

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Field and modelling studies of the effects of
herbage allowance and maize grain feeding
on animal performance
in beef cattle finishing systems**

A thesis in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy

In Animal Science

At Massey University, Palmerston North,
New Zealand

Claudio Fabián Machado

2004

ABSTRACT

Machado, C.F. 2004. Field and modelling studies of the effects of herbage allowance and maize grain feeding on animal performance in beef cattle finishing systems. *PhD Thesis, Massey University, Palmerston North, New Zealand.*

The objective of the work described in this thesis was to develop a mathematical model designed as a tool for research intended to improve the efficiency of finishing systems for 1-2 year old beef cattle under intensive grazing management on sown pastures in Argentina. The work involved a) three experiments in Argentina carried out to define the effects of herbage allowance and maize grain supplementation on herbage intake and animal performance, b) one experiment in Argentina following a preliminary study in New Zealand of seasonal variation in the composition and nutritive value of intensively managed beef pastures, and c) an exercise to develop a model of beef cattle production incorporating modules dealing with aspects of pasture production and utilisation, herbage intake and animal performance. The results from the series of short-term grazing studies showed consistency in the comparison of the effects of increasing herbage allowance and supplementation on herbage intake and animal LWG (Chapter 4). A method combining the use of n-alkane and ^{13}C method proved to be accurate for quantitative estimates of herbage and maize grain intake, and allowed estimates of a substantial variation in individual maize grain intake (between 31 to 41 % CV) when animals are supplemented in groups. The substitution rate (SR) measured in these studies varied little across experiments or level of grain at a herbage DM allowance of 2.5 % LW d^{-1} (0.36 and 0.38 kg herbage DM per kg grain DM for Chapters 3 and 4 respectively). Increasing level of herbage DM allowance increased quadratically the SR from 0.38 to 0.83 and 0.87 kg herbage DM per kg grain DM. The n-alkane method was effective in providing estimates of diet digestibility. Different methods for estimating diet composition, such as micro-histological evaluation of faeces, differences in nutrient and component selection indexes and n-alkanes were used in the initial grazing trial (Chapter 2) but they were not considered to be reliable and they were too laborious for continued use under field conditions.

The outcome of the studies on seasonal variation in herbage quality initially was

useful in establishing a database of the range of values observed, and in demonstrating their relative robustness, at least under conditions of good pasture management. In these studies, herbage nutritive value did not seem to be a limiting factor for growing beef cattle, at least in terms of the minimum observed content of metabolisable energy (10.8 MJ ME kg DM) or crude protein (17.3 % DM). Additionally, significant relationships were established between morphological and maturity estimates and herbage nutritional variables in a pasture under grazing conditions. These relationships showed promise for future use in the prediction of herbage nutritive value, but require further work.

The model developed ("BeefSim"), represents the main biological dynamic processes of the target system of this thesis, together with additional management decision and financial estimates. It was shown that the model presents adequate flexibility and can be interrogated in terms of its response to different management conditions, scenarios and timeframes. Pasture management and grain feeding were controlled in an interactive management module responding to deviations in pasture conditions and animal liveweight from pre-determined targets. Two key outcomes of the model, liveweight gain and herbage intake were accurately predicted when compared against experimental information under different levels of herbage allowance and maize feeding. System comparisons developed with the model showed agreement with the literature, and maize grain feeding associated with the monitoring procedure demonstrated an effective use of grain in the system. The model provides a good biological basis for a holistic appraisal of the effects of "process technologies" such as grain feeding in beef cattle finishing systems, and will be developed further.

Key-words: herbage allowance; maize grain feeding; beef cattle; rotational grazing; herbage quality; modelling

Dedicated to Maria (my wife), Jova and Manuel (my parents)

PREFACE

This thesis was developed as part of the research activities of the author at the Facultad de Ciencias Veterinarias, Universidad Nacional del Centro de la Provincia de Buenos Aires, FCV-UNCPBA-Argentina. The thesis was developed under a “sandwich system”, where research preparation and the final reporting, i.e. the first and the last part of the PhD activities, was developed at Massey University, and most of research was carried out in the candidate's home country (Argentina). Extra arrangements such as funding assistantship, organization of family issues and maintenance of other work responsibilities, were overcome and the way that the research was structured made it possible to focus in an Argentinean pastoral research problem, with the formal supervision from New Zealand expertise in the area.

The topic was identified from author's interaction with a group of beef cattle farmers and agricultural consultants. An early prior study was developed on a commercial farm to investigate tactical alternatives of maize grain supplementation in beef cattle finishing systems during summer¹. Beyond its stimulating results and cooperative experience, the most challenging and frustrating thing was the limitations for extending the results in terms of the whole system perspective. What would happen if supplements were used earlier in the production cycle, or in different summer conditions, with different stocking rates, or combining different animal types....? With some of these “what-if” questions in mind and with the support of New Zealand expertise, this thesis was planned to address to a limited extent of these identified issues. An understanding of changes in herbage intake and animal performance when maize grain was fed and herbage quality were identified early in the programme and incorporated into modelling as tool for information synthesis and additional insights.

The experimental part of this thesis was mostly developed on farms, and that shaped the selection of research techniques applied to the plant/animal interface. The author started as a novice in modelling, and further motivation for modelling training came from his teaching experience. The author firmly believes that the

¹ Machado et al. (2001), translated and presented in Annex A for explanation, but not as a part of the thesis.

efforts in the simulator development such as presented in this thesis, with adequate adaptation and improvement, should contribute to “experiential learning” and “systems thinking” development for agricultural students and professionals.

ACKNOWLEDGEMENTS

First, I would like to show my gratitude to my chief supervisor Associative Professor Stephen Morris. Steve guided me with patience, a constructive critical eye and perseverance, never accepting less than my best efforts. Steve generously arranged extra funding to cover any constraints to advance the project. The speed that he returned my drafts was highly valued. Thanks you very much, Steve.

I wish to acknowledge to my co-supervisors, Prof. John Hodgson and Prof. Nestor Auza. I was particularly fortunate to have as an advisor to Professor Hodgson, who is now “retired” and could therefore provide a high level of dedication to the completion of this thesis. His explanations of the basics of grazing made this thesis easier. Prof. Nestor Auza has provided valuable support for the completion of the thesis, the guidance of Nestor came continuously since my student days. Thank you very much John and Nestor for your support.

I also acknowledge the support of the funding support of my own university and the New Zealand Ministry of Foreign Affairs and Trade for providing the economic help for living expenses and travel during this study. The funding provided by ANPCyT (National Agency of Science and Technology) for some of the experimental costs, PICT 0809771, was highly appreciated.

In this venture, I have had the immense good fortune of receiving skilful and enthusiastic help for the development of grazing experiments in places and conditions where initially control field trials seemed unfeasible. The help of Fernando DiCroce, Facundo Gonzalez, Jose Oviedo and Daniel DiCroce at the beginning, and Horacio Berger and Mariano Copes at the end of the programme are highly recognised.

The challenge of model development could be much more difficult without the valuable help received from Ryan Sheriff who helped me solve different programming and mathematical issues. Gaston Martini, Horacio Berger and Eduardo Ponssa in Argentina also helped in this task. All the contributions are highly appreciated.

I want to show my gratitude to Drs. Mike Wade, Monica Agnusdei Graciela Canziani, Fernando Milano, Mariana Recabarren and Maria Bakker, who helped me in the completion of this thesis.

To Drs. P. Morel, D. McCall, S. Woodward, L. Barioni and M. Upsdell (developer of Flexi, used in some statistical procedures) for providing me knowledgeable advise. Thanks for your help.

The “sandwich” system has given me the opportunity to meet friends twice in New Zealand. From the Argentinean group, I want to record my appreciation to the Russ family (Emy, Alana, Marcela and Tato) and Alvaro, Cecilia y Poppi for so many enjoyable moments and friendship. Also Alvaro provided me with highly appreciated technical advise. I would like to thank Sergio Garcia (Yani) now in Australia, a fine scientist, for his useful insights, many interesting conversations, but always to Yani the friend, for the permanent encouragement and enthusiasm in the completion of this thesis. Valeria, Juan Cruz and Olivia were part of the good company we have had in our first stay at Massey, the same like Cesar Poli and Family. I had the privilege to share an office, the gym, some barbecues and good talk with John Alawneh. My appreciations for the support and friendship from him and his family, Leena and the small Sarah. Recently, we incorporated two new roommates, Tuluta Fisihoi and Gonzalo Tunon. Thanks for all the help and good talks. I want to show my gratitude to all that made our stay enjoyable, Elisa and Matias, Natalia y Alexis, Rene, Hector and respectives families and also the new group of student and families arrived this year.

To Dorothy, Colin Holmes and Ruth Hodgson, their kindness and friendship is highly recognised.

To all the Staff of the Science and Technology office of my University, the support and and friendship during last years is deeply acknowledged.

To my friends from Tandil, Guly, Luciano, Rodolfo, Roberto, Alejandro y Nestor, all people from ATA (Athletism association of Tandil), and those living in Pringles,

Carlos Bernal, Daniel Amores and respective families.

A Jova y Manuel (mis padres), por el amor recibido y ejemplo constante y silencioso hacia el esfuerzo y a la superación. A mi hermana Mónica y sobrinos (Manuela, Martín y Mariano), a toda mi familia directa y política, con el cariño y aliento recibido en este tiempo fuera del país.

I would like to give particular thanks to Maria (my wife), for supporting me throughout the life we have been sharing and for seeing so clearly into the areas of life where I am blind. Our children Camila y Julian were born during this study, and also she managed to complete a postgraduate diploma in the same period. My appreciations to Camila y Julian for remember me everyday that over any difficulties, the world is full of joy and hope, all is about perspectives.

Abstract		iii
Preface		vii
Acknowledgements		ix
Introduction		1
Part I: Grazing experiments		13
<i>Chapter 1</i>	A review of the effects of energy supplementation and sward characteristics on animal performance in pastoral beef cattle finishing systems	15
<i>Chapter 2</i>	Herbage intake, diet composition, grazing behaviour and performance of Angus heifers on two herbage allowances during late spring	45
<i>Chapter 3</i>	Effect of maize grain and herbage allowance on intake, animal performance and grazing behaviour of heifers in winter	63
<i>Chapter 4</i>	Effects of herbage allowance and maize grain on herbage and grain intake, and performance of Angus steers in late spring	87
Part II: Herbage quality		111
<i>Chapter 5</i>	Seasonal variation in the quality of an alfalfa-based pasture and its relationship with morphological and maturity estimates	113
Part III: Modelling		133
<i>Chapter 6</i>	Modelling studies of grain feeding in a grazing-based Beef cattle finishing operation: 1. Development of a "beef cattle finishing unit" simulator	135
<i>Chapter 7</i>	Modelling studies of grain feeding in a grazing-based beef cattle finishing operation: 2. Model evaluation and system simulations	195
Overview		217
Annexes		227
<i>Annex A</i>	Maize supplementation and feedlot as an alternative for summer steer finishing systems	229
<i>Annex B</i>	Seasonal changes of herbage quality within a New Zealand beef cattle finishing pasture	243

Index of figures

Chapter 1.

- Figure 1. Relationship between herbage allowance and liveweight gain of steers during Autumn / Winter and Spring / Summer periods (Reid 1986). 20
- Figure 2. Relationship between level of maize grain supplementation (in kg d⁻¹) and extra liveweight gain over the unsupplemented group (in kg d⁻¹) in grazing beef cattle. 24
- Figure 3. The effect of herbage mass and herbage allowance on herbage intake (drawn from Wales et al. 1999). 28

Chapter 2.

- Figure 1. Effect of herbage allowance on grazing behaviour of Angus heifers throughout the day. 53

Chapter 3.

- Figure 1. Individual maize grain intakes as recorded within each treatment replicate. 73
- Figure 2. Effect of herbage allowance and maize supplementation on grazing behaviour of heifers throughout the day. 75

Chapter 4.

- Figure 1. Relationship between herbage allowance (X) in kg d⁻¹ and individual liveweight gain (Y) in kg d⁻¹. 94
- Figure 2. Relationship between herbage allowance (X) in kg d⁻¹ and individual herbage intake (Y) in kg d⁻¹. 96
- Figure 3. Relationship between herbage allowance (X) in kg d⁻¹ and individual substitution rate (Y) in kg herbage kg maize grain⁻¹. 97
- Figure 4. Relationship between herbage allowance (X) in kg d⁻¹ and individual liveweight gain (Y), condensing information between Chapters 2, 3 and 4. 101
- Figure 5. Relationship between herbage allowance (X) in kg d⁻¹ and individual herbage intake (Y) in kg d⁻¹, condensing information between Chapters 2, 3 and 4. 102
- Figure 6. Relationship between individual herbage intake (X) in kg d⁻¹ and liveweight gain (Y) in kg d⁻¹, condensing information between Chapters 3 and present study. 102

Chapter 5.

- Figure 1. Seasonal change in herbage metabolisable energy (a) and crude protein (b) in pre-grazing samples during the sampling period. 120

Chapter 6.

Figure 1.	Cybernetic representation of the biophysical, decision and economic modules in BeefSim.	139
Figure 2.	Extend modelling structure in the BeefSim model.	140
Figure 3.	Structure of the pasture submodel used in the simulator.	144
Figure 4.	Response surface of relative intake (0-1) of a 100 kg LW animal to increasing levels of leaf herbage masses and leaf herbage allowances as predicted by Eqn.20. Leaf allowance is expressed here as % LW.	149
Figure 5.	Response surface of relative intake (0-1) of a 450 kg LW animal to increasing levels of leaf herbage masses and leaf herbage allowances as predicted by Eqn.20.	149
Figure 6.	A general outline of how different constraints to intake are estimated and integrated in the "beef cattle finishing unit" simulator.	150
Figure 7.	Diet composition at increasing level of leaf allowance (a) with a sward composition in fractions of 0.41, 0.29 and 0.29 of leaf, stem and dead respectively (as estimated by Eqns. 26-28).	152
Figure 8.	Effect of leaf fraction in the herbage DM (Eqn.26) and leaf allowances ($0 < < 1$, 1=unrestricted) on the fraction of leaf in diet DM.	153
Figure 9.	Simulation of Herbage mass composition a) pre-grazing and b) post-grazing in a series of strips of herbage grazed daily.	155
Figure 10.	a) Paddock currently under grazing and number of allocated strips and b) herbage mass and number of the paddock with the highest herbage mass in a regrazing sequence of 30 days with 12 paddocks.	159
Figure 11.	Main view of the relationship between the decision and the biophysical module.	166
Figure 12.	Extended dialog of the manager block.	166
Figure 13.	Extended dialog of economics block.	170
Figure 14.	Tracking of adjustments made to grain supplementation by the manager block in association with deviation between actual liveweight and targets liveweight (Eqn. 50).	171
Figure 15.	Dialog of the evolutionary optimizer block (front tab).	171

Chapter 7.

Figure 1.	Regression of observed liveweight gain on predicted liveweight gain from the model (Chapter 6) of beef bred animals grazing at different herbage allowances and maize supplementation levels (Chapter 3 and 4).	198
Figure 2.	Regression of observed herbage intake on predicted herbage intake from a model (Chapter 6) of beef bred animals grazing at different herbage allowances and maize supplementation levels (Chapter 3 and 4).	199
Figure 3.	Herbage allowance adjustment as a function of indicated pasture cover deviation from target.	203
Figure 4.	Monthly target animal liveweights in the “baseline” system. Liveweights at the start of the corresponding month.	205
Figure 5.	Effect of stocking rate and use of strategic feeding of maize grain on the ratio between herbage eaten (ton ha ⁻¹ yr ⁻¹) and Σ herbage accumulation rate (ton ha ⁻¹ yr ⁻¹) as and indicator of grazing efficiency in the simulated alternatives.	207
Figure 6.	Effect of the stocking rate (X) on total liveweight gain (Y) of Angus steers obtained from the model and from the literature.	208
Figure 7.	Effect of stocking rate and use of strategic feeding of maize grain on gross margin (GM) and LW production (Prod.) in the simulated alternatives.	210
Figure 8.	Accumulated probability that animals exceed a given liveweight on 1 December. Constructed from the simulation of 100 production cycles using stochastic herbage accumulation years (Table 3).	212

Annex A.

Figure 1.	Average animal liveweights (\pm standard errors) of the treatments throughout the trial.	237
-----------	---	-----

Annex B.

Figure 1.	Seasonal change in herbage metabolisable energy (a) and crude protein (b) during the sampling period (November 1998-March 2002).	249
Figure 2.	Energy-based predicted liveweight gains of a 350-kg LW Friesian bull fed at different levels of herbage intake during the year based on Freer et al. (1997)	250
Figure 3.	Total smoothing herbage metabolisable energy (a) and crude protein (b) during the sampling period (November 1998-March 2002).	251

Index of tables

Chapter 1.

Table 1.	Effect of level of maize grain supplementation under grazing conditions on liveweight gain of finishing beef cattle.	22
Table 2.	Effect of increasing leaf allowance on herbage intake.	29

Chapter 2.

Table 1.	Chemical composition means, concentration of dominant n-alkanes and herbage mass in a pre-grazed pasture at two herbage allowances.	52
Table 2.	Effect of herbage allowance on final liveweight, fasted liveweight loss, liveweight gain, herbage intake and in vivo diet digestibility of Angus heifers.	52
Table 3.	Effect of herbage allowance on the indicated grazing behaviour characteristics of Angus heifers.	54
Table 4.	Comparison of means of different pairs of component selection indexes (dead vs. green and clover vs. grass) pooled between treatments.	54

Chapter 3.

Table 1.	Chemical composition, concentration of dominant n-alkane and concentration of ^{13}C in the utilised feeds.	70
Table 2.	Effects of two herbage allowances and three supplement levels in heifers on different parameters associated with animal performance.	71
Table 3.	Effect of herbage allowance (LHA and MHA) and maize supplementation (LHA-M1 and LHA-M2) on grazing behaviour of heifers.	74

Chapter 4.

Table 1.	Chemical composition, concentration of dominant n-alkanes and concentration of ^{13}C in the forages utilised.	93
Table 2.	Final liveweight, liveweight gain and fasted liveweight loss of Angus steers fed at three herbage allowances and two maize grain levels during late spring.	93
Table 3.	Sward and animal parameters of Angus steers fed at three herbage allowances and two maize grain levels during late spring.	95

Chapter 5.

Table 1.	Means of rainfall, daily temperature and hydric balance as recorded over last 18 years and during the trial.	119
Table 2.	Seasonal variation of nutritional variables in an alfalfa-based pasture.	119

Table 3.	Seasonal variation in contents of metabolisable energy and crude protein in different sward components.	120
Table 4.	Seasonal variation of morphological and maturity variables in an alfalfa-based pasture.	121
Table 5.	Regression equations of herbage quality variables and morphological and maturity variables in an alfalfa-based pasture.	122
Table 6.	Summary of canonical correlation analysis of the whole sample set of herbage nutritional variables and morphological variables and two options of expressing maturity variables in an alfalfa-based pasture.	123
Chapter 6.		
Table 1.	Alphabetical order of model definitions.	172
Table 2.	Constants used in the pasture sub-model.	176
Table 3.	Model constants.	177
Chapter 7.		
Table 1.	Initial parameters from Chapter 3 and 4 considered for the simulations.	198
Table 2.	Regression analysis of observed (Y) values (Chapter 3 and 4) and predicted (X) values for liveweight gain and herbage intake using the model developed in Chapter 6.	199
Table 3.	Mean and standard deviations of monthly herbage accumulation rate ($\text{kg ha}^{-1} \text{d}^{-1}$) for an alfalfa-grasses pasture in the southeast of Buenos Aires province (Tres arroyos, $n=6$), and pasture cover target assumed in the simulations.	201
Table 4.	Result of setting the model as the referenced beef cattle finishing farmlet for development of a “baseline” system.	204
Table 5.	Effect of stocking rate and use of strategic feeding of maize grain in a simulated farmlet (10 ha) with Angus steers starting on the 1 March with 175 kg LW.	207
Table 6.	Assigned values for the economic parameters of the model.	210
Annex A.		
Table 1.	The percentage of dry matter digestibility, crude protein, neutral detergent fiber and acid detergent fiber of the dietary components.	233
Table 2.	Dry matter digestibility, neutral detergent fiber and crude protein of the herbage during the trial.	235
Table 3.	Total liveweight gain and shrunk liveweight losses of the different treatments.	236

Annex B.

Table 1.	Overall correlation analysis of the indicated parameters in pre-grazing herbage samples (n=74).	248
Table 2.	Annual mean and standard deviation of the overall dataset (n=74) and seasonal variation of means of the different herbage quality parameters in pre-grazing herbage samples.	249