2 AND SA[day] = 28 AND CA[2,lostCalf] = true AND HA[1,numberOfCow] > 0 AND HA[2,numberOfCalves] > ((3 * HA[1,numberOfCow]) - 5)	sell cow
R 10 SA[month] = 11 AND SA[day] = 1 AND CA[2,lostCalf] = true AND HA[2,numberOfCalves] > (3 * HA[1,numberOfCow]) - 5 AND HA[1,numberOfCow] > 0	sell cow
R 11 SA[pastureCover] < 1000 AND GP[2,greenHerbage] < 500	changePaddock
R 12 SA[pastureCover] > 1000 AND GP[2,greenHerbage] < 1000	changePaddock
R 13 SA[dayOfTheYear] < 225 OR SA[dayOfTheYear] > 285	feedHay, amount: 0

[17] PastureCover: average herbage mass on the farm
[18] bodyCondition: scale used by Freer et al. (1997), 1 is equivalent to 5 in the 1 to 9 scale.
[19] positionAgeRank: oldest cows at the top of the list

Applied to/condition	Action
R 14 **A**. SA[pastureCover] < 1600 AND HA[2,numberOfCalves]> 0 AND CA[2,positionAgeRank] < 35 **B**. SA[pastureCover] < 1600 AND HA[2,numberOfCalves] >0 AND CA[2,positionAgeRank] < 41 **C**. SA[pastureCover] < 1600 AND HA[2,numberOfCalves] > 0 AND CA[2,positionAgeRank] < 47 **D**. SA[pastureCover] < 1600 AND HA[2,numberOfCalves] > 0 AND CA[2,positionAgeRank] < 54 **E**. SA[pastureCover] < 1600 AND HA[2,numberOfCalves] > 0 AND CA[2,positionAgeRank] < 60	sell cow This rule controls "emergency" sales of cows and it has 5 versions. The same version as in R 21 is always selected.
Block: 2, nPaddocks=29	
R 15 BA[2,pastureCover] < 2000 AND HA[2,numberOfCow] > 0 AND (BA[1,numberOfPaddocks] GE 10 OR HA[1,numberOfCow] = 0 OR BA[inOffer,numberOfPaddocks] > 0)	withdrawPaddock
R 16 HA[2,numberOfCow] > 0 AND HA[2,meanBodyCondition] < 1 AND (BA[1,numberOfPaddocks] GE 10 OR HA[1,numberOfCow] = 0)	withdrawPaddock
R 17 (BA[inOffer,numberOfPaddocks] > 1 AND BA[2,numberOfPaddocks] LE 30)	withdrawPaddock
R 18 (HA[1,numberOfCow] > 0 AND (BA[1,pastureCover] < BA[2,pastureCover] AND (BA[inOffer,numberOfPaddocks] = 0 AND (PA[2,firstInRank[20]] = true AND BA[1,numberOfPaddocks] LE 10))))	depositPaddock
Herd: 1 (Replacement heifers)	
R 19 GP[1,greenHerbage] < 2500	changePaddock
R 20 CA[1,bodyCondition] < 0.6	sell cow
R 21 **A**. (SA[month] = 3 AND SA[day] = 2) AND CA[1,positionInRank] > (35 + COUNT[CAC[1,age] > 365]) **B**. (SA[month] = 3 AND SA[day] = 2) AND CA[1,positionInRank] > (41 + COUNT[CAC[1,age] > 365]) **C**. (SA[month] = 3 AND SA[day] = 2) AND CA[1,positionInRank] > (47 + COUNT[CAC[1,age] > 365]) **D**. (SA[month] = 3 AND SA[day] = 2) AND CA[1,positionInRank] > (54 + COUNT[CAC[1,age] > 365]) **E**. (SA[month] = 3 AND SA[day] = 2) AND CA[1,positionInRank] > (60 + COUNT[CAC[1,age] > 365])	sell cow This rule controls the sales of weaned heifers and it has 5 versions. The same version as in R 8 is always selected to control the cow number.
R 22 (SA[dayOfTheYear] = 305 AND HA[1,meanBodyCondition] > 0.99) OR (SA[dayOfTheYear] > 305 AND HA[1,isJoined] = true)	join

[20] firstInRank: this attribute is true if the paddock has the maximum herbage mass in block 2.

Applied to/condition	Action
R 23 SA[month] = 3 AND SA[day] = 2 AND CA[1,numberOfMatings] > 0 AND CA[1,pregnant] = false	sell cow
Block: 1, nPaddocks=10	
R 24 BA[1,pastureCover] > 2500 AND PA[1,grazingDay] = 0 AND PA[1,firstInRank] = true AND BA[1,numberOfPaddocks] > 2 AND BA[inOffer,numberOfPaddocks] = 0	depositPaddock
R 25 BA[1,pastureCover] < 2000 AND HA[1,numberOfCow] > 0	withdrawPaddock
R 26 BA[inOffer,numberOfPaddocks] > 1 AND BA[1,numberOfPaddocks] LE 10	withdrawPaddock
Herd: 3 (Mature cows on hay)	
R 27 (SA[pastureCover] < 1000 AND (SA[day] = 1 OR SA[day] = 15)) AND (CA[3,positionAgeRank] / HA[3,numberOfCow]) < 0.95	sell cow
R 28 CA[3,bodyCondition] < 0.6	sell cow
R 29 HA[3,numberOfCow] > 0 AND SA[dayOfTheYear] < 225	feedHay , amount: SA[hayStock] / (HA[3,numberOfCow] * (225 - SA[dayOfTheYear]))
R 30 HA[3,numberOfCow] = 0	feedHay , amount: 0
R 31 SA[dayOfTheYear] > 225 AND HA[3,numberOfCow] > 0	feedHay, amount: 10
Block: 3, nPaddocks=1	
R 32 HA[3,numberOfCow] = 0	depositPaddock
R 33 HA[3,numberOfCow] > 0 AND BA[3,numberOfPaddocks] = 0	withdrawPaddock
R 34 BA[3,numberOfPaddocks] > 1 AND (PA[3,lastInRank] = true AND PA[3,onGrazing] = false)	depositPaddock
HerdOrganizer (Class in charge of assigning the cows to the herds)	
R 35 CA[age] < (791 - CA[DOYOfBirth]) AND CA[gender] = 2	toHerd: 1
R 36 SA[dayOfTheYear] GE 93 AND SA[dayOfTheYear] LE 284 AND (CA[age] > 800 AND CA[lactating] = false AND SA[hayStock] > 0 AND (SA[hayStock] GE COUNT[CAC[2,age] > 800] * (1797.5 - (8 * SA[dayOfTheYear])) OR HA[3,numberOfCow] > 0)	toHerd: 3
R 37 CA[age] GE (791 - CA[DOYOfBirth]) AND CA[gender] = 2	toHerd: 2
PaddockBank	
R 38 **A.** false **B.** PA[closed] = true AND (PA[totalHerbage] > 3000 OR SA[dayOfTheYear] = 1)	makeHay This rule controls the mowing.

Applied to/condition	Action
C. PA[closed] = true AND (PA[totalHerbage] > 4000 OR SA[dayOfTheYear] = 20) **D.** PA[closed] = true AND (PA[totalHerbage] > 5000 OR SA[dayOfTheYear] = 40) **E.** PA[closed] = true AND (PA[totalHerbage] > 6000 OR SA[dayOfTheYear] = 60)	It has 5 versions corresponding to the 5 MASS treatments.
R 39 **A.** false **B.** (BA[closed,area] + SA[areaCut]) < 20 AND (SA[month] > 9 AND PA[restingDays] = 1) **C.** (BA[closed,area] + SA[areaCut]) < 30 AND (SA[month] > 9 AND PA[restingDays] = 1) **D.** (BA[closed,area] + SA[areaCut]) < 40 AND (SA[month] > 9 AND PA[restingDays] = 1) **E.** (BA[closed,area] + SA[areaCut]) < 50 AND (SA[month] > 9 AND PA[restingDays] = 1) **F.** (BA[closed,area] + SA[areaCut]) < 60 AND (SA[month] > 9 AND PA[restingDays] = 1)	closePaddock This rule controls the paddocks closing up. It has 5 versions corresponding to the 5 AREA treatments.
R 40 PA[wasCut] = true	releasePaddock
R 41 SA[dayOfTheYear] = 90 AND PA[closed] = true	makeHay
WeanerPool (Auxiliary herd containing weaners until sold or assigned to a herd)	
R 42 CA[weaners,gender] = 1	sell cow
R 43 (SA[month] = 1 OR SA[month] = 2) AND CA[weaners,positionInRank] > 40	sell cow

Table A 5.2: Analysis of variance for average total LW sold (kg DM/ha/year) in terms of the factors SR (target number of cows), AREA (area closed for haymaking) and MASS (target cutting herbage mass).

Source	DF	SS	MS	F Value	Pr > F
Model	158	7389072.3	46766.3	199.6	<.0001
Error	2641	618800.3	234.3		
Corrected Total	2799	8007872.5			

R-Square	Coeff Var	Root MSE	Mean
0.92	4.1	15.3	369

Source	DF	SS	MS	F Value	Pr > F
SR	6	5388488	898081	3833	<.0001
AREA	4	184218	46055	197	<.0001
MASS	3	777474	259158	1106	<.0001
AREA*MASS	12	77161	6430	27	<.0001
SR*AREA	24	89871	3745	16	<.0001
SR*MASS	18	204308	11350	48	<.0001
SR*AREA*MASS	72	57386	797	3	<.0001
Replicate	19	610168	32114	137	<.0001

Table A 5.3: Analysis of variance for average calf LW sold (kg DM/ha/year) in terms of the factors SR (target number of cows), AREA (area closed for haymaking) and MASS (target cutting herbage mass).

Source	DF	SS	MS	F Value	Pr > F
Model	158	1834927.5	11613.5	126.8	<.0001
Error	2641	241981.2	91.6		
Corrected Total	2799	2076908.7			

R-Square	Coeff Var	Root MSE	Mean
0.88	4.62	9.572086	207

Source	DF	SS	MS	F Value	Pr > F
SR	6	1305419.7	217570.0	2374.6	<.0001
AREA	4	18031.7	4507.9	49.2	<.0001
MASS	3	138977.2	46325.7	505.6	<.0001
AREA*MASS	12	17772.1	1481.0	16.2	<.0001
SR*AREA	24	11971.6	498.8	5.4	<.0001
SR*MASS	18	75481.2	4193.4	45.8	<.0001
SR*AREA*MASS	72	15753.4	218.8	2.4	<.0001
Replicate	19	251520.6	13237.9	144.5	<.0001

Table A 5.4: Analysis of variance for the coefficient of variation (average of 20 within-replicate CVs) of calf LW sold (kg DM/ha/year) in terms of the factors SR (target number of cows), AREA (area closed for haymaking) and MASS (target cutting herbage mass).

Source	DF	SS	MS	F Value	Pr > F
Model	158	400506.522	2534.8514	227.18	<.0001
Error	2641	29467.5215	11.1577		
Corrected Total	2799	429974.044			

R-Square	Coeff Var	Root MSE	Mean
0.93	11.6	3.3	28.8

Source	DF	SS	MS	F Value	Pr > F
SR	6	349295.163	58215.8604	5217.54	<.0001
AREA	4	1181.6383	295.4096	26.48	<.0001
MASS	3	2537.4937	845.8312	75.81	<.0001
AREA*MASS	12	454.0866	37.8405	3.39	<.0001
SR*AREA	24	1408.7116	58.6963	5.26	<.0001
SR*MASS	18	8731.9701	485.1095	43.48	<.0001
SR*AREA*MASS	72	1483.519	20.6044	1.85	<.0001
Replicate	19	35413.9404	1863.8916	167.05	<.0001

Table A 5.5: Means and standard deviation (average of 20 within-replicate SDs) for total liveweight sold (kg/ha/year) for different combinations of area closed for hay making (AREA: ha), cutting mass policy (MASS: t DM/ha), and target cow number (SR).

		MASS					
SR	AREA	3	4	5	6	Mean	NoHay
170	20	286±40	293±35	285±36	275±34	280±34	
	30	281±42	290±29	278±32	272±31[1]	281±33	
	40	279±42	288±28	281±30	275±32	283±37	
	50	276±43	291±34 (303±45[2])	284±35	282±37	282±39	
	60	276±43	291±34	283±39	278±42	272±46	
	Mean	280±42	291±32	282±34	276±35	282±36	272±46
200	20	338±51	343±51	335±51	324±48	329±48	
	30	333±50	340±45	327±47	315±48	329±52	
	40	336±55	341±50	323±51	315±52	331±55	
	50	337±54	339±54 (356±69[2])	331±55	319±58	327±62	
	60	332±57	338±62	325±61	312±67	317±59	
	Mean	335±54	340±52	328±53	317±55	330±54	317±59
230	20	374±69	380±77	371±74	359±70	369±70	
	30	376±67	381±67	367±73	351±72	369±71	
	40	381±70	384±66	364±72	346±74	366±73	
	50	381±67	379±68 (387±92[2])	360±75	344±84	358±80	
	60	377±69	373±73	350±87	330±93	351±76	
	Mean	378±69	379±70	362±76	346±78	366±73	351±76
260	20	410±93	413±96	401±107	389±107	401±98	
	30	415±91	419±94	394±104	376±103	398±97	
	40	421±87	419±89	387±107	365±104	392±101	
	50	421±89	410±97 (397±138[2])	380±110	358±110	377±107	
	60	413±88	395±104	364±116	336±119	378±105	
	Mean	416±90	411±96	385±109	365±109	394±101	378±105
290	20	439±125	429±128	419±136	402±141	418±134	
	30	440±125	433±131	408±141	391±142	414±133	
	40	445±123	433±133	403±141	376±135	403±134	
	50	444±128	423±132 (404±158[3])	387±138	360±136	388±136	
	60	436±124	406±138	369±142	339±141	397±133	
	Mean	441±125	425±132	397±140	374±139	409±134	397±133
320	20	438±195	431±201	411±196	406±189	415±194	
	30	438±202	415±205	415±186	393±185	411±190	
	40	441±202	425±200	404±183	373±176	400±185	
	50	437±207	413±199 (385±214[2])	390±174	360±160	383±186	
	60	432±210	397±199	369±172	332±163	397±199	
	Mean	437±203	416±201	398±182	373±175	406±191	397±199
350	20	424±231	414±227	406±218	400±219	410±227	
	30	429±242	421±230	410±220	381±214	405±216	
	40	435±234	418±230	397±207	370±194	388±213	
	50	413±245	408±229 (366±237[2])	382±200	348±179	373±205	
	60	420±240	388±218	362±201	320±162	382±227	
	Mean	424±238	410±227	391±209	364±194	397±217	382±227
Mean		345±113	387±117	382±116	364±115	345±112	

[1] Similar combination to Reserva 6 (see text for details). [2] Hay harvested but not fed back to the animals.

Table A 5.6: Mean and standard deviation (average of 20 within-replicate SDs) of calf liveweight sold (kg/ha/year) for different combinations of area closed for hay making (AREA: has), cutting mass policy (MASS: t DM/ha), and target cow number (SR).

		MASS					
SR	AREA	3	4	5	6	Mean	NoHay
170	20	158±32	170±20	165±21	160±23	162±23	
	30	155±32	168±19	163±21	160±21[1]	162±24	
	40	153±33	168±19	165±22	162±22	163±26	
	50	151±34	169±22 (172±32[2])	166±24	164±25	162±28	
	60	152±34	169±23	165±26	163±28	142±36	
	Mean	154±33	169±21	165±23	162±24	161±26	142±36
200	20	187±38	198±30	193±32	187±31	189±32	
	30	183±39	197±29	191±29	185±30	191±33	
	40	187±40	198±30	190±30	187±31	192±34	
	50	189±40	198±32 (202±45[2])	194±32	189±34	190±37	
	60	186±40	198±35	191±36	184±40	167±45	
	Mean	186±40	198±31	192±32	187±33	189±34	167±45
230	20	206±47	215±45	211±44	204±45	211±44	
	30	208±48	219±42	213±42	204±43	213±43	
	40	212±48	223±41	213±41	204±43	213±46	
	50	214±49	221±43 (216±60[3])	213±43	205±47	208±49	
	60	212±50	218±46	207±48	195±52	179±57	
	Mean	210±48	219±43	211±44	203±46	209±46	179±57
260	20	222±58	227±57	221±60	215±62	223±58	
	30	226±58	235±56	221±59	212±59	225±58	
	40	231±58	237±56	221±60	211±58	224±59	
	50	233±59	235±58 (214±81[2])	221±59	208±59	216±62	
	60	231±59	226±62	213±62	194±64	188±65	
	Mean	229±58	232±58	219±60	208±60	220±59	188±65
290	20	235±71	233±72	228±74	219±77	229±74	
	30	237±72	238±73	224±76	217±74	232±74	
	40	242±72	242±74	229±75	213±72	228±74	
	50	243±74	241±76 (211±89[2])	222±75	206±72	220±74	
	60	241±72	230±77	213±75	195±72	196±74	
	Mean	240±72	237±74	223±75	210±74	226±74	196±74
320	20	234±96	232±96	222±97	220±94	227±96	
	30	236±98	225±99	230±94	216±92	227±93	
	40	239±98	236±98	226±91	206±87	224±91	
	50	238±98	232±97 (201±103[3])	221±89	205±81	215±90	
	60	238±99	223±98	212±86	188±79	202±94	
	Mean	237±98	230±98	222±91	207±87	223±93	202±94
350	20	221±108	219±107	214±102	211±104	218±106	
	30	224±113	226±108	219±103	203±101	219±102	
	40	233±111	226±108	216±101	201±90	213±99	
	50	221±111	222±106 (183±108[2])	213±97	196±81	206±96	
	60	226±109	214±104	201±92	182±78	187±101	
	Mean	225±110	221±107	213±99	199±91	213±102	187±101
Mean		345±113	212±66	215±62	206±60	196±59	

[1] Similar combination to Reserva 6 (see text for details). [2] Hay harvested but not fed back to the animals.

CHAPTER 6

COMPARISON OF HAYMAKING STRATEGIES: INCORPORATING FLEXIBILITY

Abstract

During the spring-summer period, pasture production normally exceeds demand, and conserving forage at this time for use during the following winter is a widespread practice. The objective of this study was to analyse the long term performance of a range of haymaking policies, specifically to assess the possible advantages of incorporating flexibility into the calendar-based haymaking policy developed at the experimental cow-calf farm of INTA-Balcarce Experimental Station ("Reserva 6"). The results suggest that controlling haymaking in a flexible fashion, basing the decisions of closing, releasing and cutting paddocks on a simple pasture budget, could give the system productive advantages over using a calendar-based approach. Compared at the same area harvested, the benefits would include increases in productivity together with reductions in the variability of the system. However, whether or not the advantages are sufficiently attractive against the simplicity of the Reserva 6 approach would depend on each particular case. In the simulations, taking a flexible haymaking approach reduced the range of hay digestibility values across treatments, but increased the variability within treatments. The results indicated that allocating more than 50-60% of the farm area to conservation would only be advantageous at very high stocking rates. Also, making more hay than required for the immediate next winter, where possible, can reduce system variability.

6.1. INTRODUCTION

Pasture production is highly seasonal, with 50-70% of the total production occurring in spring-summer in many parts of the world (Orbea, 1970; Orbea et al., 1971; McCall and Smith, 1998). During this period, pasture production normally exceeds demand, and conserving forage at this time for use during the following winter is a widespread practice. The experimental cow-calf farm (referred to hereafter as "Reserva 6") of INTA-Balcarce Experimental Station, allocates 30% of the total area of the farm to produce hay in this way (Carrillo et al., 1998).

Conservation can improve herbage utilization, but can also be used in risk management, buffering the system against climatic variations (Lowman and Illius, 1985; McMillan, 1989). But to exploit this opportunity, hay has to made in excess of what is needed for average-year feeding.

Pasture conservation is a complicated and expensive exercise, and requires a considerable amount of planning. However, as pointed out by Hodgson (1990), preliminary judgments about the proportion of the total area taken out for conservation have to be made, and because this area must be isolated for some time, the control can only be approximate. When deciding to close paddocks it is simply not known what the future climatic conditions will be. Apart from this uncertainty arising from the environment, it is also difficult to make exact calculations because of the dynamic nature of the system. The actions taken today will affect the subsequent evolution of the system. For example, if a very high proportion of the farm is used for haymaking, then a high quantity of hay will be required in the next winter, since less standing pasture will be left at the end of the summer. Two basic elements must be defined in a haymaking strategy; how much hay is made and how much is used; and since both are interdependent at least one must be fixed arbitrarily. These, in turn, are determined by area allocated for haymaking, herbage mass at cutting and the amount of hay offered to the animals.

There are several ways to base haymaking decisions on rational considerations. A simple conceptual approach is to consider only what happens in the average year (Anderson and White, 1991). The haymaking policy followed in Reserva 6, as described in the previous chapter, is based on this idea. The problem with this is that the year-to-year climatic variations, which are crucial in strategic-tactical decision making (van Keulen and Penning de Vries, 1993), are not considered. There is no such a thing as the "typical average year" (Anderson and White, 1991). The Reserva 6 approach is designed to be easy to implement, communicate and control, which are especially important considerations in the case of large and/or intensive farms, but it could be too rigid in the face of climatic variation between years. Flexibility has been recognized as a key element in planning forage conservation. Hodgson (1990) argues that it is important to retain as much flexibility as possible in the timing and extent of the conservation program. He explains, for example, that there is no reason to assume that swards initially set up for conservation should not be used instead for grazing if conditions require it.

The objective of this chapter was to analyse the long term performance of a range of haymaking policies for cow-calf systems, specifically to assess the possible advantages of incorporating flexibility into the haymaking policy currently applied in Reserva 6. Long term simulations using real weather data were used to explore a range of possible haymaking policies.

6.2. MATERIAL AND METHODS

The haymaking policy applied in Reserva 6 was represented in terms of decision rules as was described in the previous chapter. The area harvested is mostly predetermined, in the sense that paddocks for conservation are closed in early October (calendar-based approach) and not re-included in the grazing sequence until hay is made. In general, once a paddock is set up for haymaking, the decision is not reviewed. The alternative strategies examined in Chapter 5 all shared this calendar-based approach.

In this chapter, a more flexible policy was developed and tested, in which the decisions to close paddocks for haymaking take into account the herbage supply on the farm. This flexible policy will be explained in the remainder of this section.

The animals were grouped into three herds, as explained in the previous chapters, each herd grazing its own group of paddocks ("Block"). In the model, different numbers of paddocks can initially be allocated to these blocks, but decision rules may dynamically move paddocks between blocks (and hence herds). This feature of the model permits a realistic representation of what a farmer would do. In a real situation no one would assign a fixed area to each herd, instead paddocks would be grazed alternately by each group of animals. To accomplish this, apart from the blocks used by the animals, the model creates two auxiliary blocks. One of them is the "*inOffer*" block, where the herd blocks can "*deposit*" or "*borrow*" paddocks, using a savings bank analogy. The other is the "*closed*" block, which contains paddocks that, temporarily, cannot be accessed by the animals, for example those assigned to forage conservation. Blocks 1 and 2 are grazing blocks, for heifers and cows respectively. Block 3, in this particular simulated farm, is a single wintering paddock[21]. More details about the implementation of this part of the model are explained in Chapter 2 (section 2.2.5.1).

Under this scheme, the closed paddocks operate as a kind of buffer area that can be grazed if required. That is, closed paddocks can be released without making hay in cases where there is not enough herbage for the animals. This principle is analogous to the "buffer grazing system" described by Lowman and Illius (1985) and by Hodgson (1990). This is achieved as follows. Only the paddocks in the inOffer block can be closed, provided that it is spring-summer. Blocks 1 and 2 deposit their first ranked paddock in terms of herbage mass only when:

1. the paddock herbage mass is greater than 3t DM/ha, and
2. the paddock is not currently being grazed,
3. and there are more that n paddocks with more that 1.5t of green DM/ha ahead of the herd in the projected grazing cycle (n=5 and n=10, for blocks 1 and 2, respectively).

The blocks can borrow paddocks (one at a time) if the number of paddocks with more that 1.5t DM/ha falls below 4 in block 1 or 8 in block 2.

Closed paddocks can be released for grazing:

1. After being cut (but note that a paddock that is released can be closed/cut again in the same season), or
2. at the end of summer, or

[21] This paddock returns to the grazing circuit once all the cows have calved and joined Herd 2, and is treated as any other paddock. However, this Block does not participate in the exchange of paddocks during winter.

3. when a maximum area (AREA) has been already harvested, or
4. when the number of paddocks with more that 1.5t DM/ha in the blocks is low (3 in block 1; 8 in block 2) and there are less than 4 paddocks on offer.

Closed paddocks are harvested when a minimum target herbage mass (MASS) is reached. Figure 6.1 summarizes graphically the rules that control paddock allocation.

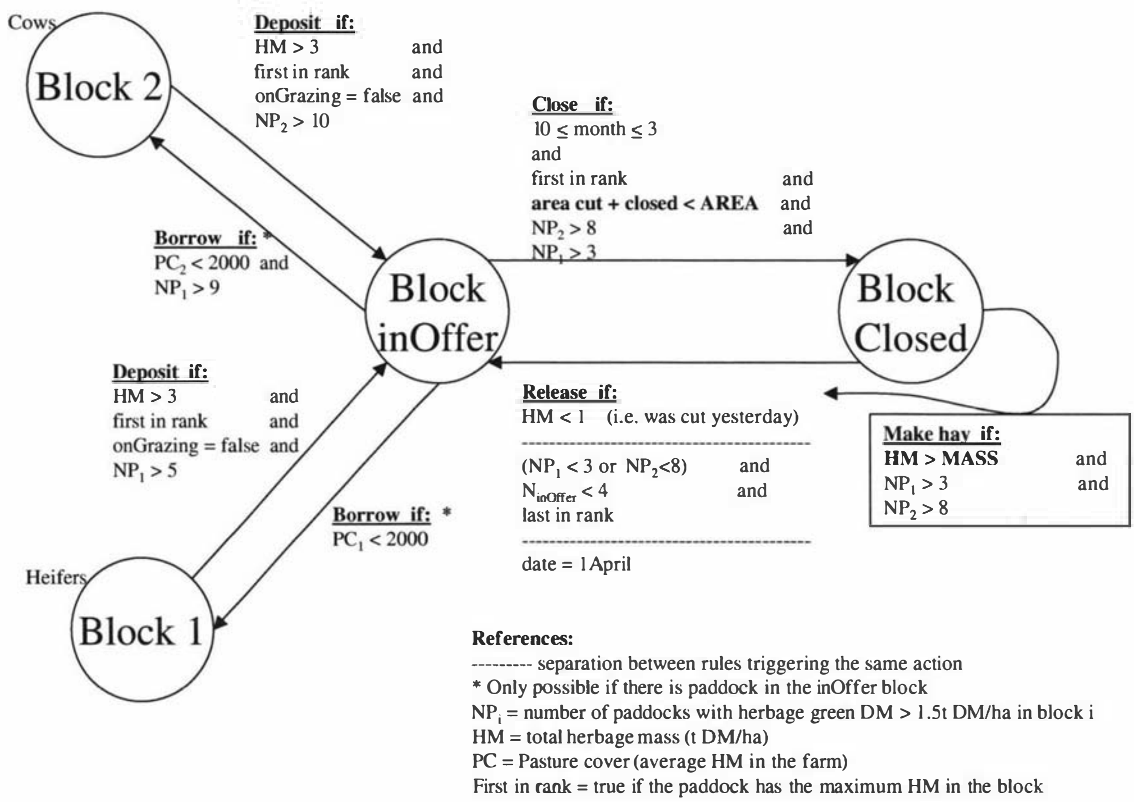

Figure 6.1: Graphical representation of the rules controlling the exchange of paddocks between the blocks.

Three management variables, comparable to those studied in the previous chapter, were explored: the target cow number (SR: target total number of cows/100ha after the autumn sales); the area allocated for hay making in spring (AREA[22]: ha) including, where appropriate, the summation of area from paddocks cut more than once; and the minimum herbage mass at which hay harvesting is decided (MASS: t DM/ha). If the target herbage mass for cutting is not reached by a limit date (1 April) the closed paddocks are released for grazing.

The experimental protocol was similar to the one described in the previous chapter. A factorial experiment was designed and implemented on a simulated 100ha cow-calf farm. In order to explore the limits of the system three more levels of the factor AREA were

[22] Note that AREA represents the maximum area that can be cut in a year, therefore it does not mean that exactly this area will be cut every year.

simulated, including a policy where no restriction was imposed on the area taken for haymaking per year (referred to hereafter as "Unlimited"). See Table 6.1 for details.

Table 6.1: Management strategies compared in the study

Variable	Levels							
SR (cows)	**170**[1]	200	230	260	290	320	350	
AREA (ha)	20	**30**[1]	40	50	60	70	100	Unlimited[2]
MASS (t DM/ha)	3	4	5	**6**[1]				

[1]Policy approximately applied in Reserva 6.
[2]No limit pre-imposed in the area allocated for haymaking

Two hundred and twenty four combinations (7 * 8 * 4, levels of SR, AREA and MASS, respectively) were generated and tested. Every strategy was repeated 20 times, each replicate being an independent simulation over a 50 year period with random weather. As in the previous experiments, the model was run for 10 years with average weather data to initialise the state variables of the system before running the actual replicates. The results were analysed as randomised complete blocks (replicate as block) for AREA, MASS, SR and their interactions, using analysis of variance. The GLM procedure of SAS was used (SAS, 1999).

6.3. RESULTS

The quantity and quality of the hay produced is shown in Table 6.2 and Table 6.3 (See also Figure A 6.1. Appendix, section 6.6). Figure 6.2 depicts the area actually harvested in each year and Figure 6.3 shows the actual mass at which hay was made on average in each policy. With this approach the variable AREA is a maximum limit and the variable MASS is a minimum limit, thus the area harvested, the actual herbage mass at cutting and consequently the amount (and quality) of hay produced are outputs of the system and exhibit wide variation between years. The area actually cut was more variable at high AREA and MASS. The herbage mass at cutting was more variable at low MASS (Figure 6.3). The variations in the area cut and in the herbage mass at cutting (which are not exactly determined by AREA and MASS) tended to reduce the differentiation between some of the polices.

Because the haymaking policies allow for closed paddocks to be released for grazing if required, the amount of hay produced was also influenced by the stocking rate of the farm. Therefore, the higher the cow numbers the smaller the chances of closing area off from grazing to make hay (Figure 6.4, upper panel). The cow numbers have also a direct effect on the amount of hay consumed each year. Figure 6.4 (lower panel) shows how both cow numbers and the haymaking policy determine the proportion of the hay made that is consumed on average in a year.

Table 6.2: Means and standard deviations[1] of the total amount of hay produced per year on the farm (t DM/year) for each haymaking policy.

	Minimum cutting herbage mass (t DM/ha)			
AREA	3	4	5	6
20	54±15	56±16	66±22	72±32
30	85±27	86±27	100±35	108±48
40	119±43	117±44	134±52	142±67
50	147±67	145±71	158±82	159±99
60	168±76	169±82	179±95	178±115
70	186±80	193±91	194±107	187±125
100	225±99	228±119	220±136	200±148
Unlimited	284±147	255±152	224±151	198±149

[1] Average SD within replicate.

Table 6.3: Means and standard deviations[1] for the hay DM digestibly for each haymaking policy.

	Minimum cutting herbage mass (t DM/ha)			
AREA	3	4	5	6
20	52±5	51±5	49±5	48±5
30	51±5	50±4	49±5	48±5
40	51±5	50±5	49±5	48±5
50	50±5	50±5	49±5	48±5
60	51±4	51±4	50±4	49±4
70	52±4	52±4	51±4	49±4
100	54±4	53±4	52±4	50±5
Unlimited	56±4	54±4	52±5	50±5
Column mean	52±4[a]	51±4[b]	50±5[c]	49±5[d]

[abcd] Means followed by different letters are significantly different ($p<0.05$), t pairwise test.
[1] Average SD within replicate.

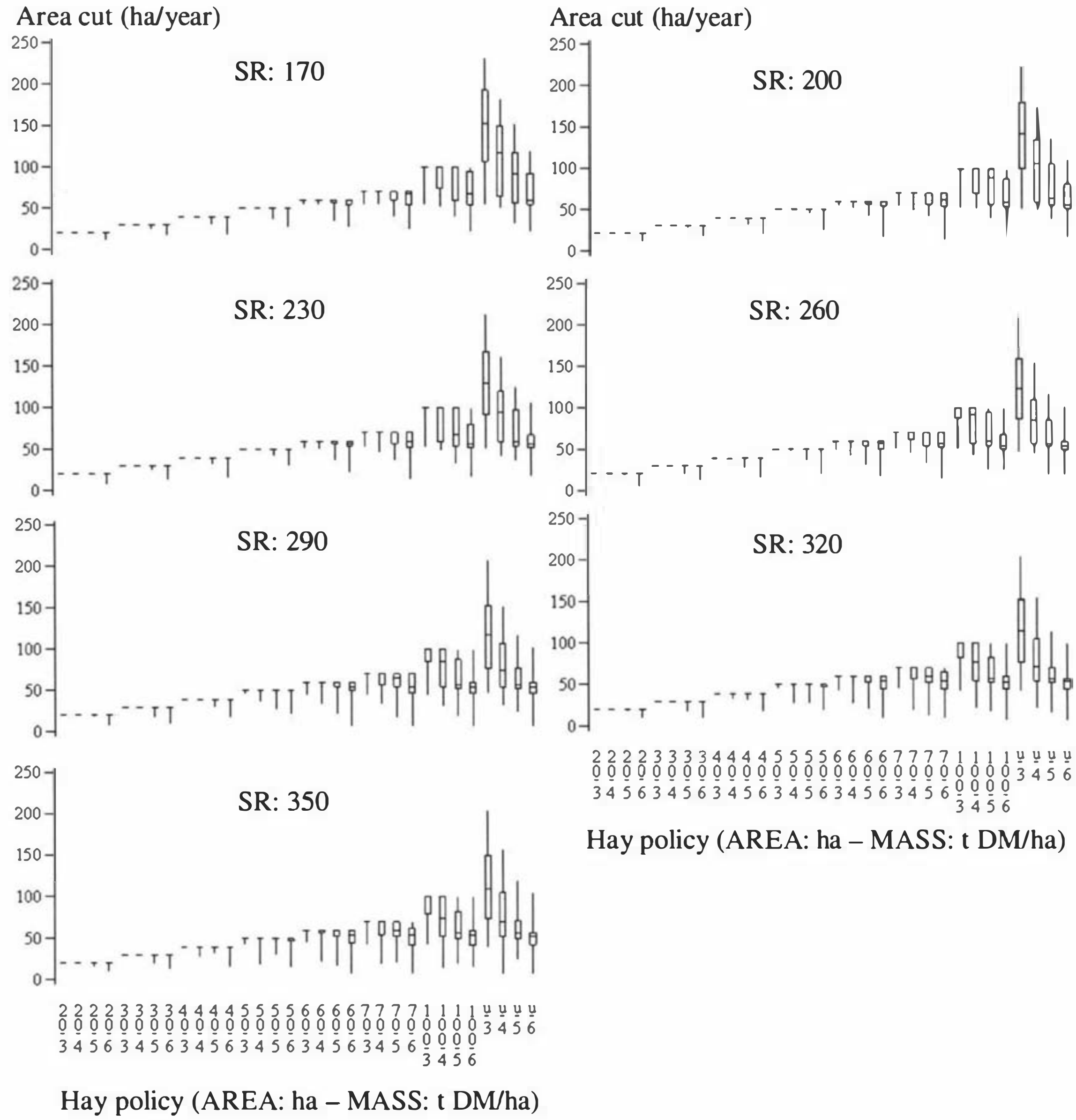

Figure 6.2: Boxplot representation of the area used for haymaking per year for each cow number (SR) and hay making policy. AREA = area closed for hay making (20 to 100 ha, and u: unlimited) and MASS = target herbage mass to decide cutting (3 to 6 t DM/ha). Combinations such as AREA=20 and MASS=3 are denoted by "20-3" on the axes. Whiskers indicate 5th percentile low, 95th high.

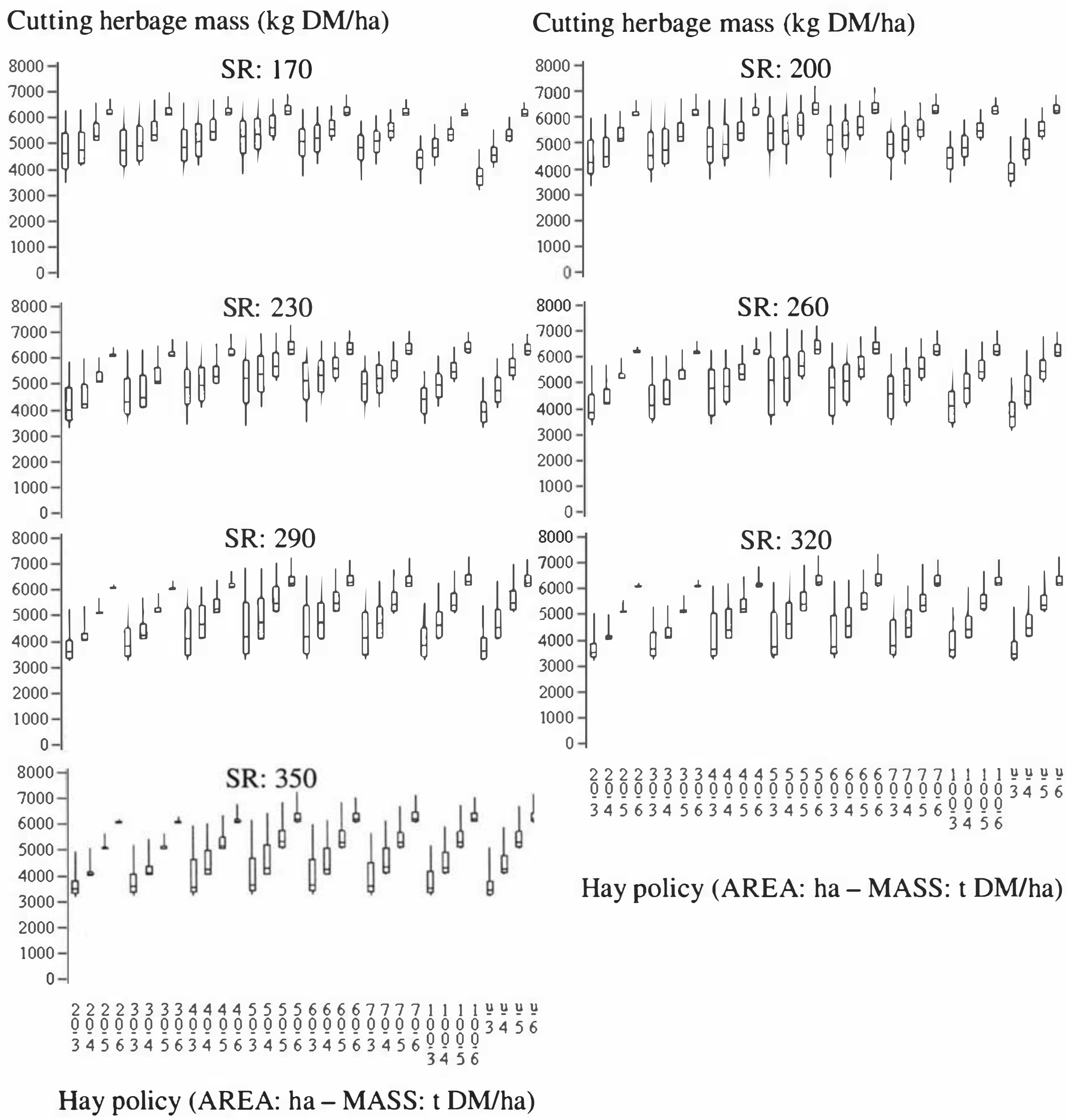

Figure 6.3:Boxplot representation of the average herbage mass at cutting for each target cow number (SR) and haymaking policy. AREA = area closed for hay making (20 to 100 ha, and u: unlimited) and MASS = target herbage mass to decide cutting (3 to 6 t DM/ha). Combinations such as AREA=20 and MASS=3 are denoted by "20-3" on the axes. Whiskers indicate 5th percentile low, 95th high.

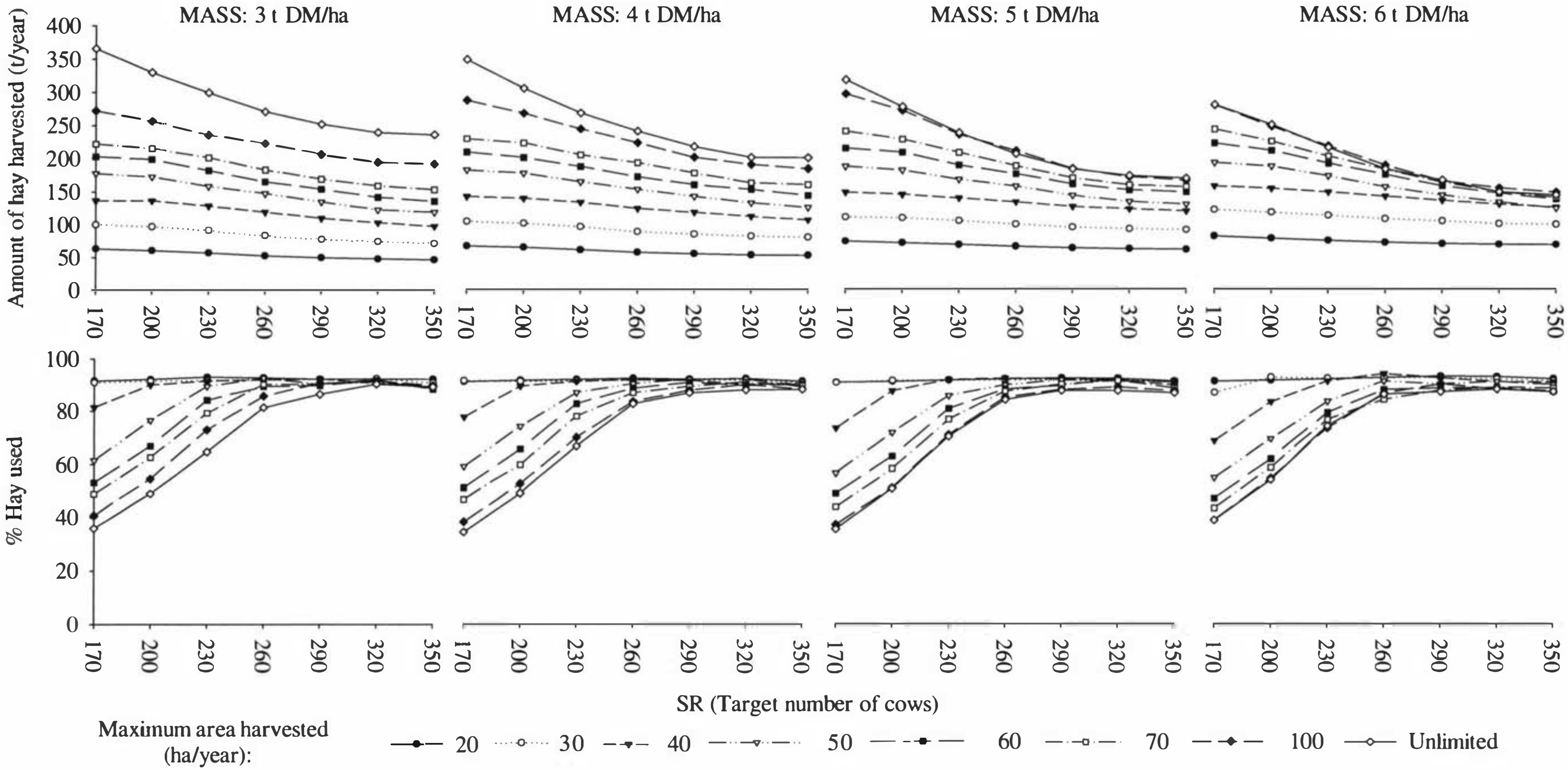

Figure 6.4: Influence of the maximum area harvested for hay and the cutting mass policy on the amount of hay produced (upper panel) and the proportion of hay used (lower panel) for each target cow number (SR).

The three main effects and the simple interactions were all significant in the ANOVA for the total amount of liveweight (LW) sold (kg LW/ha/year) and the amount of calf liveweight sold (kg LW/ha/year) (Table A 6.2 and Table A 6.3. Appendix, section 6.6). The variable SR was the most important source of variation for both variables, explaining 87 and 73% of the total variation in total LW sold and calf LW sold, respectively. AREA was more important than MASS, which is the opposite of the results obtained in the previous chapter using a calendar-based policy. Figure 6.5 shows the combined effect of AREA and MASS on calf LW sold for the different target cow numbers using contour (unlimited area policy not included), and line graphs (see also Table A 6.1. Appendix, section 6.6). The amount of calf LW sold was maximised when no limit was imposed on the area harvested, at intermediate cow numbers, and when hay was made at low herbage mass. The different haymaking policies had similar response curves to target cow numbers, although the more favourable policies showed higher maximums. Replicate was also an important independent variable in relative terms, explaining 7 and 13% of the variation in total and calf LW sold, respectively. This indicates the importance of not relying on one single simulation run in the evaluation of dynamic systems when they are subjected to external random influences such as weather.

As the area actually harvested can be smaller than the maximum specified by the variable AREA, in Figure 6.6 calf LW sold is plotted against the average area actually harvested per year for each policy and stocking rate. The figures suggest that, even with this flexible approach, cutting more that 50-60% of the area would not produce much benefit in production terms, except at very high cow numbers. Figure 6.6 also suggests that the benefits of the flexible approach with respect to the best calendar-based strategy, at the same area harvested, were less evident at the highest cow numbers. Note also in Figure 6.6 that the average production of the calendar-based option decreased when more than 40-50% of the area of the farm was harvested. This decline, did not occur with the flexible strategy.

The effect of the strategies on the variability of the system outputs was also explored. In the ANOVA for the coefficient of variation (CV) of calf LW sold, SR, AREA and their first order interactions were significant (Table A 6.4. Appendix, section 6.6). The variable SR was most important, accounting for more that 80% of the variation in CV for calf LW sold. Figure 6.7 indicates that, as expected, the variability of the system increased with cow numbers. The difference between the cutting mass policies were small and lacked any consistent pattern across the range of cow numbers. The figure also shows no further gain (i.e. reduction in variability) from harvesting beyond 50% of the area, except at high cow numbers. The flexible approach tended to be more stable than the calendar-based strategy, compared at the same area harvested (MASS = 4t DM/ha calendar-based is shown as an example in Figure 6.7).

Figure 6.8 compares the most productive calendar-based (40-4: harvest 40ha of hay cutting at a minimum herbage mass of 4 t DM/ha) and flexible haymaking strategies (UL-3: unlimited area for hay, cutting at a minimum herbage mass of 3 t DM/ha;) against the Reserva 6 approach (30-6: harvest 30ha of hay, cutting at a minimum herbage mass of 6 t DM/ha). The three strategies showed maximum calf LW production[23] at similar cow numbers (292, 294 and 297 cows/100ha, for 30-6, 40-4 and UL-3, respectively) but, at the peak of the curves, improvements of 26 and 36% with respect to the Reserva 6 strategy were predicted (218, 245 and 264kg LW/ha/year, for 30-6, 40-4 and UL-3, respectively). The coefficient of variation of calf LW production increased with the increase in cow numbers in all cases, although the increase was notably slower in the flexible combination. It must be noted that in order to achieve this increase in productivity and reduction in variability, the flexible combination (UL-3) produced large quantities of hay. For example, for a target cow number of 290cows, this strategy produced 28% more hay than the amount required for one winter.

[23] Calculated by equating to 0 the first derivative of the quadratic fitted response function of calf LW sold to the cow numbers.

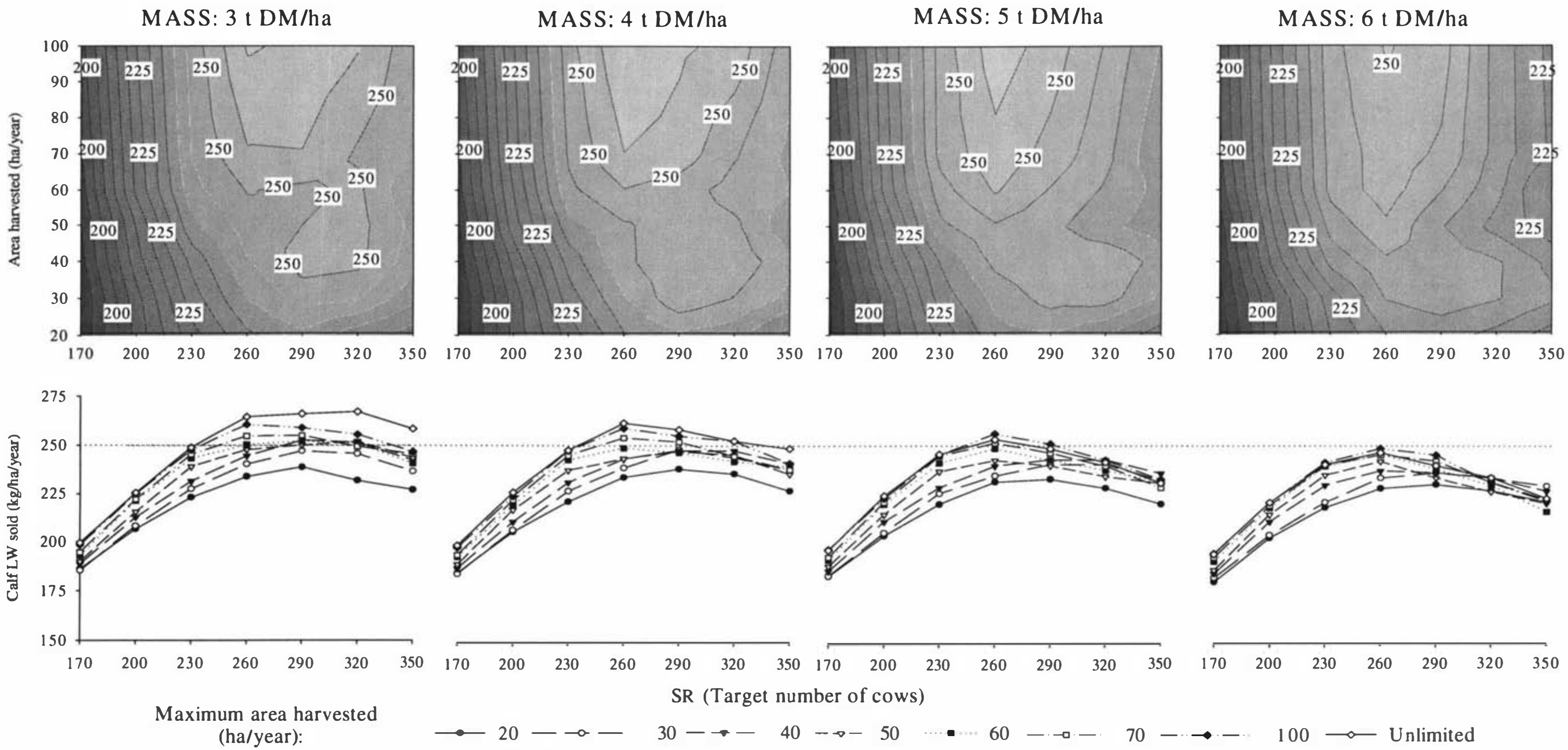

Figure 6.5: Influence of the maximum area harvested for hay and cutting mass policy on calf LW sold for each target cow number (SR).

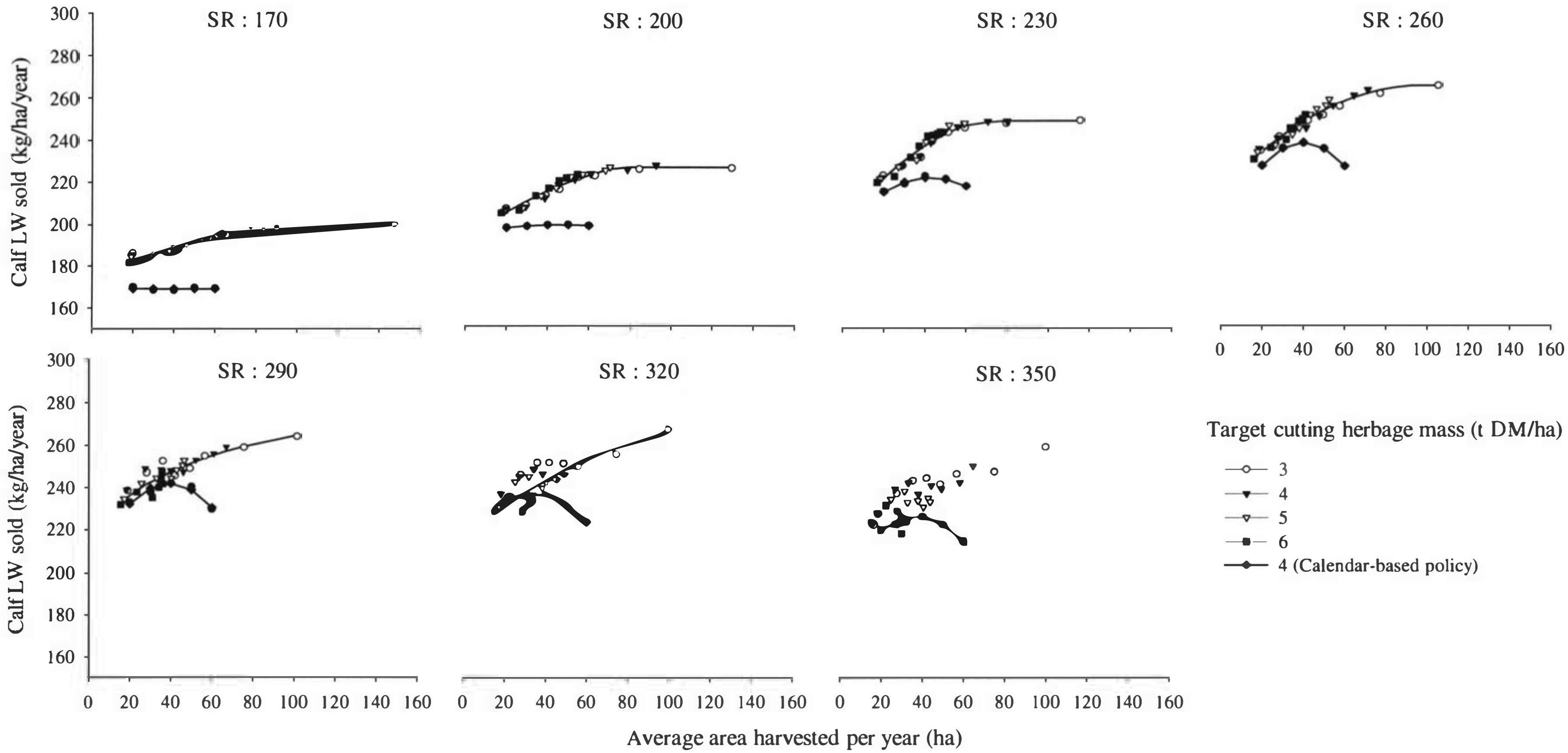

Figure 6.6: Influence of the area used for haymaking and cutting mass policy (target herbage mass to decide making hay, 3 to 6 t DM/ha) on calf LW sold for each target cow number (SR). The best cutting mass of a calendar-based approach (4t DM/ha) is included for comparative purposes.

The amount of hay that can be used is obviously limited by the number of cows in the system, their intake capacity (which is a function of hay quality) and the period of the year during which hay is fed to the cows. In this case, the potential hay intake can be approximately calculated as the product of the number of cows eating hay (SR * 0.6), the amount offered per day (≅7.5kg/day) and the number of days (≅150 days). Although wastage can be considerable, a portion of hay harvested for one winter can be used in the next. This, within certain limits, will confer some additional stability to the system. Figure 6.9 shows that system stability improved when more hay than the requirement for the following winter was harvested. Note that this was not possible at high stocking rates, even when no maximum limit was imposed on the area to be used for haymaking.

To summarize the effect of the different strategies, Figure 6.10 shows the average calf LW sold for each strategy in response to target cow number. The vertical bars indicate the standard deviation within replicate. The consequences of increasing cow numbers, that is the curvilinear response in average production and the associated increase in variability, are apparent. Note that, even though target cow number was the main determining factor, the response curves were different between haymaking strategies, showing higher peaks in the strategies involving large conservation area and at low-medium cutting herbage mass.

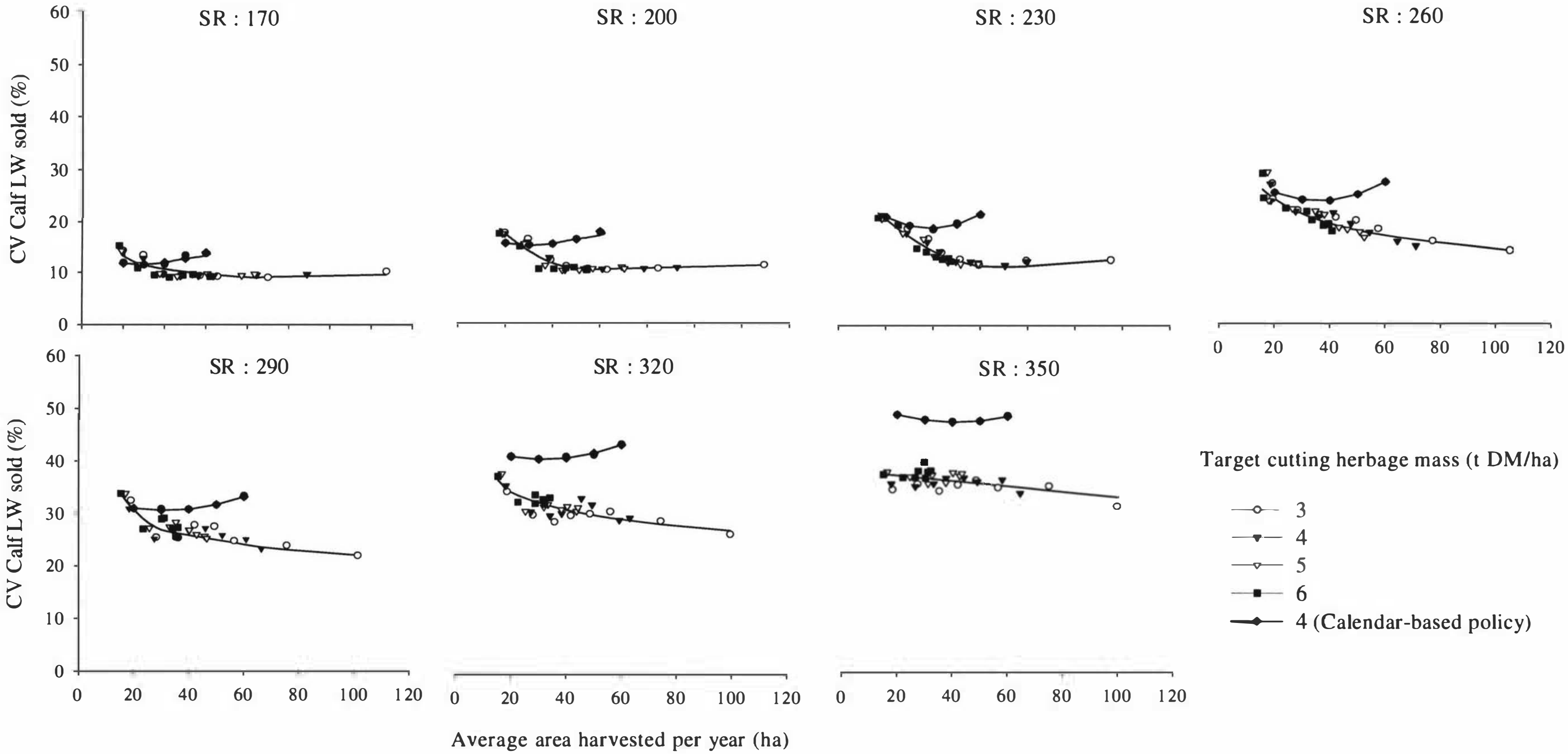

Figure 6.7: Influence of maximum area used for hay making (AREA: ha) and cutting mass policy (target herbage mass to decide making hay, 3 to 6 t DM/ha) on average coeffient of variation (CV) within replicate for calf LW sold for each target cow number (SR). A cutting mass treatment from the calendar-based policy is included for comparison purposes.

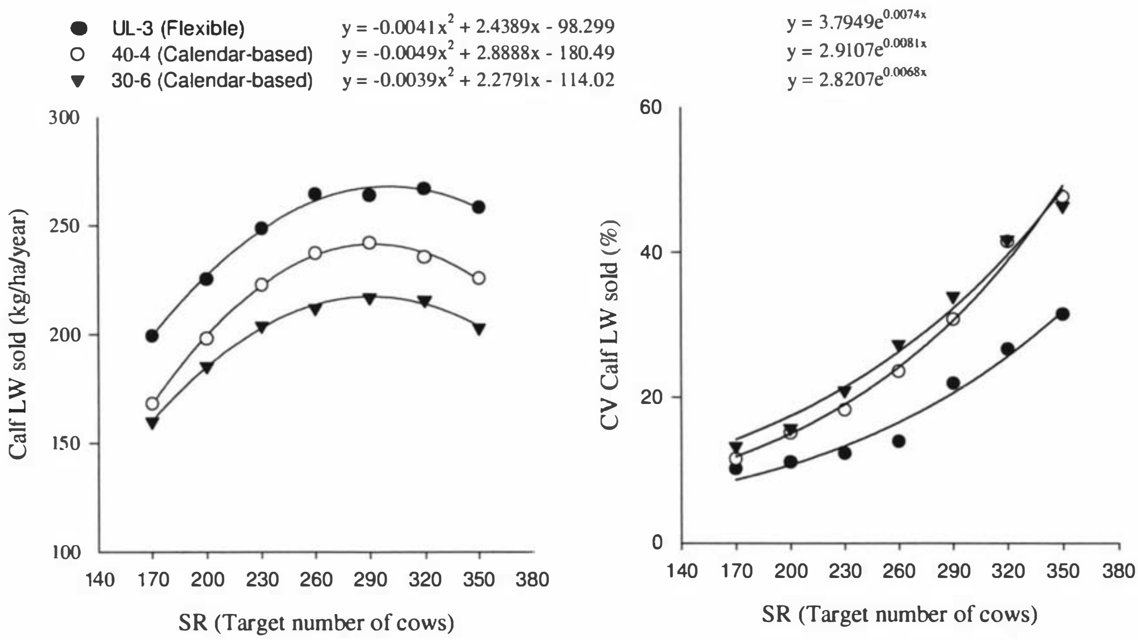

Figure 6.8: Comparison of three haymaking strategies in terms of calf liveweight sold. UL-3: unlimited area for hay, cutting at a minimum herbage mass of 3 t DM/ha; 40-4: harvest 40ha of hay, cutting at cutting at a minimum herbage mass of 4 t DM/ha (calendar based approach); 30-6 (Reserva 6 strategy): harvest 30ha of hay, cutting at a minimum herbage mass of 6 t DM/ha (calendar based approach).

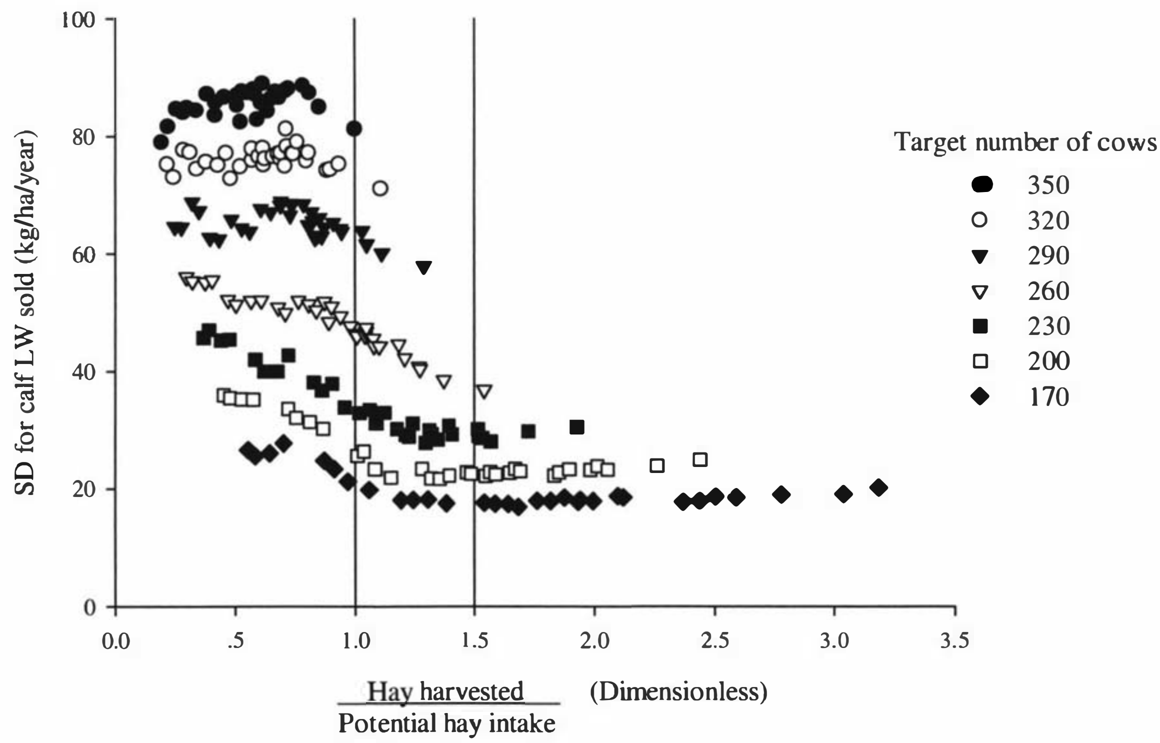

Figure 6.9: Relationship between average standard deviation within replicate and average hay production relative to potential hay intake in one year for each target cow number (SR).

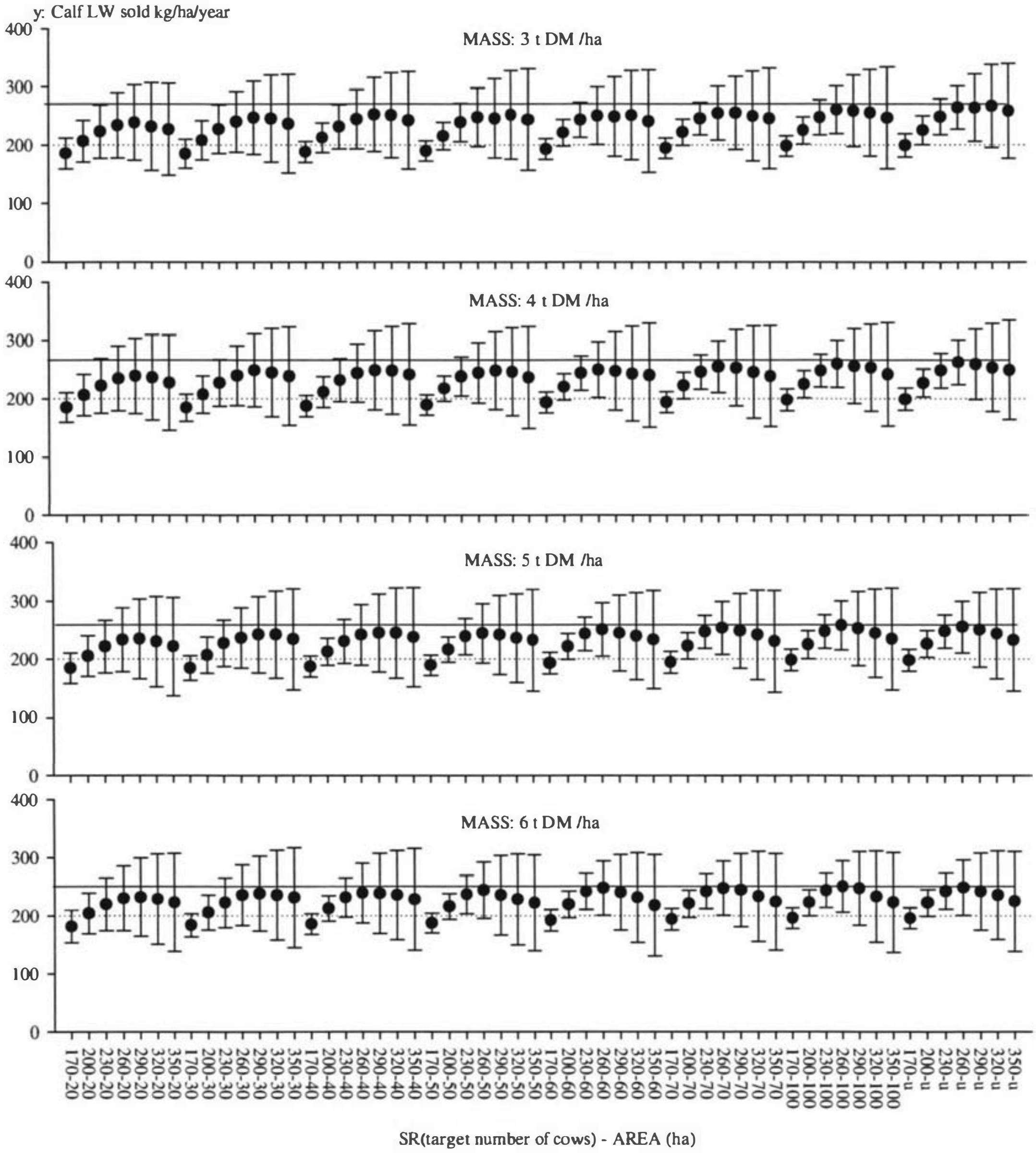

Figure 6.10: Calf LW sold for each stocking rate (SR= number of cows) and hay making policy. AREA = area closed for hay making (20 to 100 ha, and u: unlimited) and MASS = target herbage mass to trigger cutting (3 to 6 t DM/ha). Combinations such as AREA=20 and MASS=3 are denoted by "20-3" on the axes. Vertical lines indicate the average within repetition standard deviation (n=20). The horizontal lines mark the maximum value for Calf LW for each MASS.

6.4. DISCUSSION

Taking a flexible haymaking approach reduced the range of hay digestibility values across treatments, but increased the variability within treatments because of the greater complexity on the decision process involved. While this appeared to be unimportant for dry cow feeding, it could became a problem if the hay was going to be used by other stock classes. Making one decision often precludes taking others and many actions are irreversible (Sterman, 2000). For example, delaying making hay may mean that it will not be possible to produce high quality hay later on. Making low quality hay means that it can only be used for maintenance nutrition, limiting other possible uses. Thus, being flexible at one point in time (making hay) might signify restricting flexibility in the future (feeding hay back).

Target cow number was, as expected, the most important factor determining system production. However, with a flexible management policy, the decision of when to cut can be of secondary importance. It is worth noting that, with the calendar-based policy studied in the previous chapter, herbage mass at cutting was a more significant source of variation than area harvested. This is an indication that the relative importance of the management parameters can change dramatically when the general strategic context is different.

With the flexible approach described here, the optimum seems to be not to impose any rigid limit in the area allocated for haymaking. However, except at very high stocking rates, little benefit would be obtained by cutting more that 50-60% of the total area of the farm. In contrast to the calendar-based strategy, the productivity of the system would not collapse even if very high proportions of the farm were harvested. Notice that, because of the flexible approach, cutting 40-50% on average means that in some years a larger area is cut. For example, to cut 50% on average with cow numbers greater that 230 cows/100ha, it was necessary to set up the maximum limit to 70% of the area or more (Figure 6.2).

Cows cannot eat unlimited quantities of hay. However, it has been recognized that, in many cases, certain redundancy of resources (hay in this case) gives stability to systems (Skittner, 2001). Using a flexible haymaking policy that considers not only time of the year, but also animal requirements and current pasture conditions, would allow managers to exploit redundancy to improve system stability. Hay surpluses could be carried into the next year, compensating for those years when, due to environmental conditions, it is not possible to produce the target amount of hay (or when hay may not be produced at all, for example in very dry years). A proportion of these surpluses could also be marketed, and not necessarily wasted. In the case of this study, harvesting more hay than the amount estimated for one season considerably reduced system variability. It is worth mentioning that this possibility could only be realized at the medium levels of cow numbers (260-290 cows/100ha). It was not possible to accumulate that buffer of hay surplus when cow numbers were high, and there was not much benefit in doing so when cow numbers were low (see Figure 6.9). Note that with the more rigid approach used in Chapter 5, making more hay than required for the following winter was decidedly counterproductive.

In Reserva 6, there is a limited period in the year when hay is fed, between weaning and calving. Perhaps relaxing this restriction could result in further advantages when very large amounts of hay are produced, but this opportunity would also be limited. Even though beef breeding cows have an enormous nutritional flexibility (McCall, 1994; Pleasants et al., 1994; McCall and Smith, 1998), there is a limited time window in which feeding restrictions may be imposed on them. Such limitations would be more serious when low quality hay is used, since pasture access must be restricted significantly in order to force the cows to eat the hay. It should be mentioned at this point that the Reserva 6 system has already a very high capacity for consuming hay. It was actually designed to maximize the utilization of the seasonal pasture production through the use of hay by using a short mating season, and a complete restriction of pasture access for adult cows during autumn-winter.

In general, at an equal area harvested, the flexible policy was better than the best calendar-based option (more productive and more stable). Furthermore, this was almost independent of the cutting herbage mass policy. The effect of incorporating flexibility into haymaking policies has not always been considered. For example Cacho et al. (1995) and Cacho et al. (1999), simulated different levels of conservation (percentage of the farm closed for conservation) based on an event-calendar approach, where paddocks were closed at a fixed date and for a fixed period of time (4-5 weeks). Nevertheless, in a real farm, this flexibility may be unachievable (or expensive), especially when the haymaking is done by contractors, or when constrained by the availability of machinery, labour, and organizational skills of the farmer. In many cases, a well designed calendar-based plan can be easier to follow, and could be a better choice than a flexible plan that is not fully implemented.

When making decisions in complex situations, human decision makers are not expected to behave with perfect rationality (i.e. seeking objective global optimisation) (Simon, 1997). In such circumstances, the problems of complexity, time pressure, uncertainty and cognitive limitation, bound our capacity for making optimal decisions, forcing us to rely on habits and heuristic rules of thumb (Hodgson, 1997; Sterman, 2000). In the case of decisions about closing/cutting paddocks, these kinds of problems limit a farmer's capacity for carrying out a rationally flexible decision making process. Learning from experience with real systems would be slow and restricted. In this study, just counting the number of paddocks ahead in the rotational grazing cycle proved to be a useful simple criterion for controlling grazing and hay management. Identifying this type of simple rule of thumb is one of the benefits of using decision rules to simulate management.

6.5. CONCLUSIONS

Controlling haymaking in a flexible fashion, basing decisions of closing, releasing and cutting paddocks on a very simple pasture budget (number of paddocks ahead in the projected grazing cycle), should give productive advantages relative to a calendar-based approach. Compared at the same area harvested, the benefits would include increases in average productivity along with reductions in the variability of the system. However, whether or not the advantages observed here are sufficiently attractive against the simplicity of the current Reserva 6 approach will depend on each particular farm situation.

The results indicate that allocating more that 50% of the farm area to conservation would only be advantageous at very high stocking rates. Also, making more hay than required for the immediate next winter, where possible, can buffer the system and reduce production variability. However, this buffering function of haymaking would not be possible if the stocking rate is too high, and would provide little advantage if the stocking rate is too low.

6.6. APPENDIX

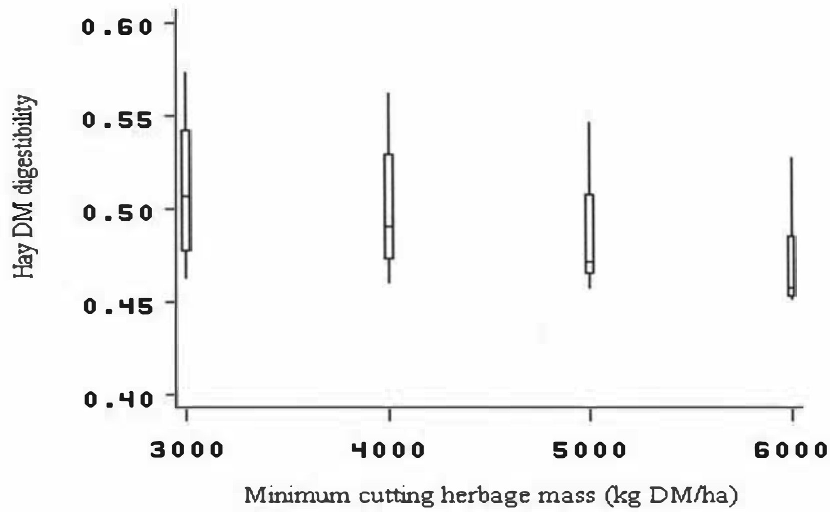

Figure A 6.1: Boxplot representation of average hay digestibility as influenced by cutting herbage mass policy.

Table A 6.1: Means and standard deviations (average of 20 within-replicate SDs) of calf liveweight sold (kg/ha/year) from the simulated farm for the different combinations of maximum area for hay making (AREA: ha), cutting mass policy (MASS: t DM/ha), and target cow number (SR).

		AREA								
SR	MASS	20	30	40	50	60	70	100	UL[1]	Mean
170	3	186±27	185±25	189±18	190±18	193±18	195±18	198±18	199±20	192±20
	4	177±23	177±21	178±19	179±20	181±20	194±18	198±19	199±19	183±20
	5	184±26	184±21	187±18	189±17	193±18	194±19	198±18	198±19	191±20
	6	182±28	184±20	186±18	188±17	192±18	194±19	196±18	196±18	190±19
	Mean	181±25	181±22	183±18	185±18	188±19	194±18	198±18	198±19	188±20
200	3	207±36	208±34	213±26	216±23	221±23	222±22	225±23	226±25	217±27
	4	202±33	202±31	205±28	208±27	209±29	223±23	225±23	227±24	210±28
	5	205±35	207±31	212±23	216±22	221±22	223±23	224±24	226±23	217±25
	6	204±35	206±30	213±22	216±22	220±23	221±23	222±22	222±23	216±25
	Mean	204±34	205±31	209±25	213±24	216±25	222±23	224±23	225±24	214±27
230	3	223±46	228±42	232±38	239±33	243±30	245±28	247±30	249±31	238±35
	4	219±46	223±41	227±39	230±38	231±38	246±29	248±28	248±30	231±38
	5	222±45	227±40	230±38	239±31	243±29	247±28	247±29	248±29	238±34
	6	220±45	223±43	232±34	237±33	242±31	242±30	243±29	242±31	235±34
	Mean	220±46	225±41	230±37	235±35	238±33	245±29	247±29	247±30	235±35
260	3	234±56	240±52	244±51	248±50	250±49	255±46	261±41	264±37	250±48
	4	231±56	237±54	241±53	240±55	238±55	255±44	260±40	262±38	242±51
	5	233±55	236±52	241±52	244±51	250±46	253±46	258±42	255±45	247±49
	6	230±56	235±52	239±51	244±48	247±46	247±47	251±44	248±47	243±49
	Mean	232±56	237±53	241±52	243±52	245±50	253±46	257±42	258±42	245±50
290	3	239±65	247±63	252±64	246±68	249±68	255±63	259±62	264±58	251±64
	4	236±68	243±68	245±71	244±71	239±72	253±65	256±64	259±60	245±68
	5	235±69	242±66	245±67	241±68	245±66	248±64	253±64	250±64	245±66
	6	232±67	238±64	238±69	235±69	240±65	244±63	247±63	242±66	240±66
	Mean	236±67	243±66	245±68	242±69	242±68	250±64	254±63	254±62	245±66
320	3	232±75	246±74	251±73	252±76	251±77	249±77	255±74	267±71	250±75
	4	235±85	235±88	242±86	239±86	233±89	246±79	253±74	253±75	240±84
	5	230±78	242±75	245±78	236±76	239±75	241±77	245±76	243±77	240±77
	6	229±77	236±77	236±77	228±78	232±77	233±77	233±78	236±76	233±77
	Mean	232±80	239±80	243±80	239±80	238±82	242±78	247±76	250±75	241±79
350	3	227±79	237±85	242±84	244±87	241±88	246±86	247±87	259±81	243±85
	4	223±95	232±96	234±97	229±97	227±97	239±87	242±89	249±85	232±94
	5	222±85	234±87	238±85	233±87	233±84	230±88	234±88	233±88	232±87
	6	223±84	231±86	228±88	222±83	218±87	224±83	223±86	225±86	224±85
	Mean	224±87	233±90	235±90	231±90	229±91	235±86	237±87	241±85	233±89
Mean		218±57	223±55	227±53	227±53	228±53	234±49	237±48	239±48	229±52

[1] Unlimited: no limit pre-imposed in the area allocated for haymaking.

Table A 6.2: Analysis of variance for average total LW sold (kg/ha/year) in terms of the factors SR (target number of cows), AREA (maximum area for haymaking) and MASS (target cutting herbage mass).

Source	DF	SS	MS	F Value	Pr > F
Model	242	10378987	42888	257	<.0001
Error	4237	707655	167		
Corrected Total	4479	11086642			

R-Square	Coeff Var	Root MSE	Mean
0.92	3.2	12.9	408

Source	DF	SS	MS	F Value	Pr > F
SR	6	9087266	1514544	9068	<.0001
AREA	7	257540	36791	220	<.0001
MASS	3	140093	46698	280	<.0001
AREA*MASS	21	17225	820	5	<.0001
SR*AREA	42	41550	989	6	<.0001
SR*MASS	18	53820	2990	18	<.0001
SR*AREA*MASS	126	19904	158	0.95	0.6523
Replicate	19	761590	40084	240	<.0001

Table A 6.3: Analysis of variance for average calf LW sold (kg/ha/year) in terms of the factors SR (target number of cows), AREA (maximum area for haymaking) and MASS (target cutting herbage mass).

Source	DF	SS	MS	F Value	Pr > F
Model	242	2160066	8926	169	<.0001
Error	4237	224029	53		
Corrected Total	4479	2384095			

R-Square	Coeff Var	Root MSE	Mean
0.88	3.2	7.3	231

Source	DF	SS	MS	F Value	Pr > F
SR	6	1586346	264391	5000	<.0001
AREA	7	162021	23146	438	<.0001
MASS	3	50869	16956	321	<.0001
AREA*MASS	21	8389	399	8	<.0001
SR*AREA	42	35023	834	16	<.0001
SR*MASS	18	29419	1634	31	<.0001
SR*AREA*MASS	126	12713	101	1.91	<.0001
Replicate	19	275285	14489	274	<.0001

Table A 6.4: Analysis of variance for the coefficient of variation (average of 20 within-replicate CVs) of calf LW sold (kg/ha/year) in terms of the factors SR (target number of cows), AREA (maximum area for haymaking) and MASS (target cutting herbage mass).

Source	DF	SS	MS	F Value	Pr > F
Model	242	479680	1982	155	<.0001
Error	4237	54260	13		
Corrected Total	4479	533940			

R-Square	Coeff Var	Root MSE	Mean
0.93	16.8	3.6	21

Source	DF	SS	MS	F Value	Pr > F
SR	6	390869	65145	5087	<.0001
AREA	7	10174	1453	113	<.0001
MASS	3	1046	349	27	<.0001
AREA*MASS	21	522	25	2	0.0061
SR*AREA	42	7396	176	14	<.0001
SR*MASS	18	1594	89	7	<.0001
SR*AREA*MASS	126	1296	10	0.80	0.9471
Replicate	19	66783	3515	274	<.0001

CHAPTER 7

COMPARISON OF HAYMAKING STRATEGIES: IMPLICATIONS IN TERMS OF HERBAGE UTILIZATION AND RISK

7.1. INTRODUCTION

As explained earlier, the main focus of the studies described in chapters 5 and 6 was to analyse the effects of different haymaking strategies on animal production in a cow-calf system at a whole farm level. However, haymaking polices have consequences at other levels that deserve equal consideration. This chapter provides preliminary discussions of issues related to herbage utilization efficiency and economic risk efficiency. Because of their extensiveness and importance, either of these two topics could be the subject of a complete PhD thesis on its own, and therefore a more comprehensive study was outside the scope of this thesis. This chapter is intended to complement the main body of the study, in order to gain understanding of the results observed in the previous chapter and establish the basis for possible areas of interest in future studies.

7.2. HERBAGE UTILIZATION EFFICIENCY

Abstract

In a grazing-conservation system, herbage utilization (*hu*) is the ratio between the amount harvested (grazing + hay) and gross herbage growth. The variables used to calculate *hu* are themselves interrelated and so cannot be explained in terms of each other. Herbage utilization should be explained by controlled experimental factors, in this study the haymaking strategy in interaction with the stocking rate policy. A flexible haymaking policy permitted significantly greater levels of herbage utilization by allowing large amounts of hay to be made without negative consequences to the carrying capacity of the system. However, maximizing herbage utilization is not an objective in itself, and can only be used as one of several indicator to assess pasture management policies.

7.2.1. Definitions

Efficiency of grazing has been defined as the proportion of the accumulated gross herbage growth that is harvested in a period of time (Hodgson, 1979). In this study, herbage can be harvested directly by grazing or as hay, so herbage utilization should be calculated as:

$$hu = \frac{I + H}{GG} = 1 - \frac{D}{GG} \quad \text{(Dimensionless)} \qquad (1)$$

Where: *I*= accumulated herbage intake (kg/ha/year)

H= accumulated hay harvested (kg/ha/year)

D= accumulated herbage decay (kg/ha/year)

GG= accumulated gross herbage growth (kg/ha/year)

The variables that compose *hu* are highly inter-dependent, as shown in the following stock and flow diagram:

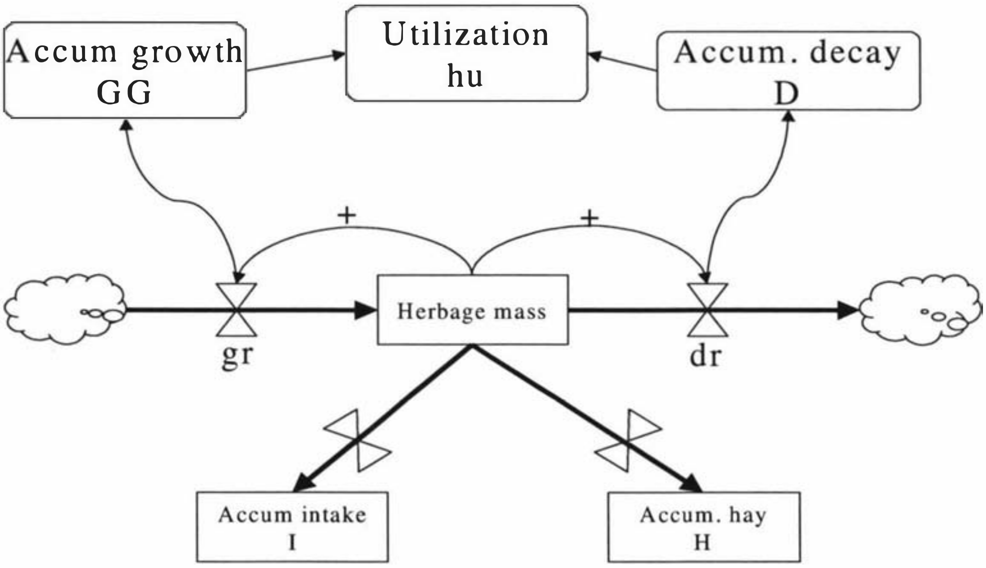

Figure 7.1: Herbage dry matter fluxes in a grazing and conservation system.

7.2.2. Results

The feedback from herbage mass to the fluxes growth rate (gr) and decay rate (dr), determine that gr and dr are influenced by the current herbage mass, and hence they are correlated with each other. The results obtained in the previous simulations illustrate this point, Table 7.1 showing the correlation matrix between the variables composing *hu* corresponding to the haymaking policies presented in Chapter 5 (calculations using the average values for each variable and for each of the 140 policies):

Table 7.1: Pearson correlation matrix between accumulated gross growth (GG), intake (I), decay (D) and hay produced (H) (N = 140, Prob > |r| under H0: Rho=0).

	D	I	H
GG	0.888 <.0001	-0.637 <.0001	-0.189 0.026
D		-0.687 <.0001	-0.303 0.0003
I			-0.481 <.0001

These are functional relationships, proper to the structure of the grazing system, but it is important to point out that the value of the correlation coefficients observed between GG, H, I and D are contingent upon the grazing-conservation strategies that were used in the simulations. If different strategies were tried, the variables could be related in different ways (or at least their correlations might be different).

Figure 7.2 depicts, as an example, the effect on the different fluxes of increasing the amount of hay produced (using a calendar-based approach, see Chapter 5) for a target stocking rate treatment of 230 cows/100ha. Note that, while herbage utilization increased with increased hay production, each of its component variables (eq. 1) tended to decrease. Thus, it is possible to increase herbage utilization and reduce herbage intake at the same time, which is rather counterintuitive. Of course, for herbage utilization to increase, the decrease in I must be compensated by an increase in H; notice that the slope for I is smaller than one.

These types of variables are what Barton (2002) calls *intermediate* variables. Intermediate variables cannot be controlled independently, but are affected by the set of independent variables. According to the same author, intermediate variables should be identified so that they are not mistakenly included as independent variables. These variables are observational, not experimental, in the sense that none of the 4 variables (GG, I, D and H) are controlled. It is therefore impossible to conclude that any of the relationships are causal. Take for example the unexpectedly weak correlation between D and H, which may seem counterintuitive at first glance. The explanation is that H is also negatively correlated to I, which in turn has a negative correlation with D. A multiple linear regression of D against I and H will illustrate the point:

$D = 14638 - 1.25\ (H+I) + 0.12\ (I-H)$ ($R^2 = 0.99$, $p<0.001$ for all variables)

As expected, the more herbage is consumed the less is lost to decay, so the regression coefficient for H+I is negative. On the other hand, the coefficient for I-H is positive, which means that, for management combinations with the same total herbage consumption (I+H), the herbage decay will be greater for those where I (i.e. direct grazing) is large relative to H (i.e. hay). Therefore, the correlation between D and H is weakened because of the confounding effect of I.

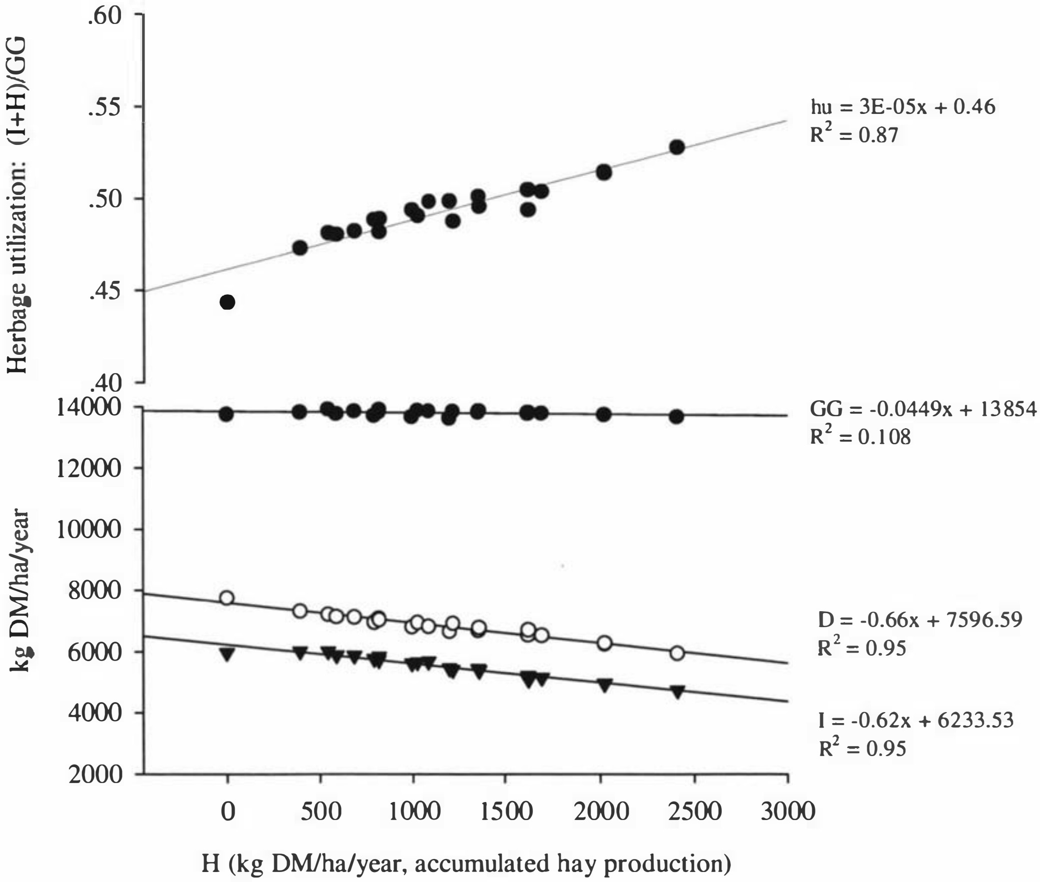

Figure 7.2: Dry matter fluxes vs. the amount of hay harvested for a target stocking rate of 230 cows/100ha.

The existence of this collinearity, where everything changes at the same time, is one of the very reasons why models are needed analyse with complex dynamic systems. The factors influencing rates of herbage growth and loss are inter-related to a degree that makes it difficult to assess their relative importance, and hence to predict the influence of particular management strategies on the balance between them (Hodgson et al., 1981). In this situation it is almost impossible to distinguish cause and effect. In other words, an intermediate variable cannot be analysed in terms of the other intermediate variable. Systems can be irreducible, and the behaviour of intermediate variables cannot be easily separated or analysed because they are intimately intertwined (Snowden, 2002).

Since the system simulated here is controlled by decision rules, it is much easier to study the effect of the management (or controlled) variables, which are, after all, the independent variables. Among the independent variables, Barton (2002) distinguishes those that are *held-constant* during an experiment from those that change, which he calls *factors*. In our experiments, the factors are AREA, MASS and SR. These are the only real "causes", and the dry matter fluxes are intermediate variables. A multiple linear regression analysis of herbage utilization against SR and AREA (MASS was not significant and was removed from the model) and for the calendar-based strategy, showed a good explicative power (Table 7.2).

Table 7.2: Multiple linear regression analysis for herbage utilization in terms of the factors AREA, MASS and SR.

Analysis of Variance					
Source	DF	SS	MS	F Value	Pr > F
Model	2	0.45005	0.22502	466.11	<.0001
Error	144	0.06952	0.000483		
Corrected Total	146	0.51957			

Root MSE	0.022	R-Square	0.866
Dependent Mean	0.505	Adj R-Sq	0.864
Coeff Var	4.348		

Variable	DF	Estimate	Standard Error	t Value	Pr > |t|
Intercept	1	0.24074	0.01	26.41	<.0001
SR	1	0.000893	3.0E-05	3.0E+01	<.0001
AREA	1	0.000851	1.1E-04	7.6E+00	<.0001

The same information is presented in the top panel of Figure 7.3, that is, herbage utilization in relation to the management variables. Herbage utilization ranged from about 0.35 up to almost 0.6. The system tended asymptotically to an upper limit value, and there seemed to be a limit beyond which it is not possible to go. Making more hay resulted in increases in herbage utilization at low stocking rates, but not at high stocking rates. At least part of the explanation for this can be found in Figure 5.9, and in the bottom panel of Figure 7.3. The system was simply not able to sustain the high target cow numbers, especially when more that 50% of the area was cut and when hay was made at high mass (i.e. 5-6t DM/ha). The target cow number may increase, but the actual cow number, and therefore herbage intake, are limited by constraints imposed by the environment and the structure of the management system. In summary, when the system was pushed too far in trying to increase herbage utilization by increasing the target cow number or harvesting more hay it became unsustainable in the long run. It is noteworthy that, at least with the types of management explored here, it seems to be impossible to consistently sustain more that 2.9 cows/ha, and that is only if the "best" calendar-based haymaking policy is implemented.

The situation described in the previous paragraph changes if a flexible haymaking strategy is implemented. Figure 7.4 shows that the herbage utilization was increased beyond 0.6 by harvesting much larger amounts of hay, without negatively affecting the carrying capacity of the system. At high target cow numbers in the calendar-based policy the actual average cow number (see Figure 5.9) was reduced when high amounts of hay were produced. In the flexible policies however, when the limit was not imposed by the target cow number, the average increased as more hay was harvested.

Herbage utilization efficiency is an intermediate variable, therefore an increase in *hu* does not represent *per se* any benefit for the systems as a whole. Although, as a general trend, system productivity increased as *hu* increased, this is not a causal relationship, since both are dependent variables. Herbage utilization was high in those cases where high cow numbers (and hence high herbage intake) were sustained and large amounts of hay were harvested, and this was also the case where system production was high. Figure

7.5 shows the relationship between *hu* and calf liveweight sold for all the calendar-based combinations, and the pattern of residuals from a linear regression. Note that although the R-squared shown in the figure was relatively high and the model was statistically significant, but for similar values of *hu* there was an enormous variation in animal production. The system response variables of interest, again following Barton (2002), are the dependent variables. Dependent variables are determined by the objectives of the study. In the present study those are variables related to animal production outputs from the systems.

It is important to observe the response of the intermediate variables to the changes in the experimental factors. This gives more confidence in the model as well as providing the opportunity to detect internal inconsistencies. One of the variables that is obviously important is the accumulated herbage production (GG). Unfortunately there is little experimental data with which to validate these results in Argentina, but at least the presence of aberrant values can be checked for. The overall average GG, shown in Figure 7.6, is quite reasonable for temperate areas (13,816 kg DM/ha/year). Annual dry matter productions in Balcarce of 13,173 and 10,889 kg/ha were reported by Orbea (1970) and Orbea et al. (1971), respectively. Note that values recorded in the cutting trials correspond to net accumulation, since part of the gross growth may have been lost to decay (note, however, that senescent standing material is also harvested by the mower).

These results are not strictly comparable with those of Bircham and Hodgson (1981) in which sward state was maintained in steady state conditions by continuous grazing. Here the sward state is only partially controlled and is not constant. However, the basic biological principles still hold, when pastures are characterized in terms of average sward state (Parsons et al., 1988). For example, because the system is operating at relatively high levels of average herbage mass, herbage gross growth appears unresponsive to the changes in management policies, similar to the asymptotic response observed by Bircham and Hodgson (1981). This agreement should not be surprising, given the similarity between the herbage dynamic concepts in Bircham and Hodgson (1981) and the underlying assumptions in the pasture model described in Chapter 3.

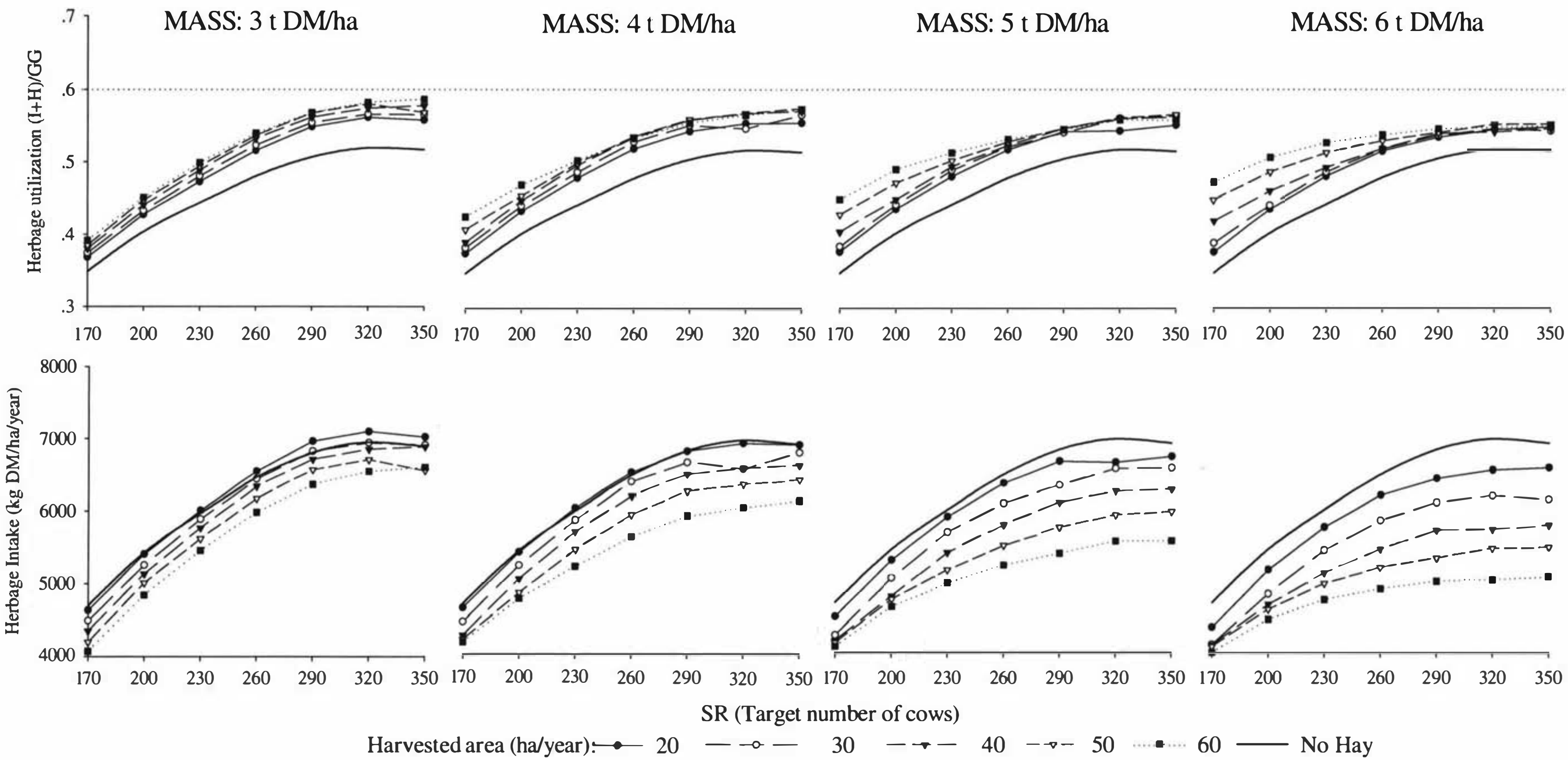

Figure 7.3: Influence of the area closed for haymaking and the cutting herbage mass policy on herbage utilization and average herbage intake for each target cow number (SR) (Calendar-based policy).

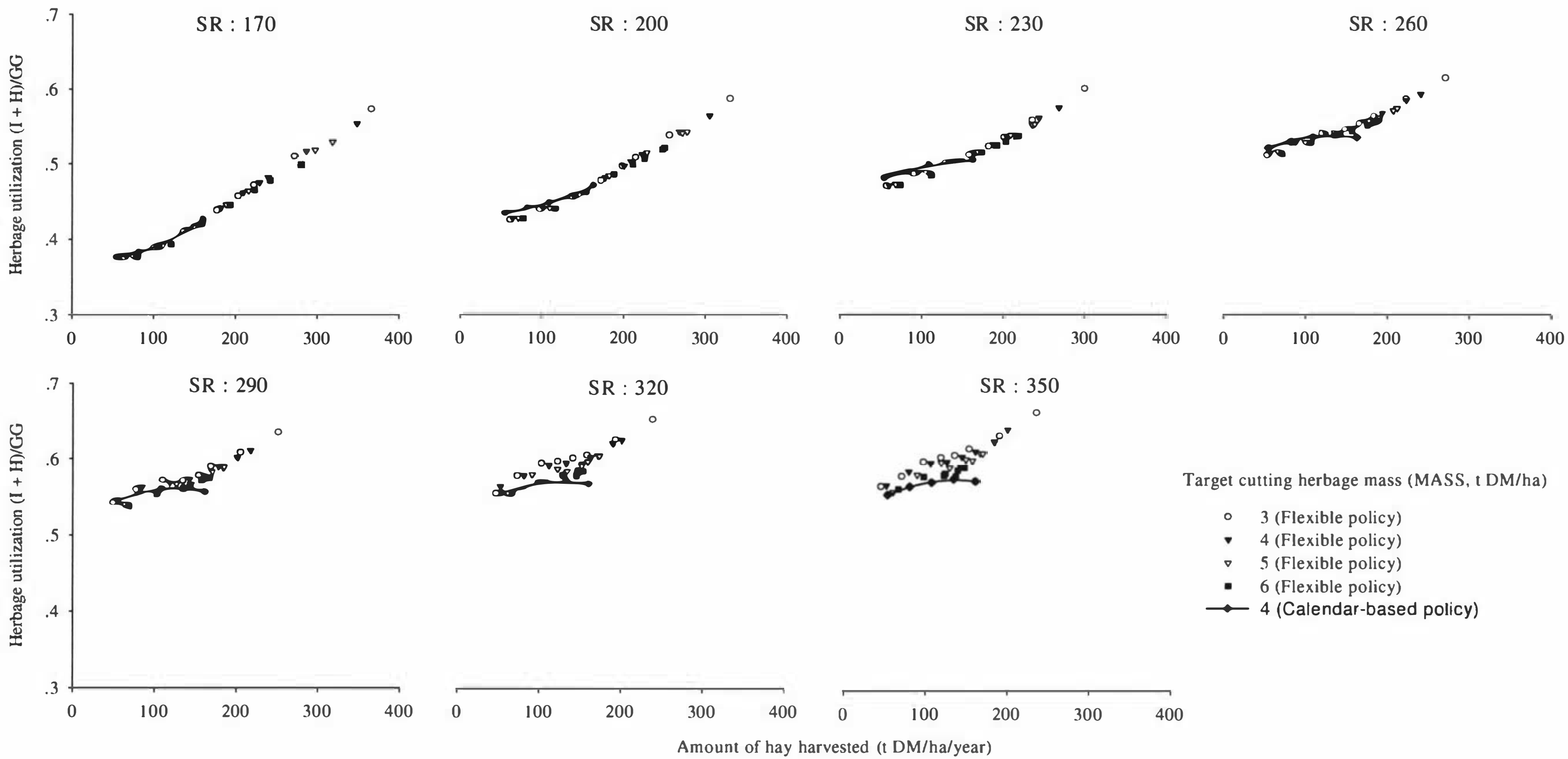

Figure 7.4: Influence of the amount of hay harvested and the cutting herbage mass policy on herbage utilization for each target cow number (SR) (Flexible strategy).

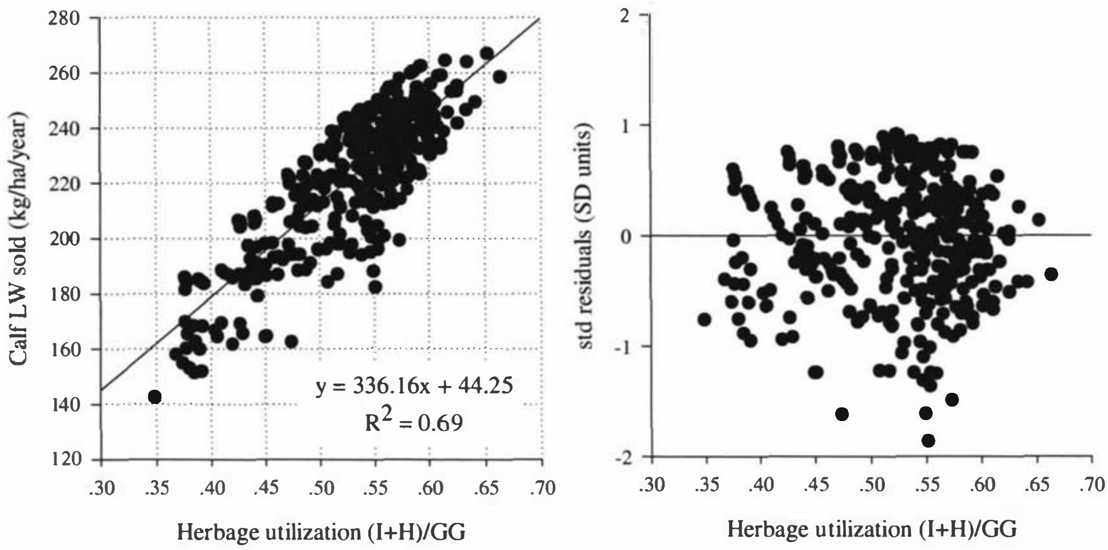

Figure 7.5: Calf liveweight sold in relation to herbage utilization. Individual points represent (averages on the right and standarised residuals for the linear regression on the left) different haymaking strategies (calendar-based and flexible) and target cow numbers.

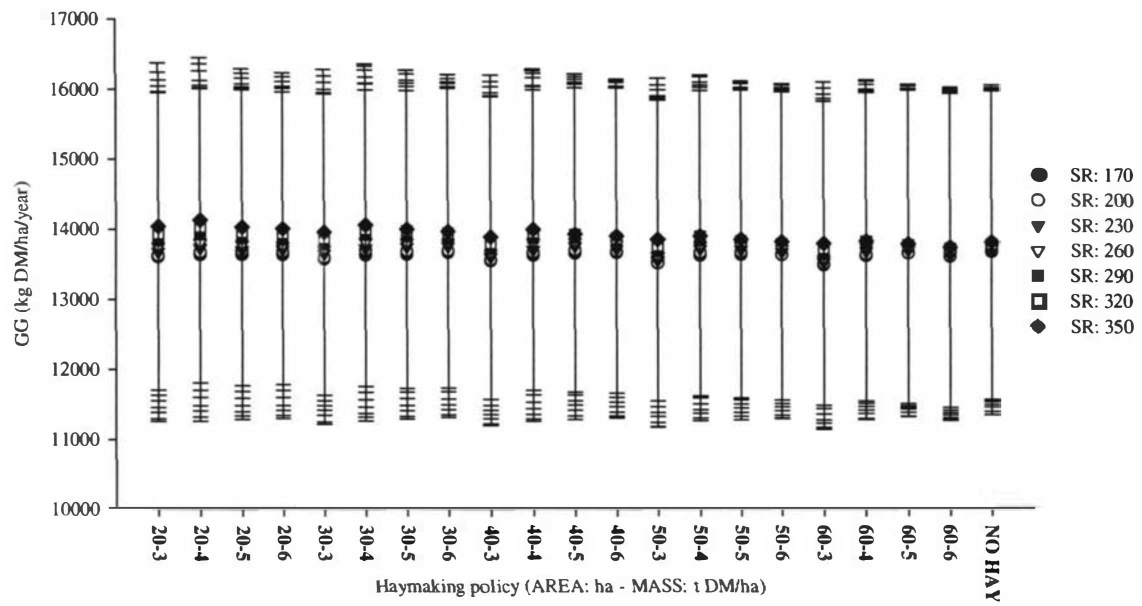

Figure 7.6: Accumulated herbage growth (GG) for haymaking policy and target cow number (SR) for the calendar-based strategy. Where AREA = area closed for hay making and MASS = target herbage mass to decide cutting. Vertical lines indicate the average standard deviation for each policy.

7.2.3. Conclusions

Herbage utilization was affected by the controlled variables in the experiment, that is, the area for haymaking, herbage mass at haymaking and cow number. The actual cow number appeared to be the most important driving variable, being determined not only by the target cow number, but also by the haymaking policy. When a rigid calendar-based approach was followed for haymaking, herbage utilization did not exceeded 0.6, because of the pressure imposed on animals while paddocks were closed for haymaking. This, in turn, reduced the carrying capacity of the system when large amounts of hay were harvested. Using a flexible haymaking policy allowed significantly greater levels of herbage utilization to be achieved, by making large amounts of hay without these negative effects.

When analysing farm system management, it is necessary to look at the overall combined effect of the different controlled factors on the relevant outputs of the systems. Herbage utilization may be one indicator for evaluating the efficiency of a grazing management policy, but it is not in itself a system objective. Focusing only on intermediate variables, like herbage growth, or herbage utilization can be misleading.

7.3. EXPLORATORY RISK ASSESSMENT

Abstract

Risk and cost consideration were used to evaluate the impact of different haymaking strategies across a range of cow numbers. A risk-efficiency methodology was used, considering the economic value of the liveweight produced per year minus the cost of haymaking as a simple measure of profit. The risk efficiency analysis highlights major advantages in using hay in cow-calf systems, especially when a flexible management approach is implemented, but some haymaking options performed less well that the option without hay. Within the risk efficient set, the area allocated for hay making and cutting herbage mass were dependent on the level of stocking rate being used.

7.3.1. Introduction

In the previous two chapters, different haymaking strategies were analysed in terms of animal production, without including any economic evaluation. Average productivity and variability were treated separately.

The objective of this section was to incorporate simple risk and cost considerations in order to complement the biophysical approach taken in the present thesis work. The analysis mostly follows the methodology proposed by Cacho et al. (1999) to analyse results obtained from dynamic risk neutral models (Antle, 1983). The experimental protocol followed in the present study, based on a factorial arrangement with multiple independent repetitions, is also similar to the one used by Cacho et al. (1999).

7.3.2. Materials and methods

A simplified profit indicator (P) was used to compare the different strategies using the risk-efficient frontier methodology described by Cacho et al. (1999). To calculate P, taking current prices from a newspaper, the price per unit of calf liveweight was considered to be 1 and the value of cow liveweight was taken to be 0.8 of the value of calf liveweight. In the case of haymaking, an equation was fitted to calculate the harvesting costs (C) in terms of units of calf LW per kg of dry matter harvested as a function of the dry matter yield obtained (Figure 7.7). Normally in Argentina the cost of haymaking is arranged with a contractor, taking into account hay yield of the paddock to be mowed. Some newspapers regularly publish reference prices as guidance for farmers and contractors. Data used for Figure 7.7 were obtained from a national newspaper ("La Nación") on 7 Novembers 2003, as were the calf and cow liveweight prices used in the calculations. Thus, all the components of P were expressed in calf LW units. The variable P was calculated as:

$$P = calfLW + 0.8*cowLW - C*H$$

Where: calfLW = amount of calf LW sold (kg/ha/year)

cowLW = amount of cow LW sold (kg/ha/year)

$\frac{\$/kg\ cow\ LW}{\$/kg\ calf\ LW} = 0.8$ (i.e. 1 unit of cow LW is worth 0.8 units of calf LW)

C = cost per unit of hay produced (kg calf LW / kg DM Hay), Figure 7.7.

H = amount of hay harvested (kg/ha/year)

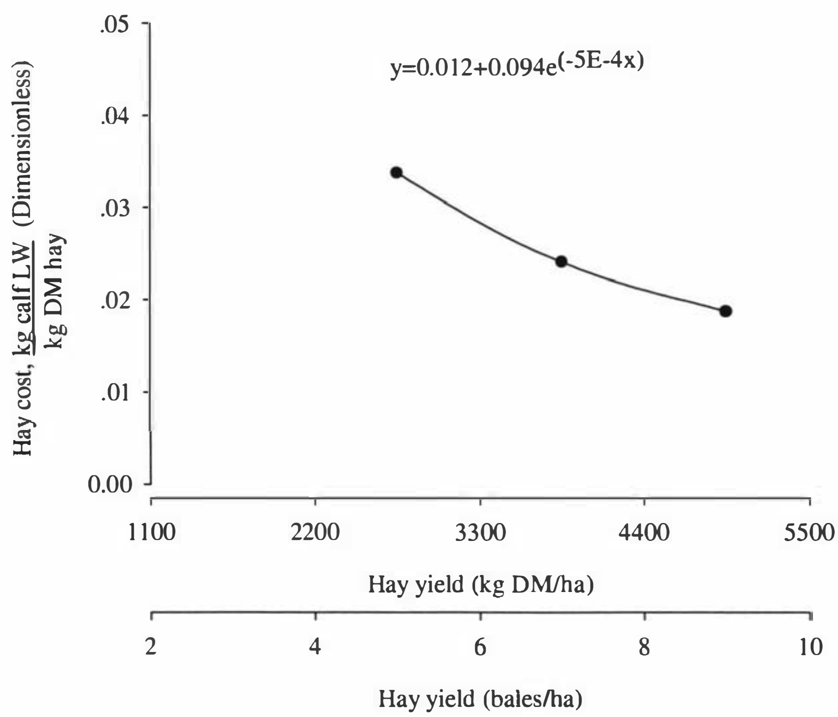

Figure 7.7: Cost per unit of hay in calf terms of liveweight units in relation to hay yield. Calculated used actual current prices taken from the newspaper ("La Nación" 7 Novembers 2003).

Current prices in Argentina were used for the calculations, making the assumption that the relative prices are more or less constant in the long run.

Two related experiments were conducted, using factorial arrangements, one using a calendar-based haymaking strategy described in Chapter 5 and the other an improved flexible strategy described in Chapter 6. Every combination of factors was simulated 20 times (replicates). Each replicate consisted of a 50 year simulation using random generated weather, created by sampling from 30 years of real weather data.

A difference between this model and the one used by Cacho et al. (1999) is that those authors generated stochastic patterns of herbage growth, while in this study the pastures were simulated using a weather-driven pasture model (McCall and Bishop-Hurley, 2003). Therefore, the stochastic component was introduced by the weather inputs used for the simulations.

The two haymaking strategies, the Reserva 6 approach (referred to henceforth as the calendar-based strategy) and the more flexible option, along with the experimental factors included in the simulated experiments, AREA, MASS and SR, have been explained in detail in Chapters 5 and 6. Basically, AREA represents how much area is allocated to haymaking, MASS is the herbage mass in the closed paddocks at which cutting is decided, and SR is the target cow numbers that the system tries to achieve and maintain.

7.3.3. Results

7.3.3.1. Risk-efficient frontier

The risk-efficient frontier is the set of the best possible combinations of expected profit (average for P in this case) and risk (standard deviation of P). Any combination outside this set is considered to be inefficient, since there are combinations (in the frontier) that make it possible to increase profit with the same risk, or reduce risk with the same profit (Cacho et al., 1999). Choosing between combinations within the frontier will depend on each decision maker's aversion to risk. This methodology, also known as mean-variance, or *E,V* efficiency rule, is based on the proposition that, if the expected value (E, i.e. mean) of a choice A is greater than or equal to the expected value of the choice B, and the variance (V) of A is less that or equal to the variance of B, with at least one strict inequality, then A is preferred to (dominates) B (Hardaker et al., 1998). Only those options that are not dominated in an E,V sense are regarded as members of the efficient E,V set. They constitute combinations having the maximum E for a given V, or minimum V for given E (Anderson et al., 1977). Figure 7.8 and Table 7.3 depict the average and standard deviation of the variable P for every combination, and those combinations belonging to the E,V efficient set are indicated in the table. The efficient sets were identified for the calendar-based and for the flexible conservation approaches. Table 7.1shows some details for the strategies included in the efficient sets.

Figure 7.8 shows that the risk-efficient frontier was markedly better (i.e. moved up/left) when a more flexible strategy were used. Using the terminology applied by Hardaker et al. (1998), the flexible strategy "*dominated*" the calendar-based strategy.

One or two combinations per target cow number were included in the frontier, but none of the efficient combinations included the maximum cow number. Within the frontier (Table 7.4), the area harvested ranged from 35 to 52ha, depending on the cow number.

The risk-efficient cutting herbage mass decreased with increased target cow number, from 6t DM/ha at 170 cows/100ha to 3t DM/ha at 320 cows/100ha. In the case of the best combinations within the calendar-based strategy, the area harvested was more or less similar to the Reserva 6 policy (i.e. cutting 20-30% of the area of farm), but cutting at a lower herbage mass.

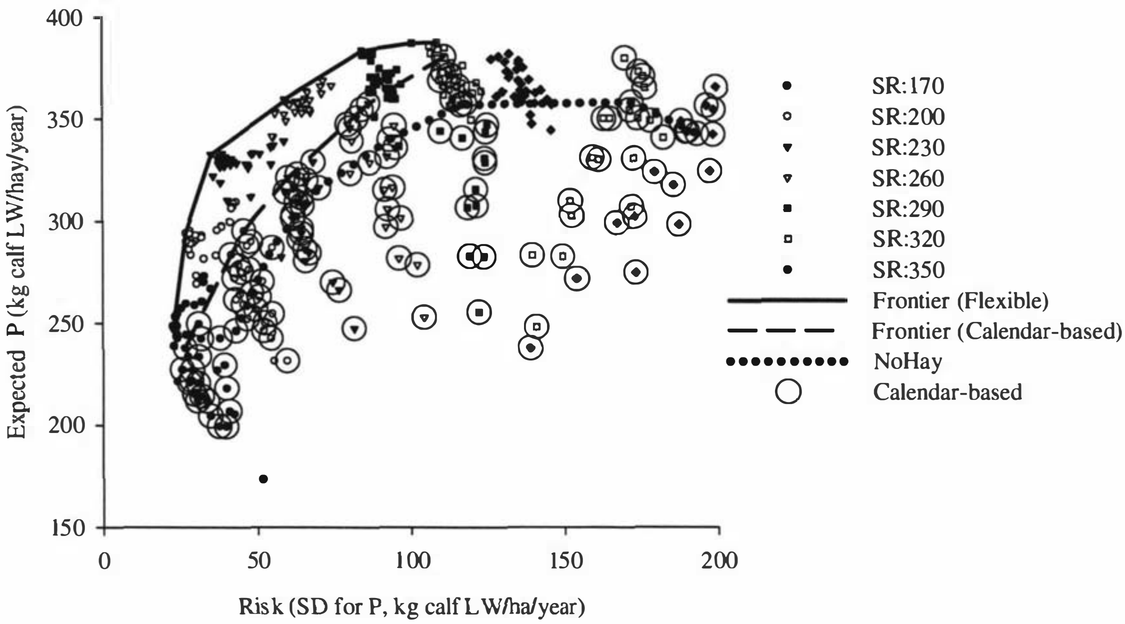

Figure 7.8: Risk-efficient frontier for the different haymaking strategies and target cow numbers (SR).

All the NoHay combinations were far below the risk-efficient frontier, but there were many combinations using hay that were clearly dominated by NoHay combinations (indicated in Table 7.3). Most of them were calendar-based combinations cutting 50-60% of the area.

Some interesting observations emerge when comparing the calendar-based and the flexible approaches (Table 7.4). Within the risk-efficient set for the calendar-based approach, almost all the hay was consumed every year. In comparison, the efficient set for the flexible approach included strategies that produced more hay, principally by cutting at higher herbage mass, and by cutting more area. However, depending on cow number, a significantly smaller proportion of the hay was used.

Table 7.3: Means and standard deviations for price-corrected live weight sold (P, kg/ha/year) for different combinations of area allocated for haymaking (AREA: ha), cutting mass policy (MASS: t DM/ha) and target cow number for the calendar-based and flexible management approaches.

			Target cow number (cows)						
Approach	AREA	MASS	170	200	230	260	290	320	350
Calendar Based	20	3	243±38	290±48	323±63	355±84[2]	381±111[2]	380±170	366±200
		4	250±31	295±46[2]	329±68	357±86[2]	372±113	373±174	357±196
		5	243±32	288±47	320±66	347±95	362±120	354±171	349±188
		6	234±31	278±44	309±63	336±95[3]	347±125[3]	350±165	344±190
	30	3	230±39	276±47	316±62	351±82	373±111	371±176	362±209
		4	238±27[2]	284±41[2]	321±60[2]	355±84	366±116	349±178[3]	355±199
		5	227±29	272±42	308±65	332±93	344±124[3]	350±163	344±190
		6	222±29	262±43	294±64	315±92	329±124[3]	330±161	318±186
	40	3	218±40	271±52	312±64	347±79	369±110	365±176	360±203
		4	227±26	275±45	314±59	346±80	358±118	350±174[3]	343±199[3]
		5	221±28	259±45	297±64	317±94[3]	331±124[3]	331±159	324±179
		6	215±30	252±47	281±66	297±92	307±119[3]	303±153	299±167
	50	3	207±41	263±51	303±62	339±81	359±114	353±180[3]	331±210[3]
		4	221±31	265±48	301±62	329±87	341±117[3]	331±173[3]	325±197[3]
		5	214±32	257±50	284±67	302±97	308±121[3]	310±152	302±173
		6	212±34	246±52	270±75[3]	282±96[3]	283±119[3]	283±140	272±154
	60	3	199±40	250±53	291±64	323±80	344±110	341±182[3]	329±205[3]
		4	212±31	255±55[3]	286±66	306±93	316±121[3]	307±172[3]	298±187[3]
		5	205±35	243±55	266±77[3]	279±102[3]	283±124[3]	283±150	275±173
		6	200±38	232±60[3]	247±82[3]	253±104[3]	255±122[3]	248±141	238±139
Flexible	20	3	273±33	310±43	341±55	366±74	381±87	380±111	379±126
		4	271±32	309±42	339±59	369±72	382±88	386±106	378±131
		5	270±33	307±42	337±55	366±71	374±96	376±117	369±139
		6	267±35	306±42	336±55	363±71	372±94	375±115	370±132
	30	3	261±32	300±41	333±51	364±66	381±85	387±109[1]	379±135
		4	259±30	298±38	333±48	363±67	383±84	385±111	382±132
		5	260±27	297±38	333±49	359±67	375±90[1]	384±109	375±137
		6	257±26	296±37	328±55	359±67	371±87	374±112	372±132
	40	3	255±24	293±32	327±47	360±66	379±88	387±101[1]	381±129
		4	253±24	292±32	328±47	359±65	372±92	382±107	377±135
		5	253±24	293±30	326±47	355±66	370±93	378±113	373±131
		6	253±24[1]	295±28	328±43	355±65	363±93	369±110	361±135
	50	3	247±24	290±30	329±42	355±66	364±93	380±109	374±135
		4	247±23	293±28	329±42	353±68	368±91	376±109	369±135
		5	248±23	291±28	330±40	355±67	363±94	366±111	364±136
		6	249±23	294±28	331±42	358±63	360±93	362±111	361±128
	60	3	244±24	289±29	328±38	353±65	361±94	373±111	367±136
		4	244±24	289±29	329±38	353±63	363±95	363±120	364±138
		5	247±24	293±27	331±37	358±60	365±92	366±111	363±130
		6	249±24	294±27[1]	333±39	358±61	365±87	363±117	352±139
	70	3	239±23	284±29	322±36	352±59	363±87	366±115	363±137
		4	239±23	286±28	327±38	353±56	363±88	365±117	359±136
		5	243±24	290±27	333±35[1]	359±59[1]	367±90	369±114	358±140
		6	249±24	294±28	332±38	357±61	367±88	364±113	361±134
	100	3	222±24	269±30	310±40	341±55	351±89	356±113	348±139
		4	227±26	273±30	319±38	353±56	360±95	368±117	357±146
		5	234±28	282±33	327±39	359±59[1]	369±93	370±115	363±141
		6	244±27	292±28	331±40	359±60	371±89	363±117	358±136
	Unlimited	3	173±52	232±55[3]	282±58	322±66	337±96	350±120	344±146
		4	206±42	264±44	312±48	349±60	360±94	363±123	364±143
		5	227±37	283±37	328±41	357±63	367±97	368±122	360±145
		6	244±29	292±31	330±39	358±63	365±93	368±115	361±137
No hay			246±43	287±55	316±70	340±93	357±116	358±172	343±193

[1] Risk efficient set, all within the flexible strategy (see text for explanation). [2] Risk efficient set within the calendar-based strategy. [3] Combination outperformed in E,V terms by NoHay.

Table 7.4: Means of hay production and hay use for the strategies included in the risk-efficient sets.

Approach	SR (cows)	AREA (ha)	MASS (t DM/ha)	Area cut (ha/year)	Hay produced (t/year)	Cutting herbage mass (kg/ha)	Proportion of hay used (%)
Calendar Based	170	30	4	30	82	4011	91
	170	40	4	40	109	4003	92
	200	20	4	20	55	4012	91
	200	30	4	30	82	4009	91
	230	30	4	30	82	4008	91
	260	20	3	20	39	3042	91
	260	20	4	20	54	4000	92
	290	20	3	20	39	3040	91
Flexible	170	40	6	35.1	158	6245	69
	200	60	6	45.5	211	6406	62
	230	70	5	51.7	209	5650	77
	260	70	5	46.4	189	6005	88
	260	100	5	52.5	211	5634	85
	290	30	4	27.5	84	4442	92
	320	30	3	27.9	73	3892	92
	320	40	3	35.8	103	4204	91

7.3.3.2. Impact of weather sequence on relative performance of the strategies

The ordering of the 371 strategies, based on average profit, was affected by the actual 50-year weather sequence used in the individual replicates of the experiment. Note that the same real weather sequence was randomly sampled every time. Figure 7.9 shows that strategies that performed well in one weather sequence may perform relatively poorly in other. There were strategies that were in the top quartile (i.e. among the best) in one replicate and in the bottom quartile in a different replicate.

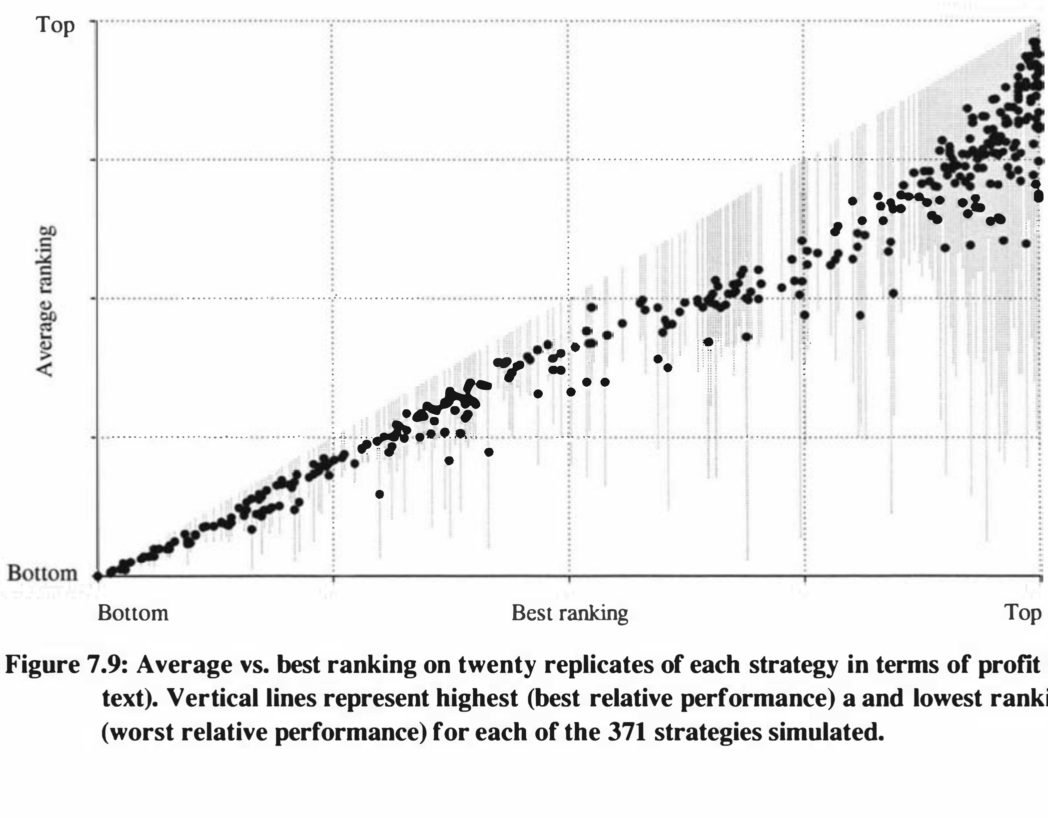

Figure 7.9: Average vs. best ranking on twenty replicates of each strategy in terms of profit (P, see text). Vertical lines represent highest (best relative performance) a and lowest ranking (worst relative performance) for each of the 371 strategies simulated.

Robinson and Freebairn (2001) found major differences in the ranking of different tillage systems depending on the weather sequence[24] used for the simulations. Those authors attributed this phenomenon to complex interactions between decision rules and weather that generated chaotic behaviour, and commented that:

> "*What was usually the poorest management could be judged the best management given a starting date that is favourable. Chance ("good luck") was as important as management in providing good outcomes in some of the scenarios...*"

Therefore, concluding that a particular strategy is the best on the basis of the results of a single weather sequence may be misleading. Using 20 such weather sequences in the simulations gives a much more reliable ranking of the strategies.

7.3.4. Discussion and Conclusions

The analyses described in this chapter were exploratory only. The main limitation was that only one source of cost was included. The assumption was made that haymaking is the main difference between the strategies. In a real system there are other costs, some of which increase with stocking rate (e.g. animal health and labour). Given that the better strategies tended to maintain higher cow numbers (which explains their superiority in animal production), including these costs in the calculations may influence the results. However, in reality these costs are normally small compared with those of haymaking.

Another arguable limitation is that, in the management strategies studied here, the decision rules are based on bio-physical indicators only. A real farmer would consider prices, for example, in making many decisions. The inclusion of economic variables in the decision rules and the evaluation of the productive and financial implications could be considered in future studies.

The risk efficiency analysis highlights major advantages in using hay in cow-calf systems, especially when a flexible management approach is implemented. It also indicates that, probably because of the decrease in the cost per unit of hay as cutting mass increases, cutting at high mass (as done in Reserva 6) is the most stochastically efficient alternative at low and medium levels of stocking rate. At high stocking rates, on the other hand, the best option seems to be making hay at low herbage mass, which, with the flexible approach, means making hay as soon as conditions permit. The area actually cut in the efficient options was also dependent on the cow number, being about 35% of the total farm on average in both extremes of the range; and more that 50% for moderate stocking rates. According to these results it is advantageous to retain the flexibility of cutting more area in climatically favourable years, instead of a fixed area each year.

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[24] Based on real weather data, the different sequences were generated by starting the simulation in a different year.

More than 33 combinations, at the same target cow number, were dominated by the NoHay strategy, which indicates that making hay is not automatically beneficial for the system, but depends on how the haymaking process is managed. It was observed that, at intermediate cow numbers, when the flexible approach was used, cutting at 5-6t DM/ha was the efficient option, but it was the worst (even compared with the NoHay combinations) with the calendar-based strategies. Another interesting observation is that, at low cow numbers, confirming what was observed in terms of liveweight production in Experiment 3 (Chapter 4), the main benefit of haymaking was in the reduction of system variability and not so much in an increase of productivity. As cow numbers increased on the other hand, both components gained importance. These apparently contradictory results warn about the difficulties of reaching unequivocal conclusions on the management of complex systems like farms. In the words of Cacho et al. (1999), any conclusion must be taken "within the experimental treatments considered ".

The methodology used here indicated that a flexible policy for haymaking management would be more risk efficient than the more rigid calendar-based approach currently used in Reserva 6. It was also observed that, following a flexible approach in some years allows hay production in excess of the immediate requirements for the following winter, increasing the stochastic efficiency of the system.

It is worth mentioning that the results obtained in this preliminary economic analysis do not contradict, in general terms, the conclusions obtained in the biological analysis (Chapters 5 and 6), although, the average areas harvested in the efficient set were below the area that maximized liveweight production. That is, the benefits of making hay were again clear, and the flexible approach showed consistent advantages relative to the calendar-based approach. Harvesting hay in excess of what would be required to cover immediate needs could be justified also in economic terms, provided a flexible strategy is followed. Notice that those results were obtained without assigning any market value to the hay not used.

There were several policies close to the frontier line, and it would be simplistic to discard them just because they were not exactly on the line. Modifications in relative prices may change the relative performance of combinations that are close to each other. The use of other techniques or the consideration other aspects of the system could further separate strategies that are close to each other in E,V terms.

CHAPTER 8

CONCLUSIONS

8.1. THE MODEL

8.1.1. Model design and programming approach

It is expected that questions will evolve during the course of any research project. In the specific case of a simulation study, not all the questions to be asked of the model are known beforehand. Thus, simulation models should be made as flexible[25] as time and resources permit. However, the more flexible the model is, the more complicated it becomes. Deciding how flexible a model will be is one of the most difficult problems to be solved in the design stage (Thornton and Herrero, 2001). The model developed here has been demonstrated to be flexible enough to represent different management strategies for pastoral cow-calf systems and to make simulations over long periods of time.

The object oriented approach (OOA) (Rumbaugh et al., 1991) used in the design of the model is in part responsible for the level of versatility attained. In the OOA, objects in the real world (e.g. cows, paddocks) are represented as objects in the computer program. Each object is designed to be a separate well defined unit, containing data (attributes) and procedures (called methods) describing how that object should respond to various stimuli (messages from other objects). The advantages of object-oriented design result from the modular structure that emerges as a natural by-product of the object oriented philosophy (Brookshear, 2000). In the present project, these characteristics facilitated systems analysis, software design and implementation. As a result, the model is as flexible as required and also easy to expand. The simulation of individual cows and individual paddocks makes it possible to distribute the feeding resources flexibly among the animals and provides many other points of flexibility in management strategies.

The other characteristic that conferred flexibility to the model was the adoption of an expert systems approach, based on decision rules, to represent farm management, (Edwards-Jones et al., 1998b). Rules are a realistic way of representing in a model how real decision makers behave (Hodgson, 1997) and is the most commonly used knowledge representation technique (Gonzalez and Dankel, 1993). There is well documented research on human problem solving which shows that individuals and organizations develop heuristic decision rules to reduce the amount of time required to find solutions (Maxwell and Randall, 1989). An ideal and very important function of

[25] Flexible is defined here as being able to represent different management alternatives.

modelling is the development and presentation of heuristics (or 'rules or thumb') that are logical, and integrated in a wider knowledge framework (Girard and Hubert, 1999).

The rule-based representation is very flexible, and also very intuitive because of its high modularity. It is also easy to communicate, as it is fairly straightforward to understand what a rule is saying. MacDonald and Penno (1998) used decision rules to make practical recommendations for pastoral dairy farm management and the same set of rules has been used to simulate management in a whole dairy farm model (Wastney et al., 2002).

The use of versatile management rules allows a model to react to changing circumstances, as a farmer would do, instead of applying a rigid sequence of actions. The degree of system resilience and compensation to management changes exhibited in this study was a direct result of the rule-based specification of farm management.

The entering of decision rules at herd or block level, without reference to individual paddocks, proved to be adequate for the purposes that the model has been used for so far. However, if the identification of particular paddocks is necessary to simulate a particular management strategy, the user could create single-paddock blocks and use them accordingly.

However, even though a single rule is simple to comprehend, it has been noticed in the present study that the tactical and strategic levels of the management system represented in a particular set of rules may be difficult to grasp. Gonzalez and Dankel (1993) commented that the division of knowledge into small distinct packets, while making each rule easier to deal with, creates a global perspective that is hard to comprehend. More complicated ways of representing knowledge, designed to deal with this difficulty, have been proposed (Girard and Hubert, 1999) and could be explored in future studies.

8.1.2. Focus of the model

The possibility of a model being able to suggest the best management option to a user often seems appealing. Even though the use of optimisation techniques for identifying optimal management of dynamic systems is technically possible (Kleijnen, 1995; Woodward, 1998; Fu, 2002) and in many cases is indeed useful, there were several reasons why this optimisation was not pursued in this project. The next two sections briefly explain some of them.

8.1.2.1. Practical reasons

Optimisation of management of dynamic systems requires significant, often prohibitive, computing resources.

In the case of problems requiring stochastic discrete-event simulation, the most common optimisation procedures (e.g. linear programming or non-linear programming) cannot be applied because they require specific mathematical formulations. Numerical techniques involving multidimensional search for extrema of non-invertable functions need to be applied, and all of them require testing large numbers of possible alternatives (Fu, 2002). Furthermore, to evaluate the likely results of policy options at a certain confidence level, long time horizon studies are required. There are several reasons for this:

1. Dynamic systems exhibit long delays in their feedback structures, and often the consequences of a management action only become evident long after the action was taken (Sterman, 2000).
2. Dynamic systems can show sensitive dependence on initial conditions (see Chapter 4). Conclusions based on short term studies could therefore biased by the initial set of initial conditions (Robinson and Freebairn, 2001).
3. The results of short term comparisons can be highly sensitive to stochastic components in the models and to environmental conditions, spuriously favouring one policy to the detriment of others.

Because the model used here is a dynamic model, which included random environmental influences, replicated long term simulations are necessary to evaluate each alternative (Fu, 2002). Therefore, if multiple long term simulations are required to test each of the large number of alternatives, this poses serious challenges to the possibility of performing optimisation with large dynamic models when available computational hardware and time may be limited. The resources needed would be several orders of magnitude greater that any currently available. The present model was planned to be used in the INTA Research Station of Balcarce, where computer hardware is limited.

Even if the required computer power was available, it would only be straightforward to optimise the parameters of the rules as entered by the user, not to create new/better rules. In other words, optimisation can be readily used to improve an existing system, but it cannot easily be used to create better systems (Coyle, 1978). For example, it is difficult to conceive how an optimisation algorithm could have discovered the flexible haymaking strategy given the calendar-based strategy as a starting point (Chapter 5 to 7).

8.1.2.2. Conceptual reasons

Optimisation of management of dynamic systems often demands simplification of the problem to the point of irrelevance.

The idea that human beings behave as perfectly rational agents has been extensively criticized (Hodgson, 1997; Edwards-Jones et al., 1998a). Sterman (2000) argues that optimal decision making is impossible, because it assumes objective rationality. Objective rationality[26] requires a complete knowledge and anticipation of the consequences that will follow each choice (Simon, 1997; Skittner, 2001). Clearly, this requirement is rarely met, except in the case of very simple problems. Human decision

[26] According to the definition of Simon (1984), a decision is objectively rational if in fact it is the correct behaviour for maximizing a given value in a given situation.

making is bounded by our cognitive limitation in the face of the complexity and extensiveness of the real world systems (Hodgson, 1997; Simon, 1997; Sterman, 2000).

Furthermore, methodologies based on optimisation and goal seeking work well for the solution of problems for which goals statement are unambiguous, but simply do not work when applied to messy, ill-structured, real-world problems (Checkland, 1985; Bossel, 1994; Vennix, 1996; Deallenbach, 2001). Kleijnen (1995) even argued that, in the case of ill-structured problems, optimisation is of academic interest at best. The definition of a single universally agreed objective function to be maximized is the first condition required to use any of these techniques, but the inability to define objectives, or to decide whose are more important, is usually part of the problem (Checkland, 1985). In the case of farm management, every farm is different, humans have multiple and often conflicting goals, and those goals change all the time, affected by current circumstances, age, past experiences and a variety of socio-economic influences. Also, when there are multiple stakeholders within the system, as is the case in farming, there is usually no single measure of utility that adequately captures all the values of these different stakeholders (Walker et al., 2002). Human decision makers, who are the ones that modelling is supposed to benefit, cannot be treated simply as economic agents assumed to want nothing more than maximization of profit (Edwards-Jones et al., 1998a; Mingers, 2000).

The model is viewed here as a micro world whose main purpose is to facilitate learning, understanding and communication (Forrester, 1961; Coyle, 1978; Sørensen and Kristensen, 1992; Sterman, 2000). The model in this study was not designed to tell the user what to do, but to facilitate a better understanding of cow-calf systems hopefully leading to better farming practices in the Salado Region. The overoptimistic view of models as "answering machines" able to directly solve all management problems has led to strong scepticism about models in the past (see for example Philip, 1991). While models cannot produce all the answers to production problems, when reasonably constructed they can be important heuristic tools in teaching, research and management applications (Sinclair and Seligman, 1996). Where models are used primarily for learning, optimisation becomes less relevant.

8.1.3. Aspects where more local research is needed

To be useful, a pastoral system model must accurately reproduce the temporal and spatial patterns of variability of the real system. The pasture model used here has empirical parameters that may need recalibration for the Salado Region. The preliminary tests performed showed satisfactory results, but the experimental data available was far from adequate. Long term experiments, covering the four seasons of the year, and spanning several years are required in order to calibrate the model for a broader range of situations.

Data from different pasture species/communities, soil types, locations, cutting regimes and fertilization levels are also necessary. Those experiments must not only collect herbage net accumulation data, but also include information about pasture composition, leaf area index, light interception at different stages, phenological changes and herbage quality. Soil water content must also be monitored.

The pasture species commonly used in the Salado region, like Agropiron and certain natural grasses, show morphological differences compared with those universally studied temperate species (e.g. ryegrass, white clover, tall fescue). Therefore, the empirical relationships between herbage intake and herbage allowance need to be re-evaluated. The data should cover the different phenological stages of the plants and also a range of animal ages and sizes. More data on dry matter intake of low quality hay is also required, alone and combined with other feeds.

The types of studies needed to generate these data are expensive and time consuming and require long-term horizons. A greater level of integration and coordination between modelling and experimental studies should be pursued in the future. This should be reflected in the ways both are designed and communicated.

The maximum level of stocking rate achieved in the Reserva 6 system was 2.54 cows/ha, with a liveweight production of 360 kg/ha/year (Burges et al., 1998), and this level was sustained for 3 years (1997-2000). For such a stocking rate, interpolating from Table A 5.5. (Appendix, section 5.6), the model would predict a production level of about 370kg LW/ha/year, indicating a good agreement (less that 3% overestimation). However, the simulations indicated that calf liveweight production would be maximised with a stocking rate of about 2.9 cows/ha, with a production level of 370-470kg LW/ha/year (depending on the haymaking strategy applied), which seems rather high in relation to the experience in the area. Some aspects in the pasture model that may be the cause of overestimation are:

1. Pasture degradation was not considered. Animal overstocking, understocking, intense drought events or excessive rain may all have long term effects on pasture that have not been considered in the pasture model.
2. Pasture heterogeneity was not considered. The pasture model showed acceptable results compared with herbage accumulation data from cutting trials. However, the soils of the Salado Region are characterized by large spatial variability, and cutting trials in general may not include the worst areas. Woodward and Rollo (2002), argued that using a representative sub-area to calculate growth rate for a large area usually results in overestimate of growth rate.
3. Treading damage was not included in the model, underestimating the reductions in pasture productivity, especially at the highest levels of stocking.

The analyses performed here focused on the relative performance of the different management alternatives that were compared. The present study assumed that the above simplifications in the pasture model did not affect the relative performance of the haymaking strategies in Chapters 5 to 7. However, these elements should be improved in the future, since producing results as realistic as possible, not only in relative terms, but also in absolute terms, is important in building model credibility among local farmers.

8.1.4. Future implications

Reserva 6 has been managed for 30 years basically using the same strategy designed in the 1960's. This provides a valuable benchmark for future studies. It has proved to be an effective and stable strategy (Carrillo, 1975; Carrillo et al., 1998), but there have been limited possibilities to evaluate alternatives for improvement. The model developed here will be used for this purpose by the researchers in Balcarce, and can be seen as a tool to help local experts in the design of better cow-calf systems. New alternatives can be tested with the model and, if promising, implemented alongside Reserva 6. The model will also be used to address questions and ideas from the farmers who regularly visit the unit.

Apart from the work required in the biological models as explained in section 8.1.3, several areas of possible improvement were identified while using the model to study haymaking alternatives (Chapter 5 to 7). The list below enumerates some of them:

1. Allow the entering of comments, so that the rationale for each rule could be explained in words from the outset.
2. Provide the possibility for tracking the "history" of certain rules selected by the user. This would allow following the operation of a rule to check whether it is working in the intended way.
3. Incorporation of user-created variables (or facts, Gonzalez and Dankel, 1993) and constants that can be used by any rule. There could be rules that assign values to these facts instead of triggering any action. Temporal landmarks (e.g. first calving, last calving, weaning, no hay left, etc.) can also be useful (as in the SEPATOU model, Cros et al., 2001).
4. Use of an improved stochastic weather simulator (see for example Podestá et al., 2002).
5. Division of hay between different stacks, corresponding to year of harvest, quality, or paddock of origin. This would give the possibility of using these stacks differently.
6. Use of different supplements apart from hay.
7. Incorporation of economic/financial variables in the decision rules and outputs.
8. Simulation of heterogeneous paddocks in terms of soil and pasture species, and genetically different animals.

These are some of the improvements that have been identified as desirable so far. It is expected that, when using the model in Balcarce, other issues will be identified and improved in an ongoing process.

8.2. THE COW-CALF SYSTEM

During this project, a better understanding of some aspects of cow-calf systems in the Salado Region in general, and of Reserva 6 in particular, has been gained. The following two sections summarize the most important conclusions.

8.2.1. Preliminary studies

Under the conditions evaluated here, the results suggest that when the appropriate management variables (i.e. weaning and sale dates) are adjusted accordingly, changing the calving period, even by as much as a month, would have little effect on the productivity of a cow-calf system.

Simple replacement rules can result in systems that exhibit long-term oscillations or that are slow to recover from catastrophic events. More flexible replacement rules can avoid these problems without adversely affecting long-term production. As shown in the present study, the year to year variations normally observed in the productivity of pastoral systems are not only the result of external influences, but can also be caused by the management policies followed by the farmer. Complex interactions between the environment and the management strategy can also be present. This makes short-term or unreplicated comparison of farming strategies problematic. The results presented here for the specific case of cow-calf systems can be taken as an example, but the same type of issues can be encountered and should be considered in other dynamic systems.

8.2.2. Haymaking

When simulations were performed for a low stocking rate (Chapter 4, Experiment 3), it was observed that haymaking gave more production stability to the farm. However, the quantitative predictions from those simulations indicated that the use of hay in cow-calf systems of this kind could only moderately improve average productivity. The results suggest that, provided hay is utilized on the farm, the pattern of use does not make much difference to production.

In the subsequent studies it was observed that the benefit of making hay, and the contrast between the effects of different haymaking strategies on animal outputs, depends on stocking rate, being maximum around the stocking rate levels that deliver the maximum production. The long term liveweight production of cow-calf farms, under a rather rigid haymaking policy like the one followed in Reserva 6 (Chapter 5), would be maximized by harvesting up to 40-50% of the total farm area and aiming to harvest hay of medium quality. The Reserva 6 farm could increase its physical productivity by making hay at lower herbage mass, and cutting more area (about 40-50 instead of 30% of the area); that is, harvesting more or less the same amount of hay, but of a better quality.

Controlling haymaking in a flexible fashion (Chapter 6), basing decisions of closing, releasing and cutting paddocks on a simple pasture budget (number of paddocks ahead in the projected grazing cycle), gave productive advantages relative to a calendar-based approach. Compared at the same area harvested, the benefits included increases in average productivity along with reductions in the variability of the system. The results indicated that allocating more than 50% of the farm area for haymaking would only be advantageous at very high stocking rates. Also, making more hay than required for the subsequent winter, where possible, can buffer the system and reduce production variability. However, this buffering function of haymaking would not be possible if the stocking rate was too high, and would provide little advantage if the stocking rate was too low. Making extra hay can operate as a safeguard for the system, and part of it can be sold to avoid excessive accumulation. Note that, with the calendar-based policy, making more hay than required was counterproductive, probably because of the rigidity of the grazing pressure imposed on the cows during the spring and summer.

Whether or not the advantages observed from the flexible haymaking strategy are sufficiently attractive against the simplicity of the current Reserva 6 approach must depend on each particular case. Because of the greater complexity of the decisions involved, a drawback of the flexible haymaking policy was difficulty in maintaining hay quality between years. This may be a problem if the hay is required for specific purposes, like feeding growing animals in addition to dry cows.

Incorporating flexibility into the haymaking policy of Reserva 6 (Chapter 7) would improve its risk-efficiency in relation to the more rigid calendar-based approach currently used. It was also observed that following a flexible approach, when the stocking rate is not too high, allows hay production in excess of the immediate requirements for the following winter, yet increases the risk-efficiency of the system.

Finally, in systems research it is always difficult to make generalizations (Menz and Knipscheer, 1981; Norman et al., 1995). This was evident in the present study. When more flexibility was incorporated into the Reserva 6 haymaking policy, some of the conclusions obtained with the more rigid policy were no longer valid. Examples are the effect of making hay at different herbage masses, or the economic advantages of making more hay that required for the next winter. In view of this, the conclusions presented in this section are valid to cow-calf systems similar to Reserva 6, but should not be extrapolated to different situations.

8.3. FINAL COMMENTS

The general objective of gaining understanding of the dynamics of cow-calf systems with a simulation model has been accomplished. The model that has been produced is considered to be flexible enough to be used to address several other management question in future studies at INTA-Balcarce. The choosing of the object oriented programming paradigm and the use of decision rules to represent management were of particular importance in achieving the expected results.

The particular objectives related to the study of haymaking strategies have also been attained. New insights have been gained on the topic, and aspects where more research is required have been identified and highlighted.

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