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**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

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ABSTRACT

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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 maintainance 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.

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Introduction

1. Context of the study

Grazing-based finishing systems for beef cattle are traditional on Argentinean farms. The feed resources used are very heterogeneous, covering natural grasslands, tropical and temperate perennial pastures and forage crops, with multiple combinations of animal breeds and duration of the finishing cycle (Rearte 1998). Grain supplementation is frequently used in beef systems (Santini & Elizalde 1993), with a fluctuating level of use depending on the ratio between grain and meat price at the time. The use of fertiliser on pasture is common only at seeding time (Rearte 1998). These conditions have led to a significant research effort on a number of issues, on the effects of grain supplementation on rumen metabolism and digestion sites (Elizalde et al. 1994; Elizalde et al. 1996), dietary nitrogen use (Recabarren et al. 2002), animal performance (Giraudó et al. 1984; Latimori et al. 2000) and meat quality (García & Casal 1993; García et al. 1999).

Recently, economic changes in Argentina including increased fixed expenses have led to intensification as a way of increasing productivity but decreasing expenses per unit of product (Rearte 1998). High turnover of cattle improves profitability, and predictability of performance, timeliness of supply all of which are increasingly important (Rearte 1999), because of the need to free land for cropping and to avoid competition with new weaners entering the system in the autumn or delay the finishing of older animals during summer (Arosteguy 1984).

In this more intensive context, utilisation of grain and maize silage has increased, including the use of simple feedlots linked to pastoral systems (Elizalde 1994). However, instead of adding value to the operation, use of supplements can sometimes become a weakness to pastoral systems because of under-utilisation of grass, usually the cheapest feed resource.

2. Scope of the study

The scope and the approach of this thesis are focused on beef cattle finishing farmers in the southeast of Buenos Aires province. In these beef cattle systems, weaner animals are finished in less than 12 months at 15-20 months of age. Animal performance during summer is extremely important to avoid overlap of feed

requirements of finishing animals with that of weaners entering the system in the autumn. One of the problems identified in the system is inadequate response to strategic grain supplementation during a dry summer (grass shortage and decline of herbage quality).

Preliminary studies highlighted the need for more detailed information on the interaction between concentrate use and sward condition, to improve the predictability of grain feeding responses (Machado et al. 2001, presented in Annex A of this thesis). Additionally, discussion with farmers and consultants raised awareness that an adequate "system" quantification of the technique is not a straightforward process. The animal response to grain feeding and ratio between grain and meat price at the time are major factors influencing choice of supplementary feeding strategy. This represents a correct (although highly conservative) evaluation, and both direct and indirect effects of the use of supplements at different time scales under grazing conditions need to be accounted for (Holmes & Matthews 2001). Grain feeding is likely to have important benefits further than simply feeding animals adequately: it may increase system flexibility, allowing intensive use of pastures in spring by maintaining a high stocking rate during winter (Rearte & Pieroni 2001), or increase the reliability of finishing animals during summer (Machado et al. 2001).

The scope of this thesis includes research on some basic biological factors, and evaluation of the outcomes within a systems context. There is agreement that when studying the relationships between sward characteristics, supplement use and animal performance, the plant-animal interface is the key process to understanding the behaviour of grazing systems (Forbes 1988; Hodgson 1990; Illius & Hodgson 1996). In Argentina, investigation of the plant-animal interface has been based on whole year studies (Kloster et al. 2000; Kloster et al. 2003) and has relied on prediction of herbage intake based on relatively simple sward measurements (Frame 1981) or more short-term detailed behavioural studies (Cangiano & Gomez 1985; Cangiano et al. 2002; Utsumi et al. 2002). However, the relationship between herbage on offer, herbage intake and animal performance has not been extensively studied. The logic of herbage allowance-intake responses has proved to be important in the management of grazing systems in different parts

of the world (Baker et al. 1981; Nicol & Nicoll 1987; Dougherty et al. 1989; Redmon et al. 1995; Wales et al. 1999). Hence, the primary objective of this study was to provide basic information on herbage allowance-intake functions when supplementary maize grain is fed, and the effect on animal performance in beef cattle finishing systems.

Methodological difficulties for accurate and reliable measurement of phenomena occurring at the plant-animal interface are well recognised (Dumont & Iason 2000). The use of n-alkanes for individual intake measurements (Mayes et al. 1986) has been successful in beef cattle grazing systems around the world (Realini et al. 1999; French et al. 2001; Moshtaghi Nia & Wittenenbergh 2002), but there was no experience with this method in Argentina when this thesis was designed. Nevertheless, the n-alkane method presents some difficulty when animals are supplemented as a group, as grains typically have a low level of n-alkanes. An iterative alkane-¹³C technique (Garcia et al. 2000), has been shown to estimate accurately the level of DM intake of herbage and maize silage in grazing dairy cows supplemented as a group, without the need of adding other external markers. Maize feeding in different forms (cracked dry grain, wet cracked grain or chopped whole plant silage) is frequently used in Argentinean beef cattle production (Rearte 1999), and a goal of the present thesis was to test this methodology in such systems.

Herbage quality is another important feature of the plant-animal interface and therefore animal performance (Pearson 1997). Herbage quality changes seasonally and dynamically when physiological changes take place in the plants, and grazing or harvesting conditions interact with those changes (Nelson & Moser 1994; Saul et al. 1999). Whereas in stall-fed animal studies, the interaction between forage quality, level of intake and grain feeding can be studied directly (Matejovsky & Sanson 1995), its investigation under grazing conditions (as the controlled variable) clearly presents difficulties. Some studies are oriented to describe seasonal variation of herbage quality under a particular management (e.g. Litherland et al. (2002)) or to describe the changes in herbage quality in grazing experiments, where other variables are controlled (Stockdale 1999). In the case of Argentina, the huge range of pastures and their variable managements makes it

difficult to choose which pastures to study. Furthermore, in order to obtain information on the seasonal change in herbage quality in a beef cattle pasture managed intensively including the potential underlying relationships between nutritional variables and morphological-maturity variables were also examined. Therefore, a second objective was to study the seasonal change of herbage quality in intensive beef cattle finishing systems.

In order to have some control, most of the analytical information about grazing systems is obtained at scales of space and time that are smaller than the scales at which it is desired to apply the knowledge (Demment et al. 1995). Furthermore, to research variables that have important whole system implications (such as grain feeding or herbage quality change), is not a straightforward process, and the selection of methods to be used in the studies plays a key role in the outcomes (McCall et al. 1994).

In the development of intensive grazed-based beef cattle production in Argentina, attention has concentrated on the monitoring of farmlets including level of fertilisation and supplementation (Garcia et al. 1998), cattle genotypes (Mezzadra et al. 1992; Romera et al. 1998; Latimori et al. 2000), and strategies of grazing management (Kloster et al. 2000; Kloster et al. 2003). However, this approach is costly and time restricted, which constrains the number of alternative systems that can be tested (Garcia 2000). An alternative for a system approach is the use of modelling as a tool for information synthesis and system understanding. There is wide agreement about the advantages of modelling studies for research in the biology of grazing systems (Wright & Dent 1969; McCall et al. 1994; Herrero et al. 1998). However, the lack of adequate local information about the plant-animal interface constrains the effectiveness of this approach (Dove 1996). This was the main reason to combine field experimentation and modelling in this thesis, as the overall benefits of associating field research with modelling have been well demonstrated (McKinion 1980; Walker et al. 1989; Garcia 2000).

3. Objectives

The major objectives in this thesis are therefore as follows:

To provide information on herbage allowance-intake functions and the effects on animal performance when maize grain is supplemented, in beef cattle finishing systems.

To investigate the seasonal change of herbage quality in a beef cattle finishing pasture

To develop a “finishing beef cattle unit” simulator driven by stocking rate and herbage allowance, as a tool for information synthesis and research on the biological and economic implications of grazing management and grain feeding in intensive beef cattle systems.

5. Thesis Structure

Part I (Grazing experimentation) contains four chapters. In Chapter 1, published information is reviewed about the effects of sward characteristics and grain supplementation on beef cattle finishing systems. In Chapter 2, the effect of herbage allowance on herbage intake and animal performance is studied in a pilot trial, oriented to explore and to adjust methodologies for studying the plant-animal interface. In Chapter 3 and 4, replicated grazing trials including levels of maize grain supplementation and measurement of herbage and grain intake, animal performance and behaviour are described. Particularly, the functional response to increasing level of maize grain fed is studied in Chapter 3, and the functional response to increasing herbage allowance is investigated in Chapter 4.

Part II (Herbage quality) includes one chapter. Chapter 5 reports on a 28-month monitoring study of an Argentinean beef finishing pasture, including a detailed sward description to identify potential descriptors of herbage quality. A preliminary study of quality in a New Zealand beef production pasture is also described in Annex B.

Part III (Modelling studies) contains two chapters. Chapter 6 covers the development of a “finishing beef cattle unit” dynamic model, where relevant

knowledge about grazing-based beef cattle finishing systems is synthesised, with special emphasis on the sward characteristics assessed under field experimentation. In Chapter 7, the predictive value of the model is tested against results from field experiments in this thesis and from the literature, and the used to investigate some management options in an intensive beef cattle finishing system.

An overview of the main findings of the thesis, highlighting their relevance and presentation of conclusions is presented at the end of the thesis.

References

- Arosteguy J. 1984: Invernada en la Pampa deprimida de la Provincia de Buenos Aires. *Revista Argentina De Producción Animal* 4:843-853.
- Baker R. D.; Alvarez F.; Le Du L. P. 1981: The effect of herbage allowance upon the herbage intake and performance of suckler cows and calves. *Grass and Forage Science* 36:189-199.
- Cangiano C. A.; Galli J. R.; Pece M. A.; Dichio L.; Rozsypalek S. H. 2002: Effect of liveweight and pasture height on cattle bite dimensions during progressive defoliation. *Australian Journal of Agricultural Research* 53:541-549.
- Cangiano C. A.; Gomez P. 1985: Estimación del consumo de forraje mediante componentes del comportamiento ingestivo de novillos en pastoreo. *Revista Argentina De Producción Animal* 5:573-579.
- Demment M. W.; Peyraud J. L.; Laca E. A. 1995: Herbage intake at grazing: a modelling approach. In: Journet, M.; Grenet, E.; Farce, M.H.; Theriez, M.; Demarquilly, C. Eds. *Recent development in Nutrition of Ruminants*:121-141.
- Dougherty C. T.; Bradley N. W.; Lauriault L. M.; Arias J. E.; Cornelius P. L. 1989: Herbage allowance and intake of cattle. *Journal of Agricultural Science, Cambridge* 112:395-401.
- Dove H. 1996: Constraints to the modelling of diet selection and intake in the

- grazing ruminant. *Australian Journal of Agricultural Research* 47:257-275.
- Dumont B.; Iason G. R. 2000: Can we believe the results of grazing experiments? Issues and limitation in methodology. *In: Rook, A.J. & Penning, P.D. Eds. The Principles and Practice of Grazing, for Profit and Environmental Gain, Within Temperate Grasslands Systems. Occasional Symposium British Grassland Society* 34 :171-180.
- Elizalde J. C. 1994: Integración del feedlot a los sistemas pastoriles. *In: Rearte, D.H. Ed. El Feedlot en Argentina. Programa de Producción animal, INTA.* 112 p.
- Elizalde J. C.; Santini F. J.; Pasinato A. M. 1994: The effect of stage of harvest on the processes of digestion in cattle fed winter oats indoors. 1. Digestion of organic matter, neutral detergent fibre and water-soluble carbohydrates. *Animal Feed Science and Technology* 47:201-211.
- Elizalde J. C.; Santini F. J.; Pasinato A. M. 1996: The effect of stage of harvest on the processes of digestion in cattle fed winter oats indoors. II. Nitrogen digestion and microbial protein synthesis. *Animal Feed Science and Technology* 63:245-255.
- Forbes T. D. A. 1988: Researching the plant-animal interface: the investigation of ingestive behavior in grazing animals. *Journal of Animal Science* 66:2369-2379.
- Frame J. 1981: Herbage Mass. *In: Hodgson, J.; Baker R.D; Davis, A.; Laidlaw, A.S. ; Leaver, J.D. Eds. Sward Measurement Handbook.* British Grassland Society: Berkshire, UK. 35-70.
- French P.; O'Riordan M. A.; O'Kiely P. O.; Caffrey P. J. 2001: Effects of concentrate level and grazing system on the performance of beef cattle grazing autumn herbage. *Irish Journal of Agricultural and Food Research* :33-44.
- Garcia P.; Pensel N. A.; Margaria C. A.; Rosso O.; Machado C. F. 1999: Intramuscular fat, cholesterol and 18:2 n6/n3 ratio in total lipids in two frame

steers under different dietary regimen. *Proceedings 45th International Congress of Meat Science and Technology, Yokohama, Japan*. 256.

Garcia P. T.; Casal J. J. 1993: Lipids in Argentine beef. *Fleischwirtschaft* 73:786-788.

Garcia S. C. 2000: System, component, and modelling studies of pasture-based dairy systems in which the cows calve at different times of the year. *PhD Thesis. Massey University, New Zealand*: 203 p.

Garcia S. C.; Holmes C. W.; Hodgson J.; MacDonald K. A. 2000: The combination of the n-alkanes and ^{13}C techniques to estimate individual dry matter intakes of pasture and maize silage by grazing dairy cows. *Journal of Agricultural Science, Cambridge* 135: 47-55.

Garcia S. C.; Santini F.; Castaño G. 1998: Producción de carne bajo pastoreo: Alternativas de intensificación. Material didáctico Nro 14. INTA, Cerbas.:52 p.

Giraud C.; Rosso O.; Cocimano M.; Gomez P.; Verde L. 1984: Suplementación energética de novillos en pastoreo. *Revista Argentina De Producción Animal* 4: 647-661.

Herrero M.; Dent J. B.; Fawcett R. H. 1998: The plant/animal interface in models of grazing systems. *In: Peart, R.M. & Curry, R.B. Eds. Agricultural System Modeling and Simulation*. New York. Marcel Dekker, Inc. 495-542.

Hodgson J. 1990: *Grazing Management: Science into Practice*. Longman Handbooks in agriculture, Longman Scientific and Technical co-published with John Wiley. New York: 203 p.

Holmes C. W.; Matthews P. N. P. 2001: Feeding of conserved forage implications to grassland management and production. *Proceedings of the XV International Grassland Congress* 671-679.

Illius A. W.; Hodgson J. 1996: Progress in understanding the ecology and management of grazing systems. *In: The Ecology and Management of Grazing System, Eds. Hodgson, J. and Illius, A.* CAB International,

Wallingford.

- Kloster A. M.; Latimori N. J.; Amigone M. A. 2000: Evaluación de dos sistemas de pastoreo rotativo a dos niveles de asignación de forraje en una pastura de alfalfa y gramíneas. *Revista Argentina De Producción Animal* 20:187-198.
- Kloster A. M.; Latimori N. J.; Amigone M. A. 2003: Comparación de sistemas de pastoreo rotativo (convencional vs. líderes y seguidores) sobre una pastura base alfalfa. *Revista Argentina De Producción Animal* 23:25-32.
- Latimori N. J.; Kloster A. M.; Amigone M. A.; Carduza F.; Grigioni G.; Garcia P. T. 2000: Productividad y calidad de carne de novillos para exportación en invernadas pastoriles intensificadas. *Revista Argentina De Producción Animal* 20:25-37.
- Litherland A. J.; Woodward S. J. R.; Stevens D. R.; Mcdougal D. B.; Boom C. J.; Knight T. L.; Lambert M. G. 2002: Seasonal variations in pasture quality on New Zealand sheep and beef farms. *Proceedings of the New Zealand Society of Animal Production* 62:138-142.
- Machado C.; Striebeck G.; Vasolo V.; Di Croce F.; Gonzalez F.; Duhalde J.; Parente M.; Auza N. 2001: Suplementación de grano de maíz en pastoreo y a corral como alternativas de terminación de novillos en el verano. *Avances En Producción Animal* 26:139-146.
- Matejovsky K. M.; Sanson D. W. 1995: Intake and digestion of low-, medium-, and high-quality grass hays by lambs receiving increasing levels of corn supplementation. *Journal of Animal Science* 73:2156-2163.
- Mayes R.; Lamb C.; Colgrove P. 1986: The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. *Journal of Agricultural Science, Cambridge* 107:161-170.
- McCall D. G.; Sheath G. W.; Pleasant A. B. 1994: The role of system research in animal science. *Proceeding of the New Zealand Society of Animal Production* 54:417-421.
- McKinion J. M. 1980: Dynamic simulation: a positive feedback mechanism for

experimental research in the biological sciences. *Agricultural Systems* 5:239-250.

Mezzadra C.; Escuder J.; Miquel M. C. 1992: Effects of genotype and stocking density on post-weaning daily gain and meat production per ha in cattle. *Animal Production* 55:65-72.

Moshtaghi Nia S. A.; Wittenenberg K. M. 2002: Evaluation of n-alkanes as markers for estimation of dry matter intake and digestibility in steers consuming all-forage or forage-concentrate diets. *Canadian Journal of Animal Science* 82:419-425.

Nelson C. J.; Moser L. E. 1994: Plant factors affecting forage quality. In: Fahey, G. C. Jr.; Collins, M.; Mertens, D.R.; Moser, L.E. Eds. *Forage Quality, Evaluation, and Utilization*. American Society of Agronomy:115-154.

Nicol A. M.; Nicoll G. 1987: Pasture for beef cattle. In: Nicol, A.M. Ed. *Livestock feeding on pasture*. Occasional publication No. 10. New Zealand Society of Animal production. 119-132.

Pearson C. J. 1997: Agronomy of grassland systems. 2nd Ed. Cambridge [England]; New York, NY, USA. Cambridge University Press:222 p.

Realini C.; Hodgson J.; Morris S. T. 1999: Effect of sward surface height on herbage intake and performance of finishing beef cattle. *New Zealand Journal of Agricultural Research* 42:155-154.

Rearte D. 1998: Beef cattle production and meat quality on grazing system in temperate regions. *Revista Argentina De Producción Animal* 18:129-142.

Rearte D. 1999: Sistemas pastoriles intensivos de producción de carne de la región templada. In: *Anais Da Reuniao Da Sociedade Brasileira De Zootenia*, 36, Porto Alegre. RS 26-28 Julho :213-223.

Rearte D.; Pieroni G. A. 2001: Supplementation of temperate pastures. *Proceedings of the XV International Grassland Congress* :679-691.

Recabarren M. I.; Del Sole M. J.; Gonda H. L. 2002: Eficiencia de utilización del

- nitrógeno dietario en borregos alimentados con heno de alfalfa y grano de maíz. *Revista Argentina De Producción Animal* 22:49-50.
- Redmon L.; McCollum T.; Horn G.; Matthew D.; Cravey S.; Gunter P.; Beck J.; Mieres M. ; San Julian R. 1995: Forage intake by beef steers grazing winter wheat with varied herbage allowances. *Journal of Range Management* 48:198-201.
- Romera A. J.; Mezzadra C. A.; Villarreal E. L.; Brizuela M. A.; Corva P. M. 1998: Productivity of grazing Angus steers of different structural size. *Animal Science* 67:455-460.
- Santini F. J.; Elizalde J. C. 1993: Utilización de granos en la alimentación de rumiantes. *Revista Argentina De Producción Animal* 13:39-60.
- Saul G. R.; Kearney G. A.; Flinn P. C.; Lescun C. L. 1999: Effects of superphosphate fertiliser and stocking rate on the nutritive value of perennial ryegrass and subterranean clover herbage. *Australian Journal of Agricultural Research* 50: 537-545.
- Stockdale R. C. 1999: The nutritive characteristics of herbage consumed by grazing dairy cows affect milk responses obtained from concentrates supplementation. *Australian Journal of Experimental Agriculture* 39:379-387.
- Utsumi S.; Galli J. R.; Cangiano C. A.; Laca E. A. 2002: Distribución espacial del forraje y comportamiento ingestivo de bovinos. 1. Intensidad de defoliación. *Revista Argentina De Producción Animal* 22:199-200.
- Wales W. J.; Doyle P. T.; Stockdale R. C.; Dellow D. W. 1999: Effects of variation in herbage mass, allowance, and level of supplement on nutrient intake and milk production of dairy cows in spring and summer. *Australian Journal of Experimental Agriculture* 39:119-130.
- Walker J. W.; Stuth J. W.; Heitschmidt R. K. 1989: A simulation approach for evaluating field data from grazing trials. *Agricultural Systems* 30:301-316.
- Wright A.; Dent J. B. 1969: The application of simulating techniques to the study of grazing systems. *Australian Journal of Agricultural Economics* 13:144-153.

Part I

Grazing experiments

A review of the effects of energy supplementation and sward characteristics on animal performance in pastoral beef cattle finishing systems

Abstract

Evidence of the effects of energy supplementation and sward characteristics on animal performance in pastoral beef cattle finishing systems is reviewed. Emphasis is on the relationship between animal response, and changes occurring at the plant-animal interface. Energy supplementation and sward characteristics have direct and indirect effects on the animal and on the system, but most experimentation is animal oriented which sometimes makes integration difficult in a systems context. Uneven descriptions of the sward or its expression in different units emphasised the need for standardisation for comparative purposes. A more integrative appraisal of short-term field experiments within a system approach is required, and the development of models as tools for synthesis of information could be useful.

Key-words: Review; herbage allowance; grain; supplementation; beef; liveweight gain

1. Introduction

Recent signals in world markets emphasise the importance of healthy and safe foods from sustainable production systems. In this context, countries with established traditions of pastoral beef production systems have been looking for ways to improve system efficiency and sustainability with environmentally friendly technologies. Additionally, the interest in pasture-based beef cattle finishing systems has increased at the expense of pen-fed finishing systems, in order to alleviate many of the welfare, social and environmental problems associated with feedlots (Gerrish et al. 1996).

This situation has led to renewed research interest in the combination of herbage and grain feeding under grazing conditions. It has been demonstrated that system performance may be highly insensitive to contrasts in grazing management, but the desire to control grass supply on a daily basis has renewed interest in rotational grazing systems (Leaver 2000), with the emphasis on herbage allowance, incorporating more detailed descriptions of sward conditions (Dougherty et al.

1989; Kim et al. 1995; Okajima et al. 1996).

The effects of grazing system and levels of herbage allowance on herbage intake, animal performance and herbage utilisation have been studied in beef cattle finishing systems in Argentina (Kloster et al. 2000) including maize feeding (Martinez Ferrer et al. 2002). However the field evidence for Argentinean conditions is limited and that constrains the development of models (Dove 1996) which could be useful when exploring the benefits of grain feeding under grazing conditions.

Herbage is usually the lowest cost feed for beef production. Decisions about whether to feed grain to grazing animals depend on the expected returns compared to the added feed expenses. Estimation of the latter are quite straightforward, but the former depends on where and how the potential biological benefits of the supplementation are assessed; as they can be both direct and indirect effects, both on the animal and the system (Holmes & Matthews 2001; Rearte & Pieroni 2001). Associated with the difficulty of an adequate quantification of these indirect benefits, it is not surprising that the most frequent economic basis for deciding grain feeding is the grain:beef price ratio at the moment (Aiken 2002). Although sufficient in some cases, this valuation constrains decisions about grain feeding more than would a holistic appraisal of the technique, based on a better understanding of the biological implications.

The objective of the research described in this thesis was to create sets of field data relevant to these questions, and to use them to evaluate a model of a beef cattle finishing system based on grazed pasture and grain supplementation. This was used then as a basis for testing alternative strategies of pasture management and supplement use. This Chapter provides a review of the available literature on these topics. However, each chapter of this thesis contains a review of the pertinent literature, therefore the objective of this brief literature review is to develop a framework of how the thesis was planned, dealing with the effects of herbage allowance, sward conditions and grain feeding on animal performance and herbage intake and implications to the whole system. Attention is concentrated on grazing beef cattle systems, but reference to dairy, sheep or indoor experiments

is made when this helps to illustrate important issues, and focus where possible is on South American data. For convenience, the review deals first with effects on animal performance, then concentrates on nutrient intake from pasture and supplement, and finally covers some of the system implications of grain supplementation under grazing conditions. The review is not exhaustive but is designed to illustrate important principles.

2. Production responses

2.1. Effect of herbage allowance

Herbage allowance has been used as the experimental variable in different systems and countries. A two-year replicated study was carried out in Argentina where two herbage DM allowances (2.8 and 3.8 % LW d⁻¹)² and two intervals of rotational grazing systems (2 and 7 days) were assigned using British bred steers grazing an alfalfa-grass pasture (Kloster et al. 2000). Individual LWG increased significantly with the level of herbage allowance from 0.51 to 0.59 kg LW d⁻¹.

The inclusion of more than two levels of herbage allowance provides a better measure of the shape of the relationship between allowance and animal performance. Redmon et al. (1995) grazed beef steers between 267 to 313 kg LW on winter wheat, and allocated these steers to a range of herbage DM allowances between 5.5 to 64 % LW d⁻¹. The LWG presented a curvilinear relationship to DM herbage allowance (HA) fitted as:

$$\text{LWG} = -0.059 + 0.12 \text{ HA} - 0.003 \text{ HA}^2, R^2 = 0.59 \text{ and } \text{MSE} = 0.07^3.$$

This resulted in a LWG plateau of 1.3 kg d⁻¹ when HA was 23 % LW d⁻¹. Similarly, in a study where three herbage allowances (6, 12 and 18 kg DM d⁻¹) of a pasture dominated by perennial ryegrass and three levels of supplements were allocated to 567±32 kg LW crossbred steers (French et al. 2001b), LWG increased from 0.14 to 0.53 and 0.75 kg d⁻¹ at HA of 6, 12 and 18 kg DM d⁻¹, respectively.

However, linear effects of herbage allowance on LWG have also been reported.

² Herbage and grain on offer, animal performance, and intakes are all expressed in this thesis as per head basis, unless otherwise stated.

³ Different forms of expressing accuracy and error on literature equations are presented literally in this review.

When steer calves were grazed at 3.0, 4.5, 6.0 or 7.5 kg pasture DM 100 kg LW⁻¹ d⁻¹ in successive 28-d cycles of grazing during summer (Marsh 1977), total LWG's were 0.29, 0.43, 0.52 and 0.63 kg LW d⁻¹ for 3.0, 4.5, 6.0 or 7.5 kg pasture DM 100 kg LW⁻¹ d⁻¹, respectively. This was explained linearly by herbage allowance as:

$$\text{LWG} = 0.081 + 0.074 \pm 0.0076 \text{ HA}, n=40 \text{ and } r=0.91.$$

Similarly, when herbage DM allowances of 3.3, 4.3 and 5.3 kg 100 kg LW⁻¹ were imposed over three years, LWG's were significantly affected ($P < 0.05$) with overall values of 0.39, 0.52 and 0.62 kg LWG d⁻¹ (Bartholomew et al. 1981). The lack of any indication of a declining response at the highest herbage allowance, is indicative that the range of HA imposed were too narrow to encompass the point of inflection (Marsh 1977), but it is worth noting that only Redmon et al. (1995) tested this point exhaustively. Implications of high HA to the system, are mentioned later in section 4.

There is evidence in the literature that the relationship between HA and LWG is seasonally affected (Figure 1), although in this comparison the effects of season and animal age are confounded (Reid 1986). When animals of a similar liveweight and breed were used in two comparisons between spring and autumn (Marsh 1975), daily liveweight gains in spring were higher (1.09 and 1.37 kg d⁻¹) than from autumn conditions (0.98 and 0.71 kg d⁻¹).

Changes in sward composition at the same allowance has been shown to affect animal performance (Hodgson 1984). The effect of herbage allowances between 2.0 to 3.0 kg DM d⁻¹ on performance of weaned lambs was assessed in a trial (repeated over two years) carried out during late spring/early summer (Butler & Hoogendoorn 1987). As the swards were dissected into components, different relationships between sward conditions and animal performance were explored. Liveweight gains were not explained by DM herbage allowance, and green DM allowance only influenced LWG in one year. Green leaf DM allowance was the best single predictor, but a combination of leaf allowance and dead content (DC) was the best, resulting in the following linear relationship:

$$\text{LWG} = 47 + 0.09 \text{ leaf allowance} - 599 \text{ DC}, R^2 = 0.79.$$

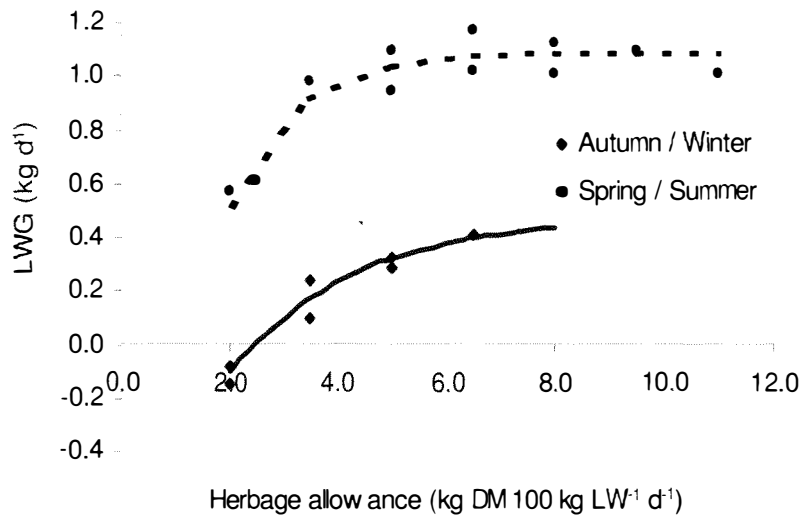


Figure 1. Relationship between herbage allowance and liveweight gain of steers during Autumn / Winter and Spring / Summer periods (Reid 1986).

For the fitted asymptotic curves:

LWG Autumn / Winter = $0.48 - 1.37 \cdot 0.65^{HA}$, $R^2 = 0.95$.

LWG Spring / Summer = $1.09 - 2.82 \cdot 0.45^{HA}$, $R^2 = 0.94$.

2.2. Effect of adding grain under grazing

2.2.1. Liveweight gain response

There is in the literature a huge diversity of supplementation trials, involving alternative production systems, different types and levels of grain use and varying duration of the trial (Horn & McCollum 1987; Paterson et al. 1994), which makes it difficult, if not impossible, to establish generalizations in the pattern of animal response when grain is fed. Table 1 gives the most relevant examples of results of maize grain feeding under grazing conditions. However, even in more constrained situations, a high variation of experimental conditions and animal responses are observed and no clear conclusions can be drawn. However the expected animal response to grain feeding is highly dependant on the level of performance by unsupplemented animals (Conway 1968; Reardon 1975; Steen 1994). When the data in Table 1 is expressed in terms of extra LWG over the unsupplemented group, a significant overall relationship is obtained (Figure 2), resulting in the following equation:

Extra LWG = $0.08 \pm 0.04 + 0.09 \pm 0.01$ Maize grain; $n=42$, $R^2 = 0.46$, $P < 0.001$ and

RMSE = 0.15 (Maize supplementation ranged from 0.45 to 6.0 kg d⁻¹).

The effect of grain feeding on the performance of grazing animals is likely to be associated with the extra energy for the animal (Allden 1981; Horn & McCollum 1987), and/or the better efficiency of utilization of the energy coming from the grain for liveweight gain (NRC 2000). However, the increased animal performance cannot simply be explained in terms of extra energy in all cases. Grigsby et al. (1991), with a low level maize-based supplement (Table 1), obtained a conversion rate of 2.2 (supplement to extra LWG ratio), and commented that an increased synthesis of microbial protein was the most likely explanation of increased animal performance. A reduction of nitrogen losses from the rumen by feeding an increasing level of maize grain has been observed (Elizalde et al. 1999b) and also a decrease of blood urea level (Karnezos et al. 1994).

Table 1. Effect of level of maize grain supplementation under grazing conditions on liveweight gain of finishing beef cattle.

Animal Class	SLW (kg)	Supp. (kg d ⁻¹)	Pasture	PQ	Season	LWG	Other comments	Reference
Crosbred heifers	213	0.0	Leucaena	H	W	0.73		(Petty et al. 1998)
		0.5	Pangola grass (irrigated)			0.78	rotational	
		1.0		0.99	Dry season			
		1.5		1.1				
		2		0.85				
Crosbred steers	408	0.0	Ryegrass	M	S	-0.04		(Boom & Sheath 1999)
		2.0	White clover			0.44	rotational	
		4.0		0.55				
	450	0.0		H	W	0.93		
		2.0				1.09		
		4.0				1.25		
Crosbred steers	414	0.0	Ryegrass	M	S	0.16	10% soybean meal	(Boom & Sheath 1998)
		2.0	White clover			0.46	Rep.1 rotational	
		4.0		0.62				
		6.0		0.71				
	411	0.0		M	S	-0.05	Rep 2	
		2.0				0.37	rotational	
		4.0				0.6		
		6.0				0.89		
Crosbred steers	460	0.0	Ryegrass	H	W	0.88	10% soybean meal	
		1.0	White clover			1.16	Rep 1 rotational	
		2.0		1.34				
	4.0	1.21						
	460	0.0		H	W	0.9	Rep 2	
		1.0				1	rotational	
		2.0				1.26		
4.0					1.48			
Crosbred steers	278	0.0	Ryegrass		W	0.9	Continuous stocked	(Rude et al. 2002)
		1.1			Sp.	0.9		

SLW= starting animal liveweight, PQ=pasture quality, LWG= animal liveweight gain, H=high pasture quality, M=moderate pasture quality, W=winter, Sp.=spring, S=summer and A=autumn.

Table 1. (Cont.)

Animal Class	SLW (kg)	Supp. (kg d ⁻¹)	Pasture	Pasture quality	Season	LWG	Other comments	Reference	
Crosbred steers	295		Russian	Low	A	0.62	Continuous stocked	(Adams 1985)	
	297	0.96	Wild ryegrass			0.62			
	282	0.95				0.82			
Crosbred steers and heifers	301	0.0	Ryegrass	High	Sp.	0.99	Continuous stocked	(Grigsby et al. 1991)	
Crosbred steers and heifers		0.76			S	1.56	Trial 1		
	270	0.0 0.51	Ryegrass	High	Sp. S	1.08 1.25	Group fed	Trial 2	
Crosbred steers	267	0.0	Bermuda Grass	High-Low	S	0.83	Continuous stocked	(Aiken 2002)	
	268	0.45				0.98			
		1.35 2.25				1.15 1.16			
Hereford steers	260	0.0	Alfalfa-grasses	High	S	0.6	Rotational	(Lake et al. 1974)	
		0.23				A			0.65
		0.45							0.74
		0.91							0.72
	1.82				0.83	Trial 1			
Hereford steers	228	0.0	Alfalfa-grasses			0.65			
		0.45			0.66	Trial 2			
		0.81			0.68				
		1.36			0.75				
		1.82			0.88				
		2.27 2.72			0.85 0.85				
British bred steers	301	0.0	Alfalfa-grasses	Moderate-High	S	0.62	Rotational	(Machado et al. 2001)	
		2.5				A			0.72
		5.5							0.98

SLW= starting animal liveweight, LWG= animal liveweight gain, W=winter, Sp.=spring, S=summer and A=autumn.

2.2.2. Other effects

Additional effects of grain feeding can be direct or indirect. A direct aspect of clear commercial interest is the effect of grain feeding on carcass characteristics. Increases in dressing percentage with increasing grain level fed have been found in lambs (Karnezos et al. 1994) and steers (Reardon 1975; Taylor & Gulbransen 1990). Similarly, in carcass studies a higher marbling score in heifers (Jeffery et al.

1996) and a higher carcass conformation score in steers has been observed (French et al. 2001b).

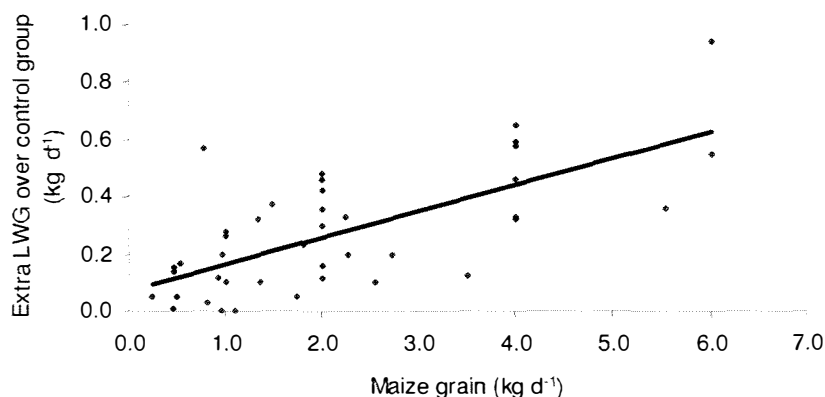


Figure 2. Relationship between level of maize grain supplementation (in kg d⁻¹) and extra liveweight gain over the unsupplemented group (in kg d⁻¹) in grazing beef cattle.

Data are from the experiments of Perry et al. (1972); Lake et al. (1974); Giraud et al. (1984); Adams (1985); Grigsby et al. (1991); Petty et al. (1998); Boom & Sheath (1998); Elizalde et al. (1998); Boom & Sheath (1999); Machado et al. (2001); Rude et al. (2002); Aiken (2002). Maize supplementation ranged between 0.45 to 6.0 kg d⁻¹.

An important system implication of grain feeding under grazing is the residual effect on animal performance in subsequent conditions, either grazing only or in a feedlot. This has important production-economic implications when combining and designing alternative productive systems and is discussed in section 4.2.3.

2.3. Combination of sward conditions and supplementation

Studies oriented to research the effects of the combination between herbage allowance and grain feeding in beef cattle systems are scarce. In a combination of two summer trials carried out with beef cattle, Reardon (1975) offered allowances between 7 to 27 kg DM d⁻¹ with herbage mass of 3000 to 3900 kg DM ha⁻¹ and feeding up 5 kg DM maize silage. A curvilinear response of carcass weight gain (CWG) to herbage allowance was obtained from 0.1 kg d⁻¹ up to a plateau at 0.5 kg CWG d⁻¹, and responses to silage was strongly related to weight gain prior to supplement addition. When carcass-weight gains were 0.2 or 0.4 kg d⁻¹, 1.0 kg of supplement improved carcass weight gain by 0.1 and 0.04 kg d⁻¹, respectively (Reardon 1975). In a factorial trial that included three levels of herbage allowance (6, 12 and 18 kg DM d⁻¹, measured to 4 cm above ground level) and three levels of

barley-based concentrate (0, 2.5 and 5.0 kg d⁻¹) fed to crossbred steers (567 kg LW d⁻¹) grazing a pasture dominated by perennial ryegrass (French et al. 2001b); increasing both HA and supplement increased LWG (range between 0.14 to 1.14 kg LW d⁻¹, P<0.05).

Using sward surface height (Steen 1994; Steen & Kilpatrick 1998) or stocking rate (Conway 1968) as an indicator of pasture on offer produces results in agreement with those obtained using herbage allowance. In the case of Steen & Kilpatrick (1998), beef-bred bulls were continuously stocked during summer-autumn on a ryegrass pasture from 5.5 to 11 months of age to maintain sward surface height of 6.5 and 10 cm with or without 1.6 kg d⁻¹ of protein-corrected barley. Supplementation increased performance at the lowest sward height (when animals were losing weight supplements alleviated the losses), but no improvement was found at a 10 cm sward height. In a 3-year study of bull beef systems, Steen (1994) continuously stocked bulls of 5 to 10 months of age in summer on ryegrass pastures to maintain sward surface heights of 7, 9 and 11 cm with or without 1.5 kg d⁻¹ of protein-corrected barley. Reducing sward height from 11 cm to 7 cm, reduced LWG by 0.27 kg d⁻¹ in unsupplemented swards during years 2 and 3 of the experiment, but this was reduced to 0.17 kg d⁻¹ when concentrates were given. There was little effect of supplementation on animals maintained at either 9 or 11 cm sward heights.

Conway (1968) carried out a factorial trial repeated over three years involving two stocking rates (1.0 and 1.4 animals ha⁻¹) and feeding 0.0 or 1.8 kg d⁻¹ of barley and beet pulp to Hereford x Angus steers of an average 353 kg LW. There were differences between years in LWG, but the author concluded that feeding supplement on pasture would give significant animal responses only when the present grazing practice is constraining LWG in the absence of supplements.

Response to grain feeding is not only affected by herbage on offer, but also by herbage quality. Boom & Sheath (1998) obtained differences in LWG between treatment replicates where the amount of herbage on offer and grain fed were similar, but with differences in sward conditions (54 and 35 % of green leaf for replicates 1 and 2 respectively), with associated changes in digestibility and protein

content.

3. Effect on the plant/animal interface

It is accepted that changes occurring at the plant-animal interface are the key drivers to understand and predict changes in animal performance under different sward conditions (Forbes 1988; Illius & Hodgson 1996; Hodgson et al. 1999). Changes in herbage allowance and sward conditions influence animal performance through their effect on herbage intake and quality of the diet (Hodgson 1984). These two aspects are not likely to be independent, but for simplicity, evidence from the literature is presented here separately.

3.1. *Herbage allowance and sward conditions*

3.1.1. Effect on herbage intake

There is general agreement in the literature that herbage intake shows asymptotic or quadratic patterns relative to herbage allowance as in the case of LWG. However, the literature value of herbage allowance where herbage intake starts to decline is highly variable, and comparisons must be made with care because of differences in the expression of herbage allowance, uneven description of the sward in terms of composition and quality, and the use of different pastures.

Herbage intake usually approaches a maximum when herbage DM allowance reaches a value around 9 to 12 % LW d⁻¹ in perennial ryegrass-white clover pastures (Hodgson 1984). Higher values have been observed using other feed sources. When the association between HA and OM intake (kg 100 kg DM LW⁻¹ d⁻¹) in beef bred steers grazing winter wheat at a HA range between 5.5 and 64 % LW d⁻¹ was studied (Redmon et al. 1995), the results fitted significantly to a quadratic function, where:

OM DM intake = 1.3 + 0.12 HA - 0.003 HA², R²=0.52, MSE=0.07, with a plateau achieved (2.57 kg 100 kg LW⁻¹ d⁻¹) when dry matter HA was 21.1 % LW d⁻¹.

Dougherty et al. (1992) used different short-term observations (2-hour grazing of

tethered animals) fitted together to establish a generalized relationship between herbage DM intake rate and herbage allowance (>5 cm ground level) in alfalfa pasture. Herbage intake rate (maximum of 0.5 kg 100 kg DM LW⁻¹ h⁻¹) declined markedly when HA was lower than twice the herbage DM intake. These authors commented that the apparent controversy with the conclusions of Hodgson (1984) are likely to be explained by differences in satiety mechanisms operating over different time frames, differences in the leaf content at the time, and by differences in how herbage allowance was expressed (>5 cm or above ground level).

Positive effects of herbage mass on herbage intake have also been observed. When dairy cows were allocated to a combination of herbage allowances and herbage masses in an irrigated ryegrass-dominated pasture (Wales et al. 1999), herbage intake (HI) in kg DM d⁻¹ was explained by the following equation (Figure 3):

$HI = 3.0 + 0.13 \pm 0.019 HA + 1.29 \pm 0.019 HM$; $R^2=0.94$, residual SS=0.56, CV=4.3%, $P<0.05$.

In a complementary study within the same trial reported by Wales et al. (1999), the defoliation pattern was further studied (Tharmaraj et al. 2003). Herbage intake was significantly explained by variations in sward surface height ($r=0.55$, $P<0.01$), area offered to each cow ($r=0.25$, $P<0.01$) and the pre-grazing bulk density ($r=-0.26$, $P<0.01$) to yield a combined equation with an $R^2=0.77$ and a residual SD of 0.016 ($P<0.01$).

Negative effects of herbage mass on herbage intake have also been reported. In a study with Friesian steers (323 kg LW) during late spring-summer (Reardon 1977) grazing a range of herbage allowances (HA from 9.9 to 42.3 kg DM d⁻¹) and pre-grazing herbage masses (HM from 1820 to 5280 kg DM ha⁻¹), herbage intake (HI, kg DM d⁻¹) was expressed by the following equation:

$HI=7.03 + 0.0945 HA - 0.000542 HM$; $r=0.55$, residual SD=1.61.

This apparent controversy of the positive or negative effect of herbage mass is likely to be explained by interactions between the quantity and quality of the herbage. There is growing evidence, mostly from dairy production studies, that leaf

allowance (LA) is a better measure of nutritional status than total DM allowance (Table 2). When the daily herbage intake was predicted from herbage allowance, green allowance and leaf allowance, R^2 increased from 0.11 to 0.37 and 0.84 for the three variables, respectively (Hoogendoorn 1986). There is now a need for standardisation of how LA is expressed for comparative purposes.

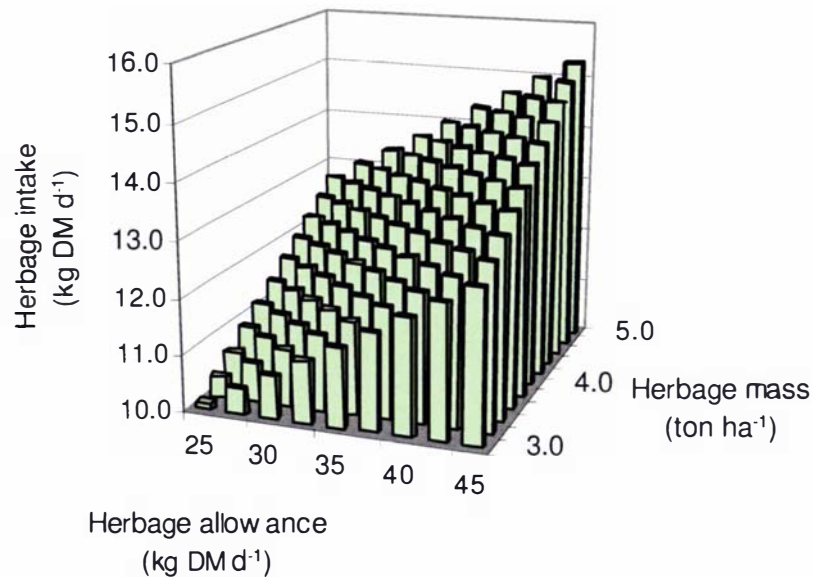


Figure 3. The effect of herbage mass and herbage allowance on herbage intake (drawn from Wales et al. 1999).

3.1.2. Effect of herbage allowance and sward conditions on diet composition and quality

The ability of the animal to harvest a nutritionally enhanced proportion of sward components declines as herbage allowance decreases (Geenty & Sykes 1982; Dougherty et al. 1989), which is likely to lead to a reduction of the nutritive value of the diet. However, this will usually have a smaller impact in relative terms on animal performance than its effect on daily herbage intake (Hodgson 1984).

Table 2. Effect of increasing leaf allowance on herbage intake.

Leaf allowance	Leaf allowance units	Herbage Intake	Herbage intake units	Pasture type	Production System	Reference
	8.1 kg OM d ⁻¹	13.9	kg OM d ⁻¹	Perennial ryegrass	Dairy	(Kim et al. 1995)
	13.5 ground level	15.2				
	19.3	15.4				
	12.0 kg DM d ⁻¹	11.9	kg DM d ⁻¹	Perennial ryegrass & white clover-based	Dairy	(Hoogendoorn 1986)
	13.3 ground level	13.0				
	15.1	13.9				
	15.2	12.2				
	15.1	11.2				
	16.0	11.4				
	16.0	13.4				
	16.2	11.9				
	17.4	16.1				
	4.3	7.9				
	26.5	21.3				
	6.7	7.1				
	14.7	13.5				
	18.4	15.0				
	12.0 kg OM d ⁻¹ > 5cm ground level	10.7	kg OM d ⁻¹	Perennial ryegrass	Dairy	(Delagarde et al. 2000)
	18.0	11.8				
	24.0	13.8				
+	Control 12.0 kg DM d ⁻¹ > 8cm ground level	14.1	kg OM d ⁻¹	Perennial ryegrass	Dairy	(Parga et al. 2000)
	Control 18.0	14.8				
	Leafy 12.0	14.7				
	Leafy 18.0	14.5				
#	4.6 kg DM d ⁻¹ > 4cm ground level	5.6	kg DM d ⁻¹	Perennial ryegrass-based	Beef	Estimated from (French et al. 2001b)
	9.1	9.4				
	13.7	12.5				

+ = type of sward, # = only unsupplemented treatments presented.

Redmon et al. (1995) found a quadratic relationship between herbage allowance and the *in vitro* OM digestibility (IVOMD) of samples obtained from oesophageal fistulates grazed at a range of herbage allowances, and the following equation was fitted:

IVOMD = 62.2 + 1.08 HA - 0.022 HA², R²=0.64, MSE=5.1, with a LWG plateau achieved (75.3 %) when HA was 24.3 % LW herbage DM d⁻¹.

Similarly, Jamieson and Hodgson (1979) observed a depression in the intake of digestible nutrients by 20-23% at low HA, when steer calves were grazed at a range of HA between 3 and 9 % LW d⁻¹. Similarly, when cattle grazed at three herbage allowances (6, 12 and 18 kg d⁻¹) and three concentrates levels (0, 2.5 and 5.0 kg d⁻¹) were fed in autumn (French et al. 2001b), *in vivo* OM diet digestibility of the unsupplemented groups was 68.4, 82.9 and 85.3 % for the herbage allowances

of 6, 12 and 18 kg d⁻¹, respectively.

3.2. Effect of adding grain on herbage intake and grazing behaviour

Usually when grain is fed to grazing animals, herbage intake is depressed. This replacement is called substitution rate (SR), and is expressed as the DM unit of change in herbage per unit increase in DM concentrate intake (Horn & McCollum 1987; SCA 1990). When grains are fed, SR can range from 0 (i.e. no effect on herbage intake) to above 1 (Dixon & Stockdale 1999). The amount of supplemented grain seems to play an important role. A low level of grain (less than 0.25-0.30 % LW d⁻¹) can be fed without causing a detrimental effect on herbage intake, particularly on high quality pastures (Griebenow et al. 1997).

The suggested explanations for the substitution rate phenomenon include those associated with rumen and whole tract digestion, metabolic regulation or voluntary herbage intake (Dixon & Stockdale 1999). Although usually a “carbohydrate effect” on herbage fiber digestion is quoted (Mould et al. 1983; Horn & McCollum 1987), substitution rate has been observed without effect on fiber digestion in an indoor study using fresh alfalfa, where maize grain levels of 0, 0.6 and 1.2 % LW d⁻¹ were fed to steers (Elizalde et al. 1999a).

The effect of level of grain fed on substitution rate has raised some controversy. Whereas a curvilinear response of SR to the level of intake has been observed in indoor (Berge & Dulphy 1985) and in grazing studies (Robaina et al. 1998), a linear effect has also been reported in indoor studies (Elizalde et al. 1999a) and under grazing conditions (Opatpatanakit et al. 1993). This point deserves more investigation. On the other hand, substitution rates reported in the literature are related to the current level of herbage intake under unsupplemented conditions. There are several equations to predict SR using the unsupplemented herbage intake as independent variable both in stall-fed and grazing animals (Meijs & Hoeskstra 1984; Dixon & Stockdale 1999; Elizalde et al. 1999a).

A direct effect of a relationship between increasing herbage allowance (likely associated to its effect on herbage intake) and higher substitution rates has been demonstrated in dairy cows (Meijs & Hoeskstra 1984) and in sheep (Carson et al.

2003). In agreement, a recent comprehensive study where continental bred steers (567 kg LW) assigned in autumn to nine grazing treatments of three herbage allowances (6, 12 and 18 kg d⁻¹) and three concentrates levels (0.0, 2.5 and 5.0 kg d⁻¹), concentrate feeding did not affect herbage intake at low HA, however it decreased herbage intake at medium and high HA (French et al. 2001b). In summary, adding grain to the diet of grazing animals increases the complexity of the already complex mechanisms controlling herbage intake (Forbes 1988). It also reinforces the importance of a better understanding of the control of unsupplemented herbage intakes, to predict potential responses to supplementation strategies.

Substitution rate at a given level of concentrate is positively correlated with herbage quality (Horn & McCollum 1987; Matejovsky & Sanson 1995; Caton & Dhuyvetter 1997). This is also an important issue for control and understanding of the results from grazing studies, where herbage quality changes dynamically and animal selectivity can enhance the nutritive value of the sward. With all these sources of change, it is not surprising that the methodology available to measure individual grain and herbage intake under grazing conditions usually constrains a deeper understanding of how substitution rate is controlled and affected (Dove 1996).

Another direct effect of feeding grain under grazing is the reduction of grazing time (Allden 1981; Giraud et al. 1984; Leaver 1986; Mayne 1988; Krysl & Hess 1993; Caton & Dhuyvetter 1997). However, the magnitude of the effect is highly variable, estimated at between 3-30 min and 20-23 min kg DM supp.⁻¹ by Leaver (1986) and Mayne (1988), respectively. This behavior has been linked to the induction of satiety-regulating mechanisms (Dixon & Stockdale 1999). As grazing time affects energy expenditure, the independent monitoring of grazing behaviour and herbage and grain intake may provide a meaningful insight about the response to feeding grain under grazing conditions (Krysl & Hess 1993).

When animals are offered supplement as a group, the coefficient of variation for individual intake of grain can be substantial (Bowman & Sowell 1997). Boom & Sheath (1998) estimated that 20% of their experimental animals were non-feeders

when increasing levels of maize grain were fed to crossbred steers during two trials carried out during summer and winter. As in the case of substitution rate, the availability of adequate methodological procedures including individual intakes of grain are needed for a better understanding of the possible practical implications of the results.

4. Implications of grain feeding and sward characteristics to the whole system

Field studies on the effect of herbage characteristics and grain feeding on animal performance are usually developed at smaller scales of time and space than those considered within a whole system approach. Additionally, most of the experimentation is animal oriented, but it is important to achieve a clear compromise between animal and sward requirements in order to maintain whole systems viability (Hodgson 1984). For example, although higher herbage allowances can increase animal performance, it can also increase residual sward height and this may result in a deterioration of sward quality in mid- and late-season (Hoogendoorn 1986).

Given the natural variability of herbage growth between months and years, one key issue to achieve the above mentioned system viability, is the necessity to develop a flexible grazing practice. This has been achieved by integration of grazing and conservation (Baker 1988), by feeding energy supplements (Rearte & Pieroni 2001) or combining animals with different feed requirements (French et al. 2001a; Kloster et al. 2003).

The reduction of forage intake when supplements are fed is not necessarily undesirable, depending on the situation, especially when the objective is to extend the use of existing herbage on the farm (Horn & McCollum 1987). However, the capitalization of the extra pasture left in the paddock is highly dependent on how this pasture is utilized, therefore the objectives for setting a level of supplementation must be clearly understood. On the other hand, the advantages of supplementation to the system are very evident when grazing intensity is adjusted (Hodgson & Tayler 1972; Reardon 1975).

Another important system implication of grain feeding under grazing conditions is the residual effect on animal performance. In the case of a subsequent feedlot phase, it seems that there is some differential residual response associated with the level of supplementation at pasture. Low to moderate levels of grain feeding under grazing (up 2.8 kg d⁻¹ in these studies) have had a neutral or positive effect on subsequent feedlot performance (Steen 1994; Owensby et al. 1995; Steen & Kilpatrick 1998; Elizalde et al. 1998). However, a negative effect ($r=-0.96$) of previous grazing supplementation on performance during the feedlot phase has been observed (Perry et al. 1972) in a 4-year replicated study during spring-summer (135 days in average) with Hereford steers fed with four levels (0, 33, 66 and 100 % of the required amount to fully feed the animals) of a concentrate based on ground maize ear.

When supplemented animals have been finished on pastures after the pasture shortfall period, compensatory growth by steers fed pasture only diets eroded all the LWG advantage of supplemented animals (Jeffery et al. 1996; Boom & Sheath 1998; Boom & Sheath 1999). For this reason, Jeffery et al. (1996) suggested that in order to achieve maximum economic returns from grain feeding, animals should be sold during or at the end of the supplementation period rather than carrying them over to the next season. However, this suggestion could become less important when supplementation is oriented to increase stocking rate rather than to increase individual animal LWG.

A holistic evaluation of the economic benefits of grain supplementation requires an understanding of the biological process involved, not only in the animal but also for all system components. This review has highlighted well-documented evidence on this aspect, but also identified aspects that require further research. Economic appraisal of different levels of intensification has been done through different approaches. These include the use of experimental or biophysically simulated performance data directly in an economic budget, or alternatively using the biological data to develop response functions that are then used in an economic model (Wachenheim et al. 2000). For studying grain feeding to grazed beef cattle systems, a whole-farm model has proved to be an adequate tool (Ruiz et al. 2000;

Perillat et al. 2004). Under Argentinean conditions, Ruiz et al. (2000) concluded that farmers' decisions adjusted better to a minimum cost model, keeping a lower stocking rate and level of supplementation, rather than an optimisation model.

5. Implications and conclusions

Grain supplementation and management of sward characteristics are important drivers of animal and system performance, and key components to incorporate flexibility to the grazing management of beef cattle finishing systems. It is important to establish some indications of the pattern of the relationship between herbage allowance, grain feeding and animal performance over a wide range of situations. The fact that the effects are direct and indirect, affecting both the animal and the whole system, emphasises that the selected research methodologies must allow the integration of information at a systems scale. Recent development of techniques for individual intake estimation of maize grain in group-fed and free-ranging animals (Garcia et al. 2000) provides an important advance in this sense. Additionally, effort is required for the development of models as tools for synthesis of information and for a more integrative appraisal of short-term field experiments, usually animal oriented, within a systems approach.

References

- Adams D. C. 1985: Effects of time of supplementation on performance, forage intake and grazing behavior of yearling beef steers grazing russian wild ryegrass in the fall. *Journal of Animal Science* 61:1037-1042.
- Aiken G. E. 2002: Cost of steer weight gain to rate of supplementation with ground corn. *Agronomy Journal* 94:1387-1392.
- Allden W. G. 1981: Energy and protein supplements for grazing livestock. In: Morley, F.H.W. Ed. World Animal Science, B.I. *Grazing Animals*. Elsevier Science Publishers:289-307 .
- Baker R. D. 1988: Grazing management and the integration of grazing and conservation. In: Frame, J. Ed. *Efficient Beef Production from Grass*. Occasional Symposium. No. 25, British Grassland Society, Berkshire, UK.:

65-78.

Bartholomew P.; McLauchlan W.; Chestnutt D. 1981: An assessment of the influence on net herbage accumulation, herbage consumption and individual animal performance of two lengths of grazing rotation and three herbage allowances for grazing beef cattle. *Journal of Agricultural Science, Cambridge* 96:363-373.

Berge Ph.; Dulphy J. P. 1985: Etude des interactions entre fourrage et aliment concentré chez le mouton. *Annales De Zootechnique* 3:313-334.

Boom C. J.; Sheath G. W. 1998: Grain supplementation of finishing beef cattle. *Proceedings of the New Zealand Society of Animal Production* 58:239-242.

Boom C. J.; Sheath G. W. 1999: Tactical supplementation of beef finishing cattle. *Proceedings of the New Zealand Society of Animal Production* 59:162-165.

Bowman J. G. P.; Sowell B. F. 1997: Delivery method and supplement consumption by grazing ruminants: a review. *Journal of Animal Science* 75:543-550.

Butler B. M.; Hoogendoorn C. J. 1987: Pasture quality and animal performance over late spring and summer. *Proceedings of the New Zealand Grassland Association* 47:31-33.

Carson A. F.; Dawson L. E. R.; Laidlaw A. S. 2003: Effect of herbage allowance and concentrate feed level offered to ewes in late pregnancy on ewe and lamb performance. *Proceedings of the British Society of Animal Science* :63.

Caton J.; Dhuyvetter D. 1997: Influence of energy supplementation on grazing ruminants: requirements and responses. *Journal of Animal Science* 75:533-542.

Conway A. 1968: Grazing management in relation to beef production: V. Effect of feeding supplements to beef cattle on pasture at two intensities of stocking. *Irish Journal of Agricultural Research* 7:105-120.

Delagarde R.; Peyraud J.; Delaby L. 2000: Influence of herbage allowance on

- intake and behaviour of dairy cows grazing perennial ryegrass swards in autumn. *In: Rook, A.J. & Penning, P.D. Eds. The Principles and Practice of Grazing, for Profit and Environmental Gain, Within Temperate Grasslands Systems.* Occasional Symposium No 34, British Grassland Society 34:101-102.
- Dixon R. M.; Stockdale R. C. 1999: Associative effects between forages and grains: consequences for feed utilisation. *Australian Journal of Agricultural Research* 50:757-753.
- Dougherty C. T.; Bradley N. W.; Lauriault L. M.; Arias J. E.; Cornelius P. L. 1989: Herbage allowance and intake of cattle. *Journal of Agricultural Science, Cambridge* 112:395-401.
- Dougherty C. T.; Bradley N. W.; Lauriault L. M.; Arias J. E.; Cornelius P. L. 1992: Allowance-intake relations of cattle grazing vegetative tall fescue. *Grass and Forage Science* 47:211-219.
- Dove H. 1996: Constraints to the modelling of diet selection and intake in the grazing ruminant. *Australian Journal of Agricultural Research* 47:257-275.
- Elizalde J. C.; Cremin J. D.; Faulkner D. B.; Merchen N. R. 1998: Performance and digestion by steers grazing tall fescue and supplemented with energy and protein. *Journal of Animal Science* 76: 1691-1701.
- Elizalde J. C.; Merchen N. R.; Faulkner D. B. 1999a: Supplemental cracked corn for steers fed fresh alfalfa: I. Effects on digestion of organic matter, fiber, and starch. *Journal of Animal Science* 77:457-466.
- Elizalde J. C.; Merchen N. R.; Faulkner D. B. 1999b: Supplemental cracked corn for steers fed fresh alfalfa: II. Protein and amino acid digestion. *Journal of Animal Science* 77:467-475.
- Forbes T. D. A. 1988: Researching the plant-animal interface: the investigation of ingestive behavior in grazing animals. *Journal of Animal Science* 66:2369-2379.
- French P.; O'Riordan M. A.; O'Kiely P. O.; Caffrey P. J. 2001a: Effects of

concentrate level and grazing system on the performance of beef cattle grazing autumn herbage. *Irish Journal of Agricultural and Food Research*:33-44.

French P.; O'Riordan M. A.; O'Kiely P. O.; Caffrey P. J.; Moloney A. P. 2001b: Intake and growth of steers offered different allowances of autumn grass and concentrates. *Animal Science* 72:129-138.

Garcia S. C.; Holmes C. W.; Hodgson J.; MacDonald K. A. 2000: The combination of the n-alkanes and ¹³C techniques to estimate individual dry matter intakes of pasture and maize silage by grazing dairy cows. *Journal of Agricultural Science, Cambridge* 135: 47-55.

Geenty K.; Sykes A. R. 1982: Influence of herbage allowance on diet quality in lactating ewes. *Proceedings of the New Zealand Society of Animal Production* 42:161-163.

Gerrish J. R.; Martz F. A.; Tate V. G. 1996: Sward characteristics of beef finishing pastures. *Proceedings of the American Forage Grassland Council* 5:130-134.

Giraud C.; Rosso O.; Cocimano M.; Gomez P.; Verde L. 1984: Suplementación energética de novillos en pastoreo. *Revista Argentina De Producción Animal* 4: 647-661.

Grigsby K. N.; Rouquette F. M.; Ellis W. C.; Hutcheson D. P. 1991: Use of self-limiting fishmeal and corn supplements for calves grazing rye-rye grass pastures. *Journal of Production Agriculture* 4:476-480.

Hodgson J. 1984: Sward conditions, herbage allowance and animal production. *Proceedings of the New Zealand Society of Animal Production* 44: 99-104.

Hodgson J.; Matthews P. N. P.; Matthew C.; Lucas R. J. 1999: Pasture measurements. In: White, J. & Hodgson, J. Eds. *New Zealand Pasture and Crop Science*. Oxford University press. 59-66.

Hodgson J.; Tayler J. C. 1972: The effect of supplementary barley upon growth and efficiency of food conversion in calves kept at high grazing intensity.

Journal of the British Grassland Society 27:7-11.

- Holmes C. W.; Matthews P. N. P. 2001: Feeding of conserved forage implications to grassland management and production. *Proceedings of the XV International Grassland Congress*: 671-679.
- Hoogendoorn C. J. 1986: Studies on the effects of grazing regime on sward and dairy cow performance. *PhD Thesis. Massey University, New Zealand*:363 p.
- Horn G. W.; McCollum F. T. 1987: Energy supplementation of grazing ruminants, July 23-24. *Proceedings of the Grazing Livestock Nutrition Conference* :125-136.
- Illius A. W.; Hodgson J. 1996: Progress in understanding the ecology and management of grazing systems. *In: The Ecology and Management of Grazing System, Eds. Hodgson, J. and Illius, A. CAB International, Wallingford.*
- Jamieson W. S.; Hodgson J. 1979: The effect of daily herbage allowance and sward characteristics upon the ingestive behavior and herbage intake of calves under strip-grazing management. *Grass and Forage Science* 34:261-271.
- Jeffery M.; Loxton I.; James T.; Holroyd R. 1996: Utilisation of grain rations on sown pastures in Central Queensland. *Proceedings of the Australian Society of Animal Production* 21:88-89.
- Karnezos T. P.; Matches A. G.; Preston R. L.; Brown C. P. 1994: Corn supplementation of lambs grazing alfalfa. *Journal of Animal Science* 72:783-789.
- Kim T. H.; An K. W.; Jung W. J. 1995: Effects of daily herbage allowance on sward structure, herbage intake and milk production by dairy cows grazing a pure perennial ryegrass sward. *Asian-Australasian Journal of Animal Sciences* 14:1383-1388.
- Kloster A. M.; Latimori N. J.; Amigone M. A. 2000: Evaluación de dos sistemas de

pastoreo rotativo a dos niveles de asignación de forraje en una pastura de alfalfa y gramíneas. *Revista Argentina De Producción Animal* 20:187-198.

Kloster A. M.; Latimori N. J.; Amigone M. A. 2003: Comparación de sistemas de pastoreo rotativo (convencional vs. Líderes y seguidores) sobre una pastura base alfalfa. *Revista Argentina De Producción Animal* 23:25-32.

Krysl L. J.; Hess B. W. 1993: Influence of supplementation on behavior of grazing cattle. *Journal of Animal Science* 71:2546-2555.

Lake R. P.; Hildebrand R. L.; Clanton D. C.; Jones L. E. 1974: Limited energy supplementation of yearling steers grazing irrigated pasture and subsequent feedlot performance. *Journal of Animal Science* 39:5:827-833.

Leaver J. D. 1986: Effect of supplements on herbage intake and performance. In: J.Frame Ed. Grazing Occasional Symposium. No. 19, British Grassland Society, Berkshire, UK. 79-88.

Leaver J. D. 2000: Future directions for grazing research and practice. In: Rook, A.J. & Penning, P.D. Eds. *The Principles and Practice of Grazing, for Profit and Environmental Gain, Within Temperate Grasslands Systems*. Occasional Symposium No 34, British Grassland Society. 257-267.

Machado C.; Striebeck G.; Vasolo V.; Di Croce F.; Gonzalez F.; Duhalde J.; Parente M.; Auza N. 2001: Suplementación de grano de maíz en pastoreo y a corral como alternativas de terminación de novillos en el verano. *Avances En Producción Animal* 26:139-146.

Marsh R. 1977: The effect of level of herbage dry matter per animal on efficiency of utilization of pasture by young Friesian cattle. *Proceedings of the New Zealand Society of Animal Production* 37:62-66.

Martinez Ferrer J.; Simondi J.; Brunetti M. A.; Ustarroz E.; De Leon M.; Boetto C.; Faner C.; Gonzalez Palau C.; Ramos C.; Garcia Astrada A.; Faya F. 2002: Asignación forrajera y suplementación energética en invernadas pastoriles. 2. Aumento de peso individual y por ha. *Revista Argentina De Producción Animal* 22:9-10.

- Matejovsky K. M.; Sanson D. W. 1995: Intake and digestion of low-, medium-, and high-quality grass hays by lambs receiving increasing levels of corn supplementation. *Journal of Animal Science* 73:2156-2163.
- Mayne C. S. 1988: Effects of supplementation on the performance of both growing and lactating cattle at pasture. In: Frame, J. Ed. *Efficient Beef Production from Grass*. Occasional Symposium. No.25, British Grassland Society, Berkshire, UK. 55-71.
- Meijs J. A. C.; Hoeskstra J. A. 1984: Concentrate supplementation of grazing dairy cows. 1. Effects of concentrate intake and herbage allowance on herbage intake. *Grass and Forage Science* 39:59-66.
- Mould F. L.; Orskov E. R.; Mann S. O. 1983: Associative effect of mixed feeds. I. Effects of type and level of supplementation and the influence of the rumen pH on cellulolysis *in vivo* and dry matter digestion of various roughages. *Animal Feed Science and Technology* 10:15-30.
- NRC. 2000: Nutrient requirements of beef cattle. *National Research Council. National Academy Press. Washington, D.C.*
- Okajima T.; Kamijoh T.; Yokota H.; Ohshima M. 1996: Relationships between daily herbage intake of grazing cattle with daily herbage allowance and leafiness. *Asian-Australasian Journal of Animal Sciences* 9:577-582.
- Opatpatanakit Y.; Kellaway R. C.; Lean I. J. 1993: Substitution effects of feeding rolled barley grain to grazing dairy cows. *Animal Feed Science and Technology* 4:25-38.
- Owensby C. E.; Cochran R. C.; Brandt R. T.; Vanzant E. S.; Auen L. M.; Clary E. M. 1995: Grain supplementation on bluestem range for intensive-early stocked steers. *Journal of Range Management* 48:246-250.
- Parga J.; Peyraud J.; Delagarde R. 2000: Influence of herbage allowance on intake and behaviour of dairy cows grazing perennial ryegrass swards in autumn. In: Rook, A.J. & Penning, P.D. Eds. *The Principles and Practice of Grazing, for Profit and Environmental Gain, Within Temperate Grasslands Systems*.

Occasional Symposium No 34, British Grassland Society 34:61-66.

- Paterson J. A.; Belyea R. L.; Bowman J. P.; Kerley M. S.; Williams J. E. 1994: The impact of forage quality and supplementation regimen on animal intake and performance *In: Fahey, J.R. Ed. Forage Quality, Evaluation and Utilization.* American Society of Agronomy, Inc.:59-114.
- Perillat B. J.; Brown W. J.; Cohen R. D. H. 2004: A risk efficiency analysis of backgrounding and finishing steers on pasture in Saskatchewan, Canada. *Agricultural Systems* 80:213-233.
- Perry T. W.; Huber D. A.; Mott G. O.; Rhykerd C. L.; Taylor R. W. 1972: Effect of level of pasture supplementation on pasture, drylot and total performance of beef cattle. II. Spring plus summer pasture. *Journal of Animal Science* 34:647-652.
- Petty S. R.; Poppi D. P.; Triglone T. 1998: Effect of maize supplementation, seasonal temperature and humidity on the liveweight gain of steers grazing irrigated *Leucaena leucocephala/Digitaria eriantha* pastures in north-west Australia. *Journal of Agricultural Science, Cambridge* 130:95-105.
- Reardon T. F. 1975: Summer feeding of beef cattle. *Proceedings of the Ruakura Farmers' Conference* 27:14-18.
- Reardon T. F. 1977: Effect of herbage per unit area and herbage allowance on dry matter intake by steers. *Proceedings of the New Zealand Society of Animal Production* 37: 58-61.
- Rearte D.; Pieroni G. A. 2001: Supplementation of temperate pastures. *Proceedings of the XV International Grassland Congress* :679-691.
- Redmon L.; McCollum T.; Horn G.; Matthew D.; Cravey S.; Gunter P.; Beck J.; Mieres M.; San Julian R. 1995: Forage intake by beef steers grazing winter wheat with varied herbage allowances. *Journal of Range Management* 48:198-201.
- Reid T. 1986: Comparison of autumn/winter with spring pasture for growing beef cattle. *Proceedings of the New Zealand Society of Animal Production*

46:145-147.

- Robaina A. C.; Grainger C.; Moate P.; Taylor J.; Steward J. 1998: Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* 38:541-549.
- Rude B. J.; Hanson K. C.; Tucker W. B. 2002: Effect of supplementing corn or hay to beef cattle consuming annual ryegrass (*Lolium multiflorum*) on performance and nutrient utilization. *Journal of Applied Animal Research* 21:35-48.
- Ruiz D. E. M.; Pardo Sampere L.; Garcia Martinez A.; Rodriguez Alcaide J.; Pamio J. O.; Pena Blanco F.; Domenech Garcia V. 2000: Technical and allocative efficiency analysis for cattle fattening on Argentina Pampas. *Agricultural Systems* 65:179-199.
- SCA. 1990: Feeding Standards for Australian livestock. *Standing Committee on Agriculture, Ruminants Subcommittee. CSIRO Publications.* 266 p.
- Steen R. W. 1994: A comparison of pasture grazing and storage feeding, and the effects of sward surface height and concentrate supplementation from 5 to 10 months of age on the lifetime performance and carcass composition of bull. *Animal Production* 58:209-219.
- Steen R. W.; Kilpatrick D. J. 1998: Effects of pasture grazing or storage feeding, and concentrate input the effects of sward surface height from 5.5 to 11 months of age on the performance and carcass composition of bulls and on subsequent growth and carcass composition at 620 kg live weight. *Animal Science* 66:129-141.
- Taylor K. M.; Gulbransen B. 1990: Feeding grain for profitable finishing of grazing steers. *Proceedings of the Australian Society of Animal Production* 18:388-391.
- Tharmaraj J.; Wales W. J.; Chapman D. F.; Egan A. R. 2003: Defoliation pattern, foraging behaviour and diet selection by lactating dairy cows in response to sward height and herbage allowance of a ryegrass-dominated pasture.

Grass and Forage Science 58:225-238.

Wachenheim C. J.; Black J. R.; Schelgel M. L.; Rust S. R. 2000: Grazing methods and stocking rates for direct-seeded alfalfa pastures: III. Economics of alternative stocking rates for alfalfa pastures. *Journal of Animal Science* 78:2209-2214.

Wales W. J.; Doyle P. T.; Stockdale R. C.; Dellow D. W. 1999: Effects of variation in herbage mass, allowance, and level of supplement on nutrient intake and milk production of dairy cows in spring and summer. *Australian Journal of Experimental Agriculture* 39:119-130.

Herbage intake, diet composition, grazing behaviour and performance of Angus heifers on two herbage allowances during late spring

Abstract

Eighteen beef heifers (253 ± 4.8 kg LW) were allocated during late spring (26 October – 21 December) to either a low herbage DM allowance (LHA) or moderate herbage DM allowance (MHA) of 2.5 and 5.0 % LW d^{-1} respectively. Heifers were strip-grazed daily for 57 days (15 pre-experimental and 42 experimental days) on a red clover-perennial ryegrass pasture, with an average pre-grazing herbage mass of 2800 kg DM ha^{-1} . Intakes were assessed by slow release n-alkanes capsules (Captec®), and pre- and post-grazing herbage mass differences using a rising plate meter. In two 24-h periods, individual animals were observed at 10 min. intervals to record their grazing behaviour. Micro-histological evaluation of faeces and differences in nutrient and component selection indexes were used as indicators of diet characteristics. Heifers grazing the moderate herbage allowance achieved higher ($P < 0.01$) liveweight gain (0.79 kg d^{-1}) and final live-weight (293 kg LW) than LHA heifers (0.58 kg d^{-1} and 275 kg LW, respectively). Moderate allowance heifers had a significantly higher ($P < 0.05$) herbage intake when calculated from both methods (6.5 and 7.6 kg DM d^{-1} at MHA and 3.5 and 6.3 kg DM d^{-1} for intakes estimated from pre- and post-grazing herbage mass differences and using n-alkanes, respectively). The difference method underestimated herbage intake compared with the n-alkane method by 2.7 and 1.1 kg DM d^{-1} for LHA and MHA, respectively). Average post-grazing herbage mass were of 1180 and 1320 kg DM ha^{-1} for LHA and MHA, respectively. Low allowance heifers grazed longer ($P < 0.05$), mainly during the night ($P < 0.001$), and had higher bite rates and bites per day ($P < 0.05$), while the MHA heifers had a higher bite weight ($P < 0.05$). No differences between allowance treatments were found in diet digestibility, harvesting efficiency, micro-histological evaluation of faeces, nutrient and component selection indices.

Key-words: n-alkanes; herbage allowance; herbage-intake; liveweight gain, Angus heifers

1. Introduction

In pasture-based animal production systems, a major challenge is manipulating the

seasonal forage production cycle to meet animal feed requirements. Some animal production enterprises come closer than others to matching the seasonal pattern of pasture production, but in all cases there is a certain degree of imbalance (Hodgson 1990). Feed intake is the main determinant of the animal response, so alternative management options (including supplementation) should be based on an understanding of animal feed intake (Forbes 1988). It is generally accepted that there is an asymptotic relationship between herbage allowance, and intake or animal liveweight gain (Chapter 1). However, differences in experimental design and methods of estimating herbage intake have generated inconclusive or contradictory results. Indirect techniques to estimate individual herbage intake in free grazing animals such as n-alkane markers (Mayes et al. 1986) have overcome some of the limitations of other internal markers (Parker et al. 1990). Controlled release n-alkane capsules have been used to measure intake in beef cattle (Realini et al. 1999), but have not been evaluated under Argentinean conditions.

Herbage allowance and its impact on herbage intake have been studied in groups of animals in Argentina beef cattle (Gandara et al. 1987; Kloster et al. 2000) and dairy production systems (Romero et al. 1995; Gagliostro et al. 1996) using the pre- and post-grazing difference method (Frame 1981). Estimation of herbage intake with n-alkanes has been shown to be precise (Mayes et al. 1986), however the method is costly and time limited. For this reason, it is important to combine and adjust both alternatives to estimate feed intake.

The objective of this experiment was to establish routines and evaluate techniques under Argentinean conditions to study herbage intake (using n-alkanes and the pre- and post-grazing difference method), grazing behaviour and indicators of diet composition to complement other measurements used throughout the thesis. Specifically, the impact of either low or moderate herbage allowance on individual animal herbage intakes, liveweight gain and grazing behaviour of Angus heifers were measured.

2. Material and Methods

Eighteen 15-month-old Angus heifers weighing 253 ± 4.8 kg LW were obtained from

a commercial farm, where they had been weaned the previous fall, and grazed on a range pasture prior to the start of the trial. Treatments were unreplicated, and animals were allocated to either a low (LHA) or moderate herbage DM allowance (MHA) of 2.5 and 5.0 kg DM 100 kg animal LW⁻¹ d⁻¹, respectively (i.e. 9 animals per treatment). The trial was carried out at the Agricultural School “Jose Ramon Santamarina” Tandil, Argentina (37.2° S 59.2° W) during late spring. Animals in both treatments grazed a pasture containing perennial ryegrass (*Lolium perenne*) and red clover (*Trifolium pratense*). Fifty measurements per treatment using a rising plate meter (Earle & McGowan 1979) were taken each day, after which daily herbage DM allowances were allocated. Herbage residuals were also estimated using the rising plate meter.

Herbage intake was calculated from differences between pre- and post-grazing herbage masses (Frame 1981). Animals were strip-grazed and moved daily (at 1:00 pm) to a fresh strip with no back grazing of experimental areas. A 15-d pre-experimental period was used and experimental measurements were then taken over a 42-d period. Animals were de-wormed with ivermectin (Ivomec™) 48 h prior to allocation to treatments and on day 30 of the study. All heifers were treated with a progesterone-based compound (M.P.H™, Burnet lab.) with the objective of avoiding oestrus and hence alterations in animal grazing behaviour.

2.1. Animal measurements

Animals were weighed unfasted (within 1 h of removal from herbage) fortnightly and after a 15-h fast at the start and end of the trial. Measurements of ingestive behaviour were carried out on days 30 and 37 of the trial. All animals (identified with a phosphorescent number painted on both sides for night observation) were observed once every 10 min. and their activities were recorded as grazing, ruminating or idling over a 24-h period (Hodgson 1982). Biting rates were recorded for individual animals at their peak intake (morning and afternoon), by measuring the time to make 20 prehension bites (Hodgson 1982), taking the average of three measurements, and then using this information to compute the daily number of bites.

On day 14 all animals were inserted with capsules (Captec® 150-300 kg LW)

containing dotriacontane (C₃₂) and hexatriacontane (C₃₆) with a constant release rate for each n-alkane of approximately 200 mg d⁻¹ to estimate individual herbage intakes. Routines for sampling and estimation of individual intake and digestibility are described elsewhere (Mayes et al. 1991). The capsules have an active period of 20 days, and two independent periods of intake measurement were recorded from days 7 to 12 and days 15 to 19 post-application. During each period, faecal samples were collected daily from individual animals by morning or evening observation (2-h periods) of animals defecating and immediately refrigerated (Morris et al. 1993). Samples were pooled within animal on a wet-basis for each period (36 samples). Sub-samples were dried in an oven at 60 °C for 48 h and were conserved for micro histological analysis of faeces (see below). The rest of the pooled samples were freeze-dried then ground in a mill (1 mm) and analyzed for n-alkanes composition by gas chromatography (Mayes et al. 1986). Three animals in the second period (two from LHA and one from MHA) were discarded for intake and digestibility estimation because of extremely low C₃₂ and C₃₆ concentrations. In order to check capsule release rate, two capsules from the same batch used in the main experiment were placed in the rumen of a fistulated animal that grazed similar herbage in a nearby paddock. At days 0, 1, 3, 7, 10, 15, 20 and 21 the length of residual n-alkane content was measured with a ruler. A regression analysis was used to estimate capsule release rate by converting length to weight.

During each day that individual intakes were estimated, two enclosure cages were placed in each strip to be grazed. Thirty hand-plucked herbage samples per cage were taken post-grazing to represent the animals diet by visual comparison with the grazed sector. Another sample was collected for clover and ryegrass n-alkanes analysis. Herbage samples were pooled by sampling period and treatment (one for each 5-day period) as described by Garcia et al. (2000). Samples were sealed in polythene bags and taken to the laboratory in an icebox. Herbage samples were freeze-dried, ground (1mm screen) and divided into two sub-samples. The first was analysed for n-alkane composition and the second was analysed for dry matter *in vitro* digestibility (Dig%) (Tilley & Terry 1962), crude protein (CP%) by Micro Kjeldhal (A.O.A.C. 1960), neutral detergent fiber (NDF%) (Goering & Van Soest 1970) and non-structural carbohydrates (NSC%) by the anthrone method (Pichard & Alcalde 1990).

The following variables were estimated from grazing behaviour, individual herbage intake, individual digestibility and animal live-weight: bite weight (g DM bite^{-1}), daily energy intake (MJ ME d^{-1}) and harvesting efficiency (HE) as $\text{g DM eaten kg LW}^{-1} \text{ min grazing}^{-1}$ (Krysl & Hess 1993).

The characteristics of the diet were measured using micro histological analysis of faeces and pre- and post-grazing assessment of morphological and nutritional parameters of the sward. Similarly, diet composition was tested with n-alkanes using the software package (EatWhat) described by Dove and Moore (1995), which is based on a least squares procedure. For these analyses, alkane faecal recoveries were assumed from the literature, but no feasible solutions were found. Micro-histological analysis involved a separation of pooled herbage samples into ryegrass and red clover. The dried samples of faeces collected from each animal were ground through a 20-mesh (1mm aperture) screen using a Wiley mill knife grinder to ensure uniformity of fragment size. Additionally, from the dried herbage sub-samples, nine dry matter clover:ryegrass mixes were prepared (10:90, 20:80, 30:70, 40:60, 50:50, 60:40, 70:30, 80:20 and 90:10) and coded for a blind microscope reading. The herbage mixes were digested (Tilley & Terry 1962) and the undigested residuals were dried and stored. The digested mixes and faecal materials were washed with ordinary bleach (sodium hypochlorite 0.3%) to remove pigments, and then water-washed over a 50-mesh screen to remove the bleach and smaller non-diagnostic particles. Five slides were prepared for each sample (animals within treatments and each species mix combination) with gelatine:glycerin (1:7), and 100 microscope fields per treatment (20 per slide) were observed using a 100x microscope. Calibrations of the coded and digested proportions were recorded, and compared with the nine original mixes by linear regression analysis. Botanical composition of ryegrass and red clover fragments were recorded as density of the total identifiable fragments in 100 microscope fields (Sparks & Malechek 1968).

On days 30 and 37, five homogeneous areas per treatment of approximately 1 m^2 were selected and tagged. Pre- and post-grazing quadrats (0.1 m^2) were cut from them at ground level. Samples were sealed in polythene bags, washed in the

laboratory to eliminate soil and faeces contamination and sorted into species, green-dead proportion, lamina plus clover leaf (L) and non-leaf fraction (NL) within the green component. Total DM was estimated separately by oven-drying at 60 °C for 48 h. On day 37, a site adjacent to each pre- and post-grazing quadrat representing herbage of similar characteristics, was also sampled and refrigerated on site. These samples were freeze-dried and ground in a mill (1 mm screen) and analysed for Dig%, CP%, NDF% and NSC % as previously described.

Nutrient contents of the herbage selected by the animals were expressed using the following formula (Stockdale 1999):

$$\text{NSI} = \frac{(\text{kg DM nutrient ha}^{-1} (\text{Pre}) - \text{kg DM nutrient ha}^{-1} (\text{Post}))}{(\text{kg DM ha}^{-1} (\text{Pre}) - \text{kg DM ha}^{-1} (\text{Post}))} \quad \text{Eqn. 1}$$

Where NSI is nutrient selection index. Similarly, by using the difference in botanical composition and adapting the previous formula, each component was expressed as:

$$\text{CSI} = \frac{(\text{kg DM component ha}^{-1} (\text{Pre}) - \text{kg DM component ha}^{-1} (\text{Post}))}{(\text{kg DM ha}^{-1} (\text{Pre}) - \text{kg DM ha}^{-1} (\text{Post}))} \quad \text{Eqn. 2}$$

Where CSI is the component selection index. Experimental variables were analyzed using ANOVA as a completely random design. Final liveweight was tested also with initial liveweight as covariate. As neither period nor treatment effects were different for component selection indexes, a group analysis across treatments was developed between two pairs of indexes, green vs. dead components and clover vs. grass components. Regression analyses were performed between each component selection index and nutrient selection index. All analyses used the SAS statistical analysis system (SAS/STAT 2001).

3. Results

3.1. Animal performance and dry matter intake

Herbage morphological composition was similar between treatments, with average

values for dead material (as fraction of total sample) of 0.39 ± 0.06 (0.61 of green material), and as fraction of green material, clover represented 0.72 ± 0.08 (0.28 of grasses) and leaf contents (clover leaf plus grass leaf) was 0.31 ± 0.02 (0.69 of grass stem and sheath and legume stem fractions). Chemical composition, concentration of dominant n-alkanes and average pre-grazing herbage mass are shown in Table 1.

Table 1. Chemical composition means, concentration of dominant n-alkanes and herbage mass in a pre-grazed pasture at two herbage allowances.

	Dig	CP	NDF	NSC	C ₂₉	C ₃₁	C ₃₃	Herbage mass
	% DM				mg 100 g DM ⁻¹			kg DM ha ⁻¹
LHA	69	17	36	9	299.9	201.4	18.6	2940
MHA	66	16	38	9	350.6	172.3	14.1	2660

LHA= herbage DM allowance of 2.5 % LW d⁻¹, MHA= herbage DM allowance of 5.0 % LW d⁻¹, Dig = % DM *in vitro* digestibility, CP= crude protein, NDF = neutral detergent fiber, NSC = non-structural carbohydrates and C₂₉, C₃₁ and C₃₃ alkanes of n carbons.

Animals on the moderate herbage allowance achieved a higher live weight gain, and final live-weight when initial live-weight was added to the model as a covariate (Table 2). Heifers grazing the moderate herbage allowance had higher intakes when assessed with both n-alkanes and the pre- and post-grazing difference method. However, the difference method values were only 55 and 85% of the herbage intake estimated from n-alkane concentration for treatment LHA and MHA respectively (Table 2). The capsule release rate was linear (391 ± 1 mg d⁻¹) similar to the amount reported by the manufacturers (400 mg d⁻¹). Lower herbage residuals in the lower allowance resulted in a higher degree of herbage utilisation (52%) by the LHA animals than MHA animals (36%). *In vivo* diet digestibility was not different between treatments.

Table 2. Effect of herbage allowance on final liveweight, fasted liveweight loss, liveweight gain, herbage intake and *in vivo* diet digestibility of Angus heifers.

	LHA	MHA	#PSE	Sig.
Final LW (kg)	275	293	8.2	**
Fasted LW loss 15 h (% unfasted LW)	0.07	0.07	0.006	NS
Full LWG (kg d ⁻¹)	0.58	0.79	0.05	**
15 h fasted LWG (kg d ⁻¹)	0.49	0.76	0.07	**
n-alkanes herbage intake (kg DM d ⁻¹)	6.30	7.6	0.37	*
Post-grazing herbage mass (kg DM ha ⁻¹)	1180	1320	53.1	NS
Pre- and post-grazing herbage intake (kg DM d ⁻¹)	3.5	6.5	0.22	**
Diet digestibility (n-alkanes)	73	73	1.5	NS

LHA= herbage DM allowance of 2.5 % LW d⁻¹, MHA= herbage DM allowance of 5.0 % LW d⁻¹, #PSE= pooled standard error, Sig.=significance level, NS = no significant difference, * P<0.05 and ** P<0.01.

3.2. Grazing behaviour

Animals grazing the moderate herbage allowance grazed longer and rested less than animals grazing the lower allowance, with no differences detected in time allotted to ruminating (Table 3). Most of this difference in grazing time occurred during the night. During daylight hours, LHA heifers tended ($P < 0.1$) to graze more (Table 3), particularly during afternoon after a new pasture strip was allocated (Figure 1). Biting rate and bites per day were higher in LHA heifers, while MHA heifers had higher bite weights. Harvesting efficiencies, estimated from herbage intake calculated from n-alkane concentration, were similar between treatments (Table 3).

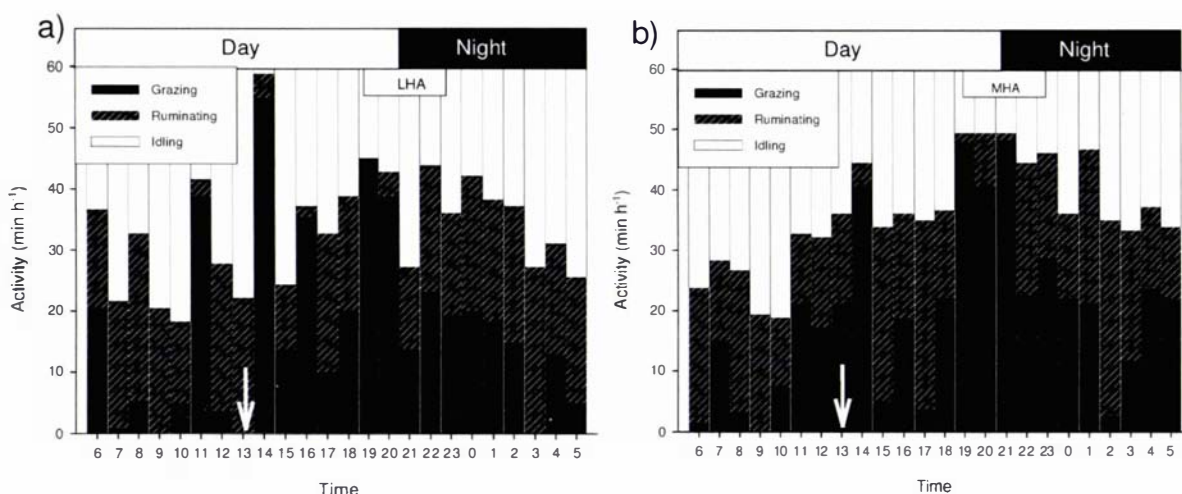


Figure 1. Effect of herbage allowance on grazing behaviour of Angus heifers throughout the day.

LHA= herbage allowance of 2.5 % LW d⁻¹ (a), MHA= herbage allowance of 5.0 % LW d⁻¹ (b). Arrows indicate time when animals were shifted to a new grazing strip (1 :00 pm).

3.3. Diet characteristics

The nine prepared clover:ryegrass percentage mixes were predicted accurately by microscope readings (clover % = 1.04x + 0.35; $R^2=0.97$ and ryegrass % = 1.02x - 1.29; $R^2=0.93$, where x is the microscope reading). The microscope readings of faeces indicated no differences in species contribution to herbage intake between the two treatments. There were also no significant differences for any component selection index or nutrient selection index. When paired indexes (dead vs. green and grass vs. clover) were compared across treatments (Table 4), the grass and dead components were eaten less than clover and green, respectively. Values

closer to zero indicate that the corresponding component of a pair was eaten less than the herbage intake estimated from pre- post-grazing differences (denominator of Eqns. 1 and 2). Green and clover components were close to 1.0, indicating that they were consumed proportionally to the herbage intake estimated from pre- post-grazing difference. From the linear regressions between the different component selection indexes and nutrient selection indexes, only dry matter digestibility was significantly explained by the leaf index (digestibility selection index = 0.52 leaf selection index + 0.51; $R^2 = 0.79$). No feasible solutions were found when testing n-alkanes for diet composition (results not shown).

Table 3. Effect of herbage allowance on the indicated grazing behaviour characteristics of Angus heifers.

	LHA	MHA	#PSE	Sig.
<u>Whole day:</u>				
Grazing time (min)	421	468	12.1	*
Ruminating time (min)	379	386	13.3	NS
Idling time (min)	614	560	20.2	**
Biting rate (bites min ⁻¹)	44.9	32.0	2.4	**
Bite number (bites d ⁻¹)	18871	15187	752.4	**
Bite weight (mg bite ⁻¹)	362	587	38.1	**
HE @ (g DM eaten kg LW ⁻¹ min grazing ⁻¹)	0.056	0.058	0.0032	NS
<u>Daylight period (6:00 pm-8:00 pm)</u>				
Grazing time (min)	293	265	10.1	+
Ruminating time (min)	208	238	9.3	*
Idling time (min)	398	396	12.4	NS
<u>Morning period (6:00 am –12:00 am)</u>				
Grazing time (min)	75	66	4.9	NS
Ruminating time (min)	124	117	7.1	NS
Idling time (min)	221	238	9.6	NS
<u>Afternoon period (1:00 pm-8:00 pm)</u>				
Grazing time (min)	218	199	6.9	+
Ruminating time (min)	84	122	5.1	***
Idling time (min)	178	159	6.4	*
<u>Night period (9:00 pm – 5:00 am)</u>				
Grazing time (min)	127	198	10.2	***
Ruminating time (min)	177	159	8.9	***
Idling time (min)	210	158	10.7	+

LHA= herbage DM allowance of 2.5 % LW d⁻¹, MHA= herbage DM allowance of 5.0 % LW d⁻¹, #PSE= pooled standard error, Sig.=significance level, HE @ = herbage efficiency, NS = no significant difference (P>0.1), + P<0.1, *P<0.05, ** P<0.01, *** P<0.001.

Table 4. Comparison of means of different pairs of component selection indexes (dead vs. green and clover vs. grass) pooled between treatments.

		#PSE	Sig.
Dead	Green		
-0.02	1.02	0.17	**
Clover	Grass		
0.91	0.08	0.17	**

#PSE= pooled standard error, Sig.=significance level and ** P<0.01.

4. Discussion

The overall heifer liveweight gains of this study were high if compared with fully fed animals either at feedlot or under grazing conditions. Feedlot heifers fed a high grain-based diet *ad libitum*, achieved 1 kg d^{-1} (Machado et al. 1997). Under winter grazing conditions, when Holstein-Friesian heifers of two different genetic lines (heavy and light) were fed *ad libitum* herbage allowances (of around 12 % of LW) of a high quality pasture, live-weight gains of 0.92 kg d^{-1} were obtained (Garcia-Muniz 1998). In the present trial, heifers were dosed with a progesterone-based compound to avoid grazing behaviour disturbance and this may have increased LWG. Improvement in LWG of around 5% could be expected from using this type of compound (Duckett & Andrae 2001).

Herbage intake was higher at the moderate herbage allowance, associated with higher final liveweight gains. Direct relationships between herbage allowance, herbage intake and animal liveweight gain are well established in the literature (Hodgson 1984; Stockdale 1985). One of the objectives of this trial was the comparison of two methods of estimating herbage intake. Although separate calibrations of the rising plate meter for pre- and post-grazing were performed in the present trial, the pre- and post-grazing difference method underestimated intake (by 2.7 and 1.1 kg DM d^{-1} for LHA and MHA, respectively) when intake using the n-alkanes method was taken as a reference (Table 2). The theoretical intakes derived from recorded live weight gains and herbage digestibilities were 4.7 and 5.5 kg DM d^{-1} for LHA and MHA animals respectively (AFRC 1993), representing 74 and 72% of the herbage intakes estimated using the n-alkanes. As both treatments were unreplicated, this prevented the development of any formal statistical test to compare both method of estimate the herbage intake. Robaina et al. (1998) compared both methods and reported an under-estimation with pre- and post-grazing difference method, however, because of herbage treading, it seems more likely that the rising plate meter over-estimates herbage intake (Reeves et al. 1996; Garcia 2000). Possible reasons for under-estimation may be associated with changes between pre- and post-grazing sward structure in a more mature sward, which leads to a higher resistance of residual dry matter to the rising plate meter. The estimation of herbage intake of late spring-summer pastures using sward

sampling techniques is often difficult when pasture is clumpy and may contain a mixture of dry stem material and green herbage (Robaina et al. 1998). The pre- and post-grazing difference method underestimated herbage intake differentially in the two treatments, possibly as a consequence of modifications in structure and mass of the herbage residuals as the same post-grazing equation was used for both treatments.

The lower herbage C_{33} content in MHA herbage as shown in Table 1, contributed to the difference between intake methods, because the herbage (and faeces) C_{33} is used to estimate herbage intake. The difference between herbage C_{33} in LHA and MHA swards may be associated with a slightly higher clover content (although non significant) in the sward grazed by LHA heifers, as the C_{33} concentration for ryegrass and clover were 8 and 34 mg 100 g DM⁻¹, respectively (results not shown).

Heifers grazing the low herbage allowance grazed for 47 min less time than heifers grazing the moderate herbage allowance. At a low herbage allowance animals usually graze longer in an attempt to compensate for the reduced herbage on offer, but reduction in daily grazing time at very low herbage allowance has been reported under rotational grazing (Jamieson & Hodgson 1979). Dougherty et al. (1988) observed that grazing time of beef animals increased when herbage DM allowances fell from 2.5 to 1.5 % LW⁻¹, but dropped abruptly with a further reduction in allowance from 1.5 to 1.0 % LW⁻¹.

Additional differences were found when grazing time was analysed separately for morning and afternoon activities. Heifers grazing the low herbage allowance allotted 52 % of their daily grazing time during the afternoon (1:00 pm-8:00 pm) coinciding with the shift to a new strip, which agrees with other authors (Jamieson & Hodgson 1979). This behaviour has been associated with an unwillingness to eat prior to strip shifting caused by low residuals in low allowance paddocks (Forbes & Hodgson 1985). However, herbage residuals in Jamieson and Hodgson (1979) and in the present trial, were 1643 kg OM ha⁻¹ and 1717 kg DM ha⁻¹ respectively, so other factors might be present. The low green herbage residual in both trials (28 and 46%, respectively) and the fouling and trampling caused by the high

concentration of the heifers ($22 \text{ m}^2 \text{ d}^{-1} \text{ heifer}^{-1}$) may have contributed to this grazing behaviour. Animals grazing the low herbage allowance had higher biting rate and a lower bite weight, consistent with the literature where the animal tries to compensate for a lower bite mass by increasing biting rate (Hodgson & Brookes 1999). There was no difference in harvesting efficiencies (expressed as $\text{g DM eaten kg LW}^{-1} \text{ min grazing}^{-1}$) between heifers grazing either low or moderate herbage allowances. Although LHA heifers had a significantly lower dry matter intake, they also had a lower liveweight and grazed for a shorter time.

Heifers showed clear preference for green material over dead components, which is in agreement with Cohen and Garden (1983). Similarly, a preference for clover over grass was detected by the index comparison across treatments. The micro-histological analysis technique was sensitive, but it did not detect a clover preference from the treatments as shown in the component selection indexes (Table 4). Differences might be related more to canopy structure and intensity of grazing down than to selectivity. Component selection and nutrient selection indexes are mechanistic in their approach, but they have a high standard error as they accumulate the variation of four independent measurements (see equations 1 and 2).

5. Conclusions

The performance of the Angus heifers grazing the low herbage allowance was unexpectedly high (although significantly lower than at the moderate allowance) considering they grazed half of the herbage allowance. The rising plate meter was an acceptable tool for allocating herbage, but when used for estimating herbage intake for groups of animals, it should be used carefully when pre- and/or post-grazing sward structures differ between treatments.

The techniques used for obtaining information about diet characteristics were not reliable enough, so the efforts involved may not be justified when the objective of the research is to estimate herbage intake. The trial allowed the testing of methodologies under local Argentinean conditions to allow progress with more complex experimental designs focused on herbage allowance, herbage intake and

animal performance using grain supplementation. This will be the subject of chapters 3 and 4.

References

- A.O.A.C. 1960: *Official Methods of Analysis*. 9th ed. AOAC. Washington:957 p.
- AFRC. 1993: Energy and protein requirements of ruminants. *Published by the AFRC Technical Committee on Response to Nutrients*:176 p.
- Cohen R.; Garden D. 1983: Relationship between botanical composition of herbage on offer and herbage eaten by grazing beef cattle. *Proceedings of the XIV International Grassland Congress*: 678-681.
- Dougherty C.; Smith E.; Bradley N.; Forbes T.; Cornelius P.; Lauriault L.; Arnold C. 1988: Ingestive behaviour of beef cattle grazing alfalfa (*Medicago sativa* L.). *Grass and Forage Science* 43: 121-130.
- Dove H.; Moore A. D. 1995: Using a least-squares optimization procedure to estimate botanical composition based on the alkanes of plant cuticular wax. *Australian Journal of Agricultural Research* 46:1535-1544.
- Duckett S. K.; Andrae J. G. 2001: Implant strategies in an integrated beef production system. *Journal of Animal Science* 79 (E.Suppl):E110-E117.
- Earle D.; McGowan A. 1979: Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19:337-343.
- Forbes T. D. A. 1988: Researching the plant-animal interface: the investigation of ingestive behavior in grazing animals. *Journal of Animal Science* 66:2369-2379.
- Forbes T. D. A.; Hodgson J. 1985: Comparative studies of the influence of sward conditions on the ingestive behaviour of cows and sheep. *Grass and Forage*

Science 40: 69-77.

- Frame J. 1981: Herbage Mass. In: Hodgson, J.; Baker R.D; Davis, A.; Laidlaw, A.S. ; Leaver, J.D. Eds. *Sward Measurement Handbook*. British Grassland Society: Berkshire, UK. 35-70.
- Gagliostro G. A.; Cangiano C.; Santini F. J. 1996: Efecto de la suplementación sobre el consumo de forraje y la producción de leche de vacas en pastoreo. *Revista Argentina De Producción Animal* 16:215-226 .
- Gandara F. R.; Goldfarb M. C.; Gutierrez M. S. 1987: Utilización invernal de pasturas de Pangola (*Digitaria decumbens*) diferidas de otono. 1. Efecto de la oferta inicial de forraje sobre la ganancia diaria de peso vivo de vacunos en crecimiento. *Revista Argentina De Producción Animal* 7:541-555.
- Garcia-Muniz J. G. 1998: Studies of Holstein-Friesian cattle bred for heavy or light mature live weight. *PhD Thesis. Massey University, New Zealand* :269 p.
- Garcia S. C. 2000: System, component, and modelling studies of pasture-based dairy systems in which the cows calve at different times of the year. *PhD Thesis. Massey University, New Zealand*: 203 p.
- Garcia S. C.; Holmes C. W.; Hodgson J.; MacDonald K. A. 2000: The combination of the n-alkanes and ¹³C techniques to estimate individual dry matter intakes of pasture and maize silage by grazing dairy cows. *Journal of Agricultural Science, Cambridge* 135: 47-55.
- Goering H. K.; Van Soest P. 1970: Forage fiber analysis (apparatus reagents, procedures and some applications). *Agriculture Handbook Nr 379, USDA. Washington, DC*. 20 p.
- Griebenow R. L.; Martz F. A.; Morrow R. E. 1997: Feed and forage: Forage-based beef finishing systems: a review. *Journal of Production Agriculture* 10: 84-91.
- Hodgson J. 1982: Ingestive behaviour. In: Leaver, J. Ed. *Herbage Intake Handbook*. British Grassland Society. Hurley, United Kindom. 113-139.

- Hodgson J. 1984: Sward conditions, herbage allowance and animal production. *Proceedings of the New Zealand Society of Animal Production* 44: 99-104.
- Hodgson J. 1990: *Grazing Management: Science into Practice*. Longman Handbooks in agriculture, Longman Scientific and Technical co-published with John Wiley. New York: 203 p.
- Hodgson J.; Brookes I. M. 1999: Nutrition of grazing animals. In: White, J. & Hodgson, J. Eds. *New Zealand Pasture and Crop Science*. Oxford University press. 117-132.
- Jamieson W. S.; Hodgson J. 1979: The effect of daily herbage allowance and sward characteristics upon the ingestive behavior and herbage intake of calves under strip-grazing management. *Grass and Forage Science* 34:261-271.
- Kloster A. M.; Latimori N. J.; Amigone M. A. 2000: Evaluación de dos sistemas de pastoreo rotativo a dos niveles de asignación de forraje en una pastura de alfalfa y gramíneas. *Revista Argentina De Producción Animal* 20:187-198.
- Krysl L. J.; Hess B. W. 1993: Influence of supplementation on behavior of grazing cattle. *Journal of Animal Science* 71:2546-2555.
- Machado C.; Matoso H.; Auza N. 1997: A note of productive performance of feedlot heifer-calves fed on two daily feeding frequencies. *Journal of Animal and Feed Sciences* 6:81-85.
- Mayes R.; Lamb C.; Colgrove P. 1986: The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. *Journal of Agricultural Science, Cambridge* 107:161-170.
- Mayes R. W.; Dove H.; Lamb C. S.; Ellis K. J. 1991: Evaluation of an intraruminal device for the controlled release of an alkane marker for intake estimation in sheep. *Proceedings of the 42nd Annual Meeting of the European Association of Animal Production* 1:457-461.
- Morris S. T.; Hirschberg S. W.; Michel A.; Parker W. J.; McCutcheon S. N. 1993: Herbage intake, liveweight gain of bull and steers continuously stocked at

- fixed sward heights during autumn and spring. *Grass and Forage Science* 48:109-117.
- Parker W. J.; Morris S. T.; Garrick D.; Vincent G.; McCutcheon S. 1990: Intraruminal chromium controlled release capsules for measuring herbage intake: a review. *Proceedings of the New Zealand Society of Animal Production* 50:437-442.
- Pichard G.; Alcalde J. A. 1990: Determinación de carbohidratos no estructurales. In: Ruiz, M.E. and Ruiz, A. Eds. *Nutrición De Rumiantes: Guía metodológica de Investigación*. IICA. San José De Costa Rica :3-20.:3-20.
- Realini C.; Hodgson J.; Morris S. T. 1999: Effect of sward surface height on herbage intake and performance of finishing beef cattle. *New Zealand Journal of Agricultural Research* 42:155-154.
- Reeves M.; Fulkerson W.; Kellaway R.; Dove H. 1996: A comparison of three techniques to determine the herbage intake of dairy cows grazing kikuyu (*Pennisetum clandestinum*) pasture. *Australian Journal of Experimental Agriculture* 36 : 23-30.
- Robaina A. C.; Grainger C.; Moate P.; Taylor J.; Steward J. 1998: Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* 38:541-549.
- Romero L. A.; Comeron E. A.; Bruno O. A.; Diaz M. C. 1995: Efecto del nivel de asignación de pasturas de alfalfa sobre la respuesta de vacas lecheras. 1. Consumo y comportamiento ingestivo. *Revista Argentina De Producción Animal* 15 :623-626.
- SAS/STAT. 2001: Release. 8 SAS. *Inst. Inc., Cary, NC*.
- Sparks D. R.; Malechek J. C. 1968: Estimating percentage dry weight in diets using a microscopic technique. *Journal of Range Management* 21:267-268.
- Stockdale R. C. 1985: Influence of some sward characteristics on the consumption of irrigated pastures grazed by lactating dairy cows. *Grass and Forage Science* 40:31-39.

- Stockdale R. C. 1999: The nutritive characteristics of herbage consumed by grazing dairy cows affect milk responses obtained from concentrates supplementation. *Australian Journal of Experimental Agriculture* 39:379-387.
- Tilley J. M. A.; Terry R. A. 1962: two-stage technique for the in vitro digestion of forage crops. *Journal of the British Grassland Society* 18:104-111.

Effect of maize grain and herbage allowance on intake, animal performance and grazing behaviour of heifers in winter

Abstract

Thirty-four 13-month old Angus x Hereford heifers (227 ± 8 kg LW) were strip-grazed daily for 64 days during winter (13 August to 14 September) in groups of four or five on a pasture containing predominantly *Festuca arundinacea* and *Trifolium repens*. Replicated treatments were: Low herbage DM allowance without maize grain (LHA: $2.5 \% \text{ LW d}^{-1}$), moderate herbage DM allowance without maize grain (MHA: $5 \% \text{ LW d}^{-1}$) and at the low herbage allowance, two levels of DM maize grain: 0.5 and $1.0 \% \text{ LW d}^{-1}$ for LHA-M₁ and LHA-M₂, respectively. Soybean meal was fed to all treatments to reach a diet crude protein level above 15% . Herbage and grain intakes were assessed by slow release n-alkanes and ^{13}C , and from pre- and post-grazing estimations of herbage mass. Two 24-h periods of grazing behaviour were recorded. The herbage intake in treatment MHA (6.5 and 4.6 kg DM d^{-1} from pre- and post-grazing estimations of herbage mass and n-alkanes & ^{13}C , respectively) was significantly higher ($P < 0.05$) than LHA (4.8 and 3.3 kg DM d^{-1} from pre- and post-grazing estimations of herbage mass and n-alkanes & ^{13}C , respectively) using both methods for intake estimation, and also decreased linearly with maize feeding level when the n-alkanes and ^{13}C was used. The LWG of MHA was significantly higher ($P < 0.05$) than LHA (0.65 and 0.25 kg d^{-1} , respectively) and increased linearly ($P < 0.01$) with level of maize fed. Substitution rates (SR) did not change with maize feeding level (average of 0.36 kg herbage DM kg maize DM⁻¹). The MHA and LHA treatments had a similar grazing time (average of 373.5 min. d^{-1}) and *in vivo* digestibility of herbage eaten (0.68 , as proportion of total DM). As maize grain feeding level was increased, idling time, bite weight and harvesting rate (g DM eaten kg LW⁻¹ min. spent grazing⁻¹) increased. Maize feeding decreased grazing time, and also tended to decrease the coefficients of variation of LWG. Animals on MHA had higher fasting liveweight losses than LHA, with no effect of level of maize grain fed. Estimates of herbage intake using the alkane & ^{13}C technique were in good agreement with the prediction of energy requirement for the attained animal performance, and allowed (without the need of adding other markers) definition of an important variability in maize intake within groups of animals.

Keywords: n-alkane; herbage allowance; intake; maize, liveweight gain, heifers

1. Introduction

Direct utilization of forage by grazing is the main component of Argentinean beef cattle systems, however in recent years more silage, hay and concentrate have been used (Rearte 1998). Grain feeding in grazing systems acts as a buffer to smooth out the inherent risk of variation in herbage mass and quality, with additional benefits of system flexibility and intensive use of pastures through increasing the stocking rate (Rearte & Pieroni 2001). However, it is important to encourage graziers to get maximum benefit from grazed grass, and to keep supplementary feed costs low and hence limit overall expenses.

When grain is fed, typically there is substitution of grain for herbage expressed in kg DM herbage kg DM grain⁻¹ (Dixon & Stockdale 1999). Some controversy regarding the effect of level of supplement on the substitution rate (SR) has been observed in the literature. Substitution rate was not affected by the level of supplements when steers were fed maize grain and fresh alfalfa indoors (Elizalde et al. 1999) or grain was fed to grazing animals (Boom & Sheath 1998). However, in some experiments SR increased with the level of supplements, both in indoor experiments (Petchey & Broadbent 1980) and in grazing trials (Robaina et al. 1998). Because SR has clear implications to herbage utilisation and therefore to economic performance, a better understanding of it will lead to a more effective use of grain feeding.

Accurate information about individual herbage and grain intake in grazing animals is scarce (Dove 1996), partly because of the technical difficulties of making accurate measurements of the different herbage and grain components when fed together. Herbage intake of grain supplemented animals has been estimated using n-alkanes with corrections for the concentrate eaten and its n-alkane composition (Mayes et al. 1986). Alternatively, if the concentrate is sufficiently different in alkane composition and the n-alkane recovery rate is known, individual concentrate intake can be estimated (Dove & Mayes 1996). However, grains typically have a low level of n-alkanes, which affects the use of this method. To overcome this difficulty, in most of the beef cattle studies measuring herbage intake using the n-alkane method and feeding grains, the supplement has been fed individually

(French et al. 2001a,b). Although the research advantages of feeding the supplement in this way are evident, the natural expression of animal variation when group fed (as in most Argentinean beef cattle systems) is not realised. Variation exists in individual animal intake when animals are fed concentrates as a group, and this behavioural phenomenon can explain in some circumstances the contradictory effects of grain supplementation (Bowman & Sowell 1997).

To measure individual grain intakes, markers have been added to the concentrates such as Ytterbium (Curtis et al. 1994). Alternatively, beeswax may be used to increase the odd-numbered carbon chain concentrations but with a distinctive pattern (Moshtaghi Nia & Wittenenbergh 2002), to enable the use of the n-alkane method of estimating intake. However, this adds an extra operation, which is difficult to implement when the supplement is silage, and also has an inherent risk of feed deterioration. The iterative alkane & ^{13}C technique (Garcia et al. 2000) based on contrasts in the balance of ^{13}C isotopes in the herbage and the concentrate has been shown to accurately estimate the level of DM intake of herbage and maize silage in grazing dairy cows supplemented as a group. This technique is a combination of the n-alkane technique and the technique of Jones et al. (1979), whereby the contribution of temperate pastures and maize through their C_3 and C_4 contents is assessed, but it has not been previously used in beef cattle systems.

Dry and wet maize grain are common supplements in commercial Argentinean beef systems, but individual herbage intake when maize is fed has not been studied, and this information could be relevant for grazing practices. Therefore, the main aim of this study was to measure the effects of level of wet maize grain fed and herbage allowance on performance, intake and grazing behaviour of Angus heifers grazing a perennial beef finishing pasture in winter.

2. Materials and Methods

2.1. Experimental design

Thirty-four 13-month old heifers (227 ± 8 kg LW) were allocated to four replicated

treatments in winter: Low herbage DM allowance without maize grain (LHA: 2.5 % LW d⁻¹), moderate herbage DM allowance without maize grain (MHA: 5 % LW d⁻¹) and at the low herbage allowance, two levels of maize grain: Low HA+0.5 % LW d⁻¹ DM of maize grain (LHA-M₁) and Low HA+1.0 % LW d⁻¹ DM of maize grain (LHA-M₂). Each treatment was replicated twice with 4 to 5 animals in each replicate group. Herbage allowance was expressed as herbage DM mass to ground level, as a percentage of animal live weight (Hodgson 1984). The trial was carried out on a commercial farm at Gardey, Tandil - Argentina (37° 16' S 54° 19.9' W), using a uniform pasture containing predominantly tall fescue (*Festuca arundinacea*) and white clover (*Trifolium repens*), rested in advance for eight weeks and receiving no fertiliser. Animals were strip-grazed and moved daily (at 8:00 am) to a fresh strip with no back-grazing of experimental areas. The experiment lasted for 64 days (15 pre-experimental and 49 experimental days) from 13 August to 14 September. Wet cracked maize grain was used and it was stored in a plastic silage bag (50 ton), from where the amount needed was extracted daily. Protein meal (soybean meal) was fed to all groups as herbage crude protein was lower than the recommended protein content in the diet for young growing cattle (i.e. 15-18 % of crude protein in DM, Hodgson & Brookes 1999). Soybean meal was used to achieve a minimum crude protein level of 15 % DM in the diet, including grazed herbage.

2.2. Measurements

Fifty measurements of pre- and post-grazing herbage mass were taken daily in each replicate using a calibrated rising plate meter and a double sampling procedure (Earle & McGowan 1979). From the pre-grazing measurement, daily herbage allowances were allocated by adjusting the grazing area. Animal group herbage intake was calculated from the difference between pre- and post-grazing herbage masses (Frame 1981).

Animals were de-wormed with ivermectin (Ivomec™) 48 h prior to allocation to treatments and on day 30 of the study. All heifers were treated with a progesterone-based compound (M.P.H™, Burnet lab.) with the objective of avoiding oestrus and hence alterations in animal grazing behaviour. Concentrates were fed at 1:00 pm, with heifers grazing the LHA and MHA treatments receiving

only soybean, while the LHA-M₁ and LHA-M₂ treatments were fed a mixture of soybean and wet maize grain. A trough space of 80 cm per animal was assigned, and residual concentrates left after feeding (if any) were weighed and sampled for DM estimation (oven-dried at 60 °C for 48 h until constant weight). Animal group concentrate DM intake was estimated from pre- and post-feeding measurements.

Animals were weighed unfasted (within 1 hour of removal from grazing) fortnightly and after a 15-h fast at the end of the trial. Fortnightly animal live weights were used to adjust herbage and concentrate allowances. Measurements of grazing behaviour were carried out on days 25 and 33 of the trial. All individual animals (identified with a phosphorescent number painted on both sides for night observation) were observed once every 10 min. and their activities were recorded as grazing, ruminating or idling over a 24-h period (Hodgson 1982). Biting rates were recorded for individual animals at their peak grazing times (morning and afternoon), by measuring the time to make 20 prehension bites (Hodgson 1982), averaging three measurements for each animal, and then using this information to compute the daily number of bites.

On day 14 all animals were dosed with n-alkane capsules (Captec® 150-300 kg LW) containing dotriacontane (C₃₂) and hexatriacontane (C₃₆) with a constant release rate for each n-alkane of 200 mg d⁻¹. Routines for sampling and estimation of individual intake and digestibility were carried out as described by Dove & Mayes (1991). The capsules had an active period of 20 days and two independent measurements of intake and behaviour measurement were made at days 7 to 12 and 15 to 19 post-application. During each period of intake recording, faecal samples were collected daily during morning or evening observation (2-h periods) of animals defecating (Morris et al. 1993). Samples were freeze-stored and compounded within each animal over the 5-day period of collection. After defreezing, they were ground through a mill (1 mm) and analysed for n-alkane composition by gas chromatography (Mayes et al. 1986). The ¹³C was estimated (only for the period 15-19 days) from organic matter content by mass spectrometry (Finnigan Mat DeltaS, Laboratory of isotopes, INGEIS-UBA).

Individual herbage and maize intakes were estimated by using the iterative alkane

& ^{13}C method (Garcia et al. 2000). As soybean meal was added, concentrate intake was estimated using the $\delta^{13}\text{C}_{\text{concentrate}}$ (weighted average of $\delta^{13}\text{C}_{\text{maize}}$ and $\delta^{13}\text{C}_{\text{soybean}}$ from the known proportion fed in the troughs, 65 and 77 % maize for LHA-M₁ and LHA-M₂ respectively), assuming no selection between them. This assumption seemed valid from field observations, as the cracked wet maize grain mixed well with the soybean meal. Individual maize intake was estimated from individual concentrate intake and maize proportion in the mixture. In the case of those treatments supplemented with soybean meal only, differences between $\delta^{13}\text{C}_{\text{soybean}}$ and $\delta^{13}\text{C}_{\text{herbage}}$ (Table 1), although both were C₃ foods, allowed the use of the alkanes & ^{13}C technique. In unreplicated supplementation trials the grazing only group acts as the control for estimating the substitution rate. In the current trial, to estimate individual substitution rates associated with maize intake, an average “basal” herbage intake was calculated from animals allocated to both replicates of treatment LHA, and individual differences from this basal level were calculated for supplemented animals. From these herbage intake differences (kg) and maize intakes (kg), individual substitution rates were estimated.

The following variables were estimated from grazing behaviour observations, individual herbage intake, individual diet digestibility and animal liveweight: bite weight (g DM bite⁻¹), daily energy intake (MJ ME d⁻¹), and harvesting rate (HR) as g DM eaten kg LW⁻¹ min. spent grazing⁻¹ (Krysl & Hess 1993).

2.3. Herbage sampling and chemical analysis

During each intake measurement period, thirty hand-plucked herbage samples representing the diet for each replicated plot were obtained daily. Herbage samples were pooled within each replicate by sampling period (i.e one per replicate for 5 days) as described by Garcia et al. (2000). Samples were sealed in polythene bags and taken to the laboratory in an icebox. Part of the sample was freeze-dried, ground (1mm screen) and divided into two sub-samples. The first was analysed for n-alkane composition, and the second analyzed for dry matter *in vitro* digestibility (Dig %) (Tilley & Terry 1962) and crude protein (CP %) by Micro Kjeldhal. To determine the organic matter (OM) fraction the dry matter was subsequently ashed in a muffle furnace at 550 C°. The second part of the pooled sample was divided into two. The first was completely sorted by hand into tall fescue and white clover,

and then into their component parts, i.e. lamina, sheath & stem and dead (tall fescue) and leaflet, petiole & stolon and dead in white clover. These components were dried in an oven until constant weight (60 °C for 48 h) and expressed as fraction of dry matter. The rest of the sample was also oven dried and preserved for ^{13}C determination.

2.4. Statistical analysis

Measurements of pasture were analysed under a completely random design. A repeated measures design was used to analyse the behavioural variables, using treatment replicates (grazing plots) as experimental units in both designs. In the repeated measures design, the PROC MIXED procedure and ESTIMATE and CONTRAST statements for comparing means were used (Littell et al. 1998). Pre-planned contrasts included linear and quadratic contrasts for maize level for the groups fed at low herbage allowance (LHA, LHA-M₁ and LHA-M₂). The other animal variables were analysed using PROC GLM in a randomized design with animals as experimental units, and with pre-planned contrasts as stated above. Following a significant F-test ($P < 0.05$), least squares means were separated using least significant differences (Steel & Torrie 1980). All analyses were performed using SAS/STAT (2001).

3. Results

3.1. Herbage and concentrate intake and animal performance

Chemical composition, concentration of dominant n-alkanes and $\delta^{13}\text{C}$ in herbage and supplement are presented in Table 1. The pasture was dominated by *F. arundinacea* (0.96 ± 0.01 fraction of total DM), and the whole canopy morphological composition was made up 0.46 ± 0.03 , 0.35 ± 0.05 and 0.19 ± 0.03 fractions of total DM of leaf, stem and dead components, respectively.

Table 1. Chemical composition, concentration of dominant n-alkane and concentration of $\delta^{13}\text{C}$ in the utilised feeds.

Forage	DM	CP	Dig	OM	C ₂₉	C ₃₁	C ₃₃	$\delta^{13}\text{C}$
	%				mg 100 g DM ⁻¹			‰
Herbage	35.2	13.6	61.2	87.3	251.5	499.2	11.8	-28.2
Wet maize grain	73.7	9.3	85.3	96.5	1.1	0.8	0.6	-11.1
Soybean meal	88.0	41.3	92.2	92.3	3.1	2.7	2.2	-25.0

DM= dry matter, CP= crude protein, Dig= *in vitro* DM Digestibility, OM= organic matter, C₂₉=nonacosane, C₃₁= hentriacontane, C₃₃=trtriacontane, $\delta^{13}\text{C}$ = abundance of ^{13}C relative to a carbonate standard.

Table 2. Effects of two herbage allowances and three supplement levels in heifers on different parameters associated with animal performance.

	LHA	LHA-M ₁	LHA-M ₂	MHA	#PSE	Sig.	M _{Linear}
Pre-grazing mass (kg ha ⁻¹)	5330	4930	5420	4940	178	NS	NS
Post-grazing mass (kg ha ⁻¹)	1230 ^a	1370 ^a	1670 ^b	2460 ^c	106	**	**
\square DM disappearance							
Herbage intake (kg DM d ⁻¹)	4.8 ^a	4.7 ^a	4.2 ^a	6.5 ^b	0.24	**	NS
Maize intake (kg DM d ⁻¹)	-	1.33 ^a	2.76 ^b	-	0.03	**	-
Total intake (kg DM d ⁻¹)	5.4 ^a	6.7 ^b	7.7 ^c	7.1 ^{bc}	0.25	**	**
Substitution rate (kg DM herbage kg DM maize grain ⁻¹)	-	0.13	0.24	-	0.12	NS	-
<u>n-alkane & $\delta^{13}\text{C}$</u>							
Herbage intake (kg DM d ⁻¹)	3.3 ^a	2.9 ^a	2.6 ^a	4.6 ^b	0.17	**	*
Maize intake (kg DM d ⁻¹)	-	1.15 ^a	2.54 ^b	-	0.25	**	-
Total intake (kg DM d ⁻¹)	3.6 ^a	4.5 ^b	5.8 ^d	5.0 ^c	0.24	**	***
Maize in diet (% LW d ⁻¹)	-	0.5 ^a	1.00 ^b	-	0.002	**	-
Diet digestibility	0.68 ^a	0.69 ^a	0.76 ^b	0.68 ^a	0.01	•	***
Substitution rate (kg DM herbage kg DM maize grain ⁻¹)	-	0.39	0.33	-	0.24	NS	-
ME intake (MJ ME d ⁻¹)	37.5 ^a	46.9 ^b	67.1 ^c	51.5 ^b	2.29	**	***
Final LW (kg)	235 ^a	249 ^{ab}	272 ^b	256 ^{ab}	8.38	•	**
LWG (kg d ⁻¹)	0.25 ^a	0.62 ^b	1.01 ^c	0.65 ^b	0.08	**	**
Fasted LW loss (% full LW)	4.8 ^a	4.2 ^a	4.7 ^a	6.6 ^b	0.60	•	NS

LHA= 2.5 % LW d⁻¹ herbage DM allowance, LHA-M₁ = LHA plus 0.5 % LW DM maize grain d⁻¹, LHA-M₂ = LHA plus 1.0 % LW maize grain d⁻¹, MHA= 5.0 % LW d⁻¹ herbage allowance, #PSE= pooled standard error, Sig.= significance level, M_{Linear} = linear contrast of maize level effect, \square DM disappearance= pre-post-grazing dry matter difference, different letters within a row indicate significant differences (P<0.05), NS = no significant difference (P>0.1), •=P<0.05, **=P<0.01 and ***=P<0.01.

Herbage intake and total DM intake estimated by the pre- and post-grazing difference method were significantly higher (P<0.05) in MHA than in LHA (Table 2). Herbage and total DM intake estimated from the n-alkane technique followed similar patterns, but n-alkane estimations were lower in all treatments than difference values, and there was a linear declination of herbage intake (p<0.05) as level of maize fed increased. Additionally, total DM intake estimated using the n-alkane method was significantly higher (P<0.01) on LHA than LHA-M₁.

The precision of the two methods used for assessing ME intake versus the

theoretical metabolisable energy requirements for the level of performance attained, was tested. The treatment means of ME eaten estimated alternatively from the alkane & ^{13}C method (ME-alk) and from the pre- and post-grazing difference method and feed qualities (ME-diff), were regressed on predicted ME requirements (AFRC 1993) calculated from animal liveweights and LWG (ME-req) taken as independent data (Mayer & Butler 1993). In both cases the regressions fitted significantly ($P < 0.01$) for ME-alk ($R^2 = 0.98$, $\text{RMSE} = 1.9$) and ME-diff ($R^2 = 0.99$, $\text{RMSE} = 1.35$), and the intercepts were not significantly different from zero ($P > 0.05$). When they were forced through the origin both were significant at $P < 0.01$ (ME-alk $R^2 = 0.99$, $\text{RMSE} = 1.7$; ME-diff $R^2 = 0.99$, $\text{RMSE} = 1.83$), but only the slope of ME-alk (0.99 ± 0.01) was not different from unity ($P > 0.05$), which leads to $\text{ME-alk} = \text{ME-req}$ ($P > 0.05$). The ME-diff had a slope coefficient of 0.72 ± 0.01 , which was significantly lower than 1.0 ($P < 0.01$).

In vivo digestibility of the whole diet increased linearly with increasing maize levels fed, while there was no significant difference ($P > 0.05$) between LHA and MHA. The combined effect of total intake and whole diet digestibility produced a higher ME intake in MHA than LHA. Similarly, ME intake increased linearly as the level of maize grain fed was increased (Table 2).

Individual substitution rates ($\text{kg DM herbage kg DM maize}^{-1}$, soybean meal fed excluded) were not affected by maize supplementation level ($P > 0.1$), averaging 0.36 between LHA- M_1 and LHA- M_2 when intakes were estimated using the alkane & ^{13}C method (Table 2). Pre-grazing herbage mass was similar between treatments but, as a consequence of different rates of sward depletion, post-grazing residuals were higher for MHA than LHA, and increased linearly as the level of maize fed increased (Table 2). The amount of soybean meal fed (estimated from n-alkane and ^{13}C method) was significantly higher ($P < 0.05$) in LHA- M_2 (0.7 kg DM d^{-1}) than the rest of the treatments ($0.37, 0.40, 0.45 \text{ kg DM d}^{-1}$ for LHA, LHA- M_1 and MHA, respectively). This gave a crude protein level in the diet of 16.7, 14.9, 15.1 and 16.0 % DM for LHA, LHA- M_1 , LHA- M_2 and MHA, respectively. Individual substitution rates including soybean meal were 0.29 and $0.25 (\pm 0.18 \text{ PSE}) \text{ kg DM herbage kg DM supplement}^{-1}$ for LHA- M_1 and LHA- M_2 , respectively.

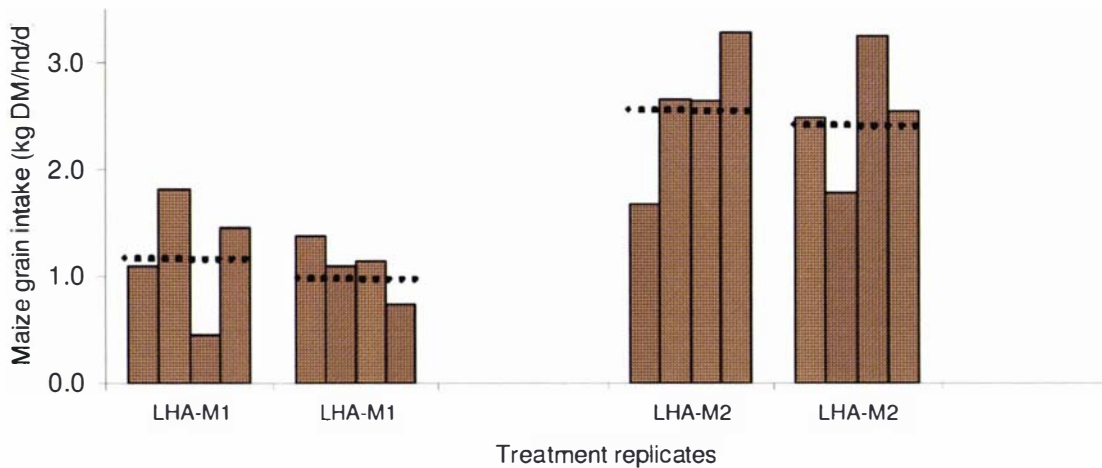


Figure 1. Individual maize grain intakes as recorded within each treatment replicate.

Dotted lines indicate mean values for each replicate. LHA-M₁ = 2.5 % LW d⁻¹ herbage DM allowance plus 0.5 % LW DM maize grain d⁻¹, LHA-M₂ = 2.5 % LW d⁻¹ herbage DM allowance plus 1.0 % LW maize grain d⁻¹.

Mean individual maize DM intakes were 1.15 ± 0.2 and 2.54 ± 0.12 kg d⁻¹ for LHA-M₁ and LHA-M₂ respectively (Figure 1). Final liveweight and liveweight gains were higher in MHA than in LHA, and increased linearly ($P < 0.01$) with the level of maize grain fed (Table 2). The coefficient of variation (CV) of LWG tended to decrease with the level of maize fed, with values of 73, 37 and 30 % for LHA, LHA-M₁ and LHA-M₂, respectively. The lowest CV in LWG was in MHA (21%). Within each supplemented treatment, individual LWG was associated linearly ($P < 0.05$) to individual maize intake (R^2 of 0.77 and 0.61 for LHA-M₁ and LHA-M₂, respectively). Animals on MHA had higher fasting weight losses than those on LHA, and the level of maize grain did not affect the fasting weight losses. None of the quadratic trends for analyzed variables in this study reached significance ($P > 0.05$).

3.2. Animal behaviour

Animals grazing treatments MHA and LHA spent a similar time ($P > 0.05$) grazing and eating soybean meal, and had a similar biting rate (Table 3). Animals in MHA ruminated more and spent less time idling, and grazed longer during the night (+40 min). At LHA, animals grazed longer during daylight hours (+41 min), principally after groups were shifted in the morning to a new grazing strip (Figure 2). Maize supplementation decreased the daily grazing time linearly (-57 min. kg maize⁻¹), and increased idling time and the time spent eating the supplement linearly. Maize

supplementation decreased (linearly) the number of bites per day. Bite weight and harvesting rate (g DM eaten kg LW⁻¹ min. spent grazing⁻¹) were higher in MHA than in LHA, and were increased (linearly) by maize feeding level.

Table 3. Effect of herbage allowance (LHA and MHA) and maize supplementation (LHA-M₁ and LHA-M₂) on grazing behaviour of heifers.

	LHA	LHA-M ₁	LHA-M ₂	MHA	#PSE	Sig	M-Linear
Whole day:							
Grazing time (min.)	374 ^c	281 ^b	226 ^a	373 ^c	14.5	**	**
Ruminating time (min.)	341 ^a	313 ^a	323 ^a	416 ^b	15.3	**	NS
Idling time (min)	714 ^a	827 ^b	863 ^b	638 ^a	24.6	**	**
Supp. Time (min)	11 ^a	19 ^b	28 ^c	13 ^a	1.2	**	**
Biting rate (bites min ⁻¹)	51	48	43	51	5.2	NS	NS
Bite number (bites d ⁻¹)	19074 ^b	13488 ^b	9718 ^a	19023 ^c	1356	**	**
Bite weight (mg bites ⁻¹)	162 ^a	203 ^b	258 ^d	238 ^c	7.5	**	*
HE (g DM eaten kg LW ⁻¹ min. grazing ⁻¹)	0.037 ^a	0.039 ^{ab}	0.045 ^b	0.053 ^c	0.003	**	*
Daylight period (7:00 am-5:59 pm)							
Grazing time (min)	294 ^c	223 ^{ab}	196 ^a	253 ^{bc}	13.8	**	**
Ruminating time (min)	78 ^a	92 ^b	109 ^b	127 ^c	5.6	**	**
Idling time (min)	277 ^{ab}	326 ^b	327 ^b	267 ^a	15.6	**	**
Supp. Time (min)	11 ^a	19 ^b	28 ^c	13 ^a	1.1	**	**
Morning period (7:00 pm –0:59 pm)							
Grazing time (min.)	168 ^b	129 ^a	113 ^a	124 ^a	10.9	*	**
Ruminating time (min)	27 ^a	25 ^a	37 ^{bc}	47 ^c	3.7	*	NS
Idling time (min)	105 ^a	146 ^b	150 ^b	129 ^{ab}	9.7	*	*
Afternoon period (0:59 pm – 5:59 pm)							
Grazing time (min)	125 ^b	94 ^a	85 ^a	129 ^b	8.8	**	*
Ruminating time (min)	52	68	72	80	12.9	NS	NS
Idling time (min)	172 ^b	180 ^b	176 ^b	138 ^a	7.9	*	NS
Supp. Time (min)	11 ^a	19 ^a	28 ^b	13 ^a	2.7	**	**
Night period (6:00 pm – 6:59 am)							
Grazing time (min)	81 ^b	58 ^{ab}	31 ^a	121 ^c	9.6	**	**
Ruminating time (min)	262 ^b	221 ^{ab}	214 ^a	289 ^c	13.6	**	+
Idling time (min)	437 ^b	501 ^c	535 ^c	370 ^a	15.5	**	•

LHA= 2.5 % LW d⁻¹ herbage allowance, LHA-M₁ = LHA plus 0.5 % LW maize grain d⁻¹, LHA-M₂ = LHA plus 1.0 % LW maize grain d⁻¹, MHA= 5.0 % LW d⁻¹ herbage allowance, #PSE= pooled standard error, Sig.= significance level, M_{Linear} = linear contrast of maize level effect, different letters within a row indicate significant differences (P<0.05), NS = no significant difference (P>0.1), += P<0.1, * =P<0.05, **=P<0.01.

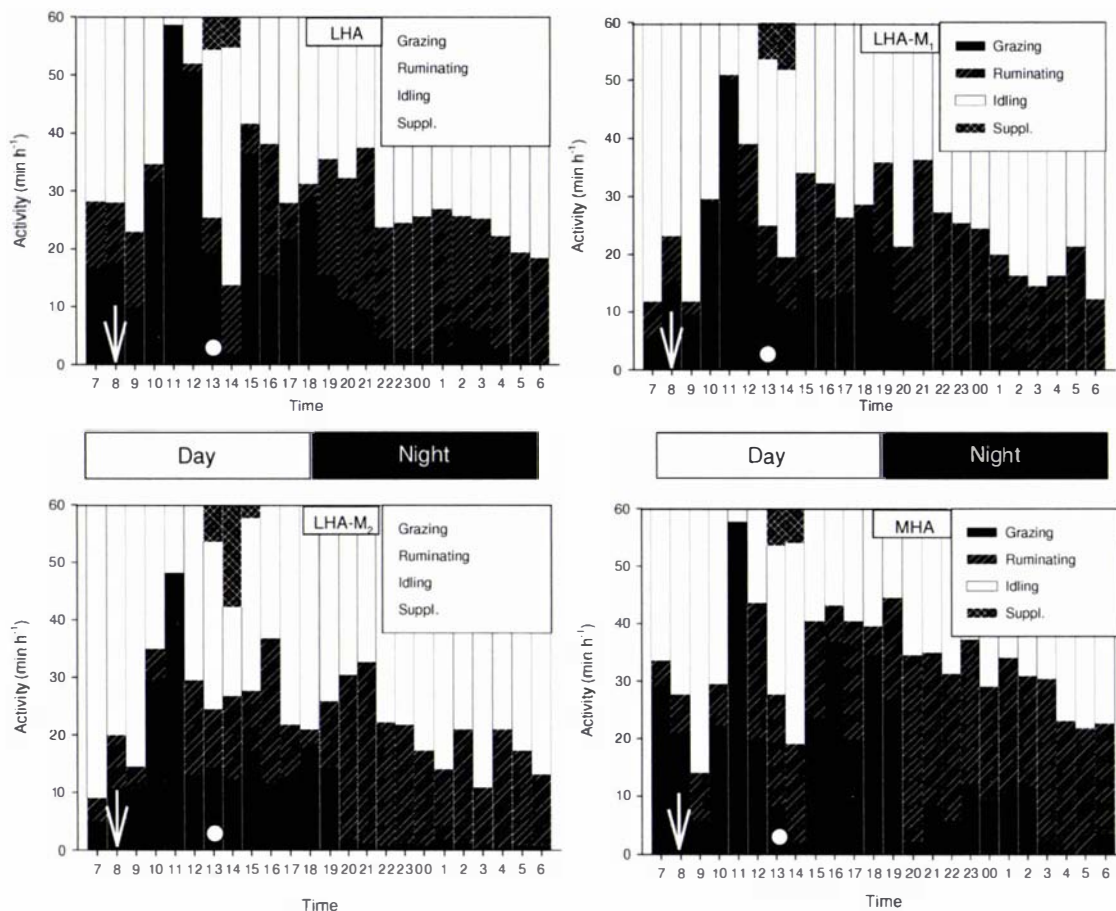


Figure 2. Effect of herbage allowance and maize supplementation on grazing behaviour of heifers throughout the day.

Treatments details are explained in material and methods. White arrows indicate time when animals were shifted to a new strip (8:00 am), and white circles indicate time when supplements were fed (1:00 pm). Each bar represent a mean of two replicates of 4-5 animals measured on two different days.

4. Discussion

Refusals of maize grain and soybean meal were negligible. The quantity of maize DM fed was lower than originally planned (0.6 and 1.2 % LW d⁻¹), but differences were maintained at a factor of 2 (0.5 and 1.0 % of LW for LHA-M₁ and LHA-M₂ respectively), and reached a level that did not jeopardize the objectives of the trial. This is partly explained by the fact that grain allocation was adjusted every 15 days when the animals were weighed. Diets were not isonitrogenous, but in all treatments dietary nitrogen content exceeded values considered adequate for this animal class (Hodgson & Brookes 1999).

Maize feeding reduced herbage intake linearly and consequently increased post-

grazing residuals, which agrees with other reports (Horn & McCollum 1987; Mayne 1988; Robaina et al. 1998). If herbage intake expressed as $\text{kg kg LW}^{-1} \text{d}^{-1}$ instead of kg d^{-1} is used for SR estimations to avoid any bias from the different liveweights (i.e. unsupplemented animals were lighter), substitution rates of 0.29 and 0.38 (± 0.19 PSE) were obtained for LHA-M₁ and LHA-M₂, respectively. These values differ slightly from those estimated using the absolute herbage intakes (Table 2), but these differences could increase in longer supplementation trials where the LW of control and supplemented animals differ more than in the present trial. Substitution rates did not change significantly across the different maize levels for both methods of intake estimation (Table 2). Adding the soybean meal eaten in the individual SR estimation did not significantly affect the results ($P > 0.05$), with a slightly lower SR (average of 0.27 kg DM herbage kg DM maize plus soybean meal⁻¹) than when only maize grain was used (Table 2). The lack of effect of level of supplementation on SR agrees with the findings of Opatpatanakit et al. (1993), who fed 0, 4 and 8 kg d⁻¹ of rolled barley to dairy cows, and Elizalde et al. (1999) who fed steers fresh alfalfa indoors together with cracked maize at 0, 0.6 and 1.2 % LW d⁻¹. However in terms of absolute values, the substitution rate obtained in the current study (average of 0.36 kg DM herbage kg DM maize⁻¹) is low compared with the value of 0.63 obtained by Opatpatanakit et al. (1993) and the 0.69 found by Elizalde et al. (1999). Differences between these trials are likely to be associated with the lower herbage allowance (2.5% LW above ground level d⁻¹) in the current study. A direct positive relationship between herbage allowance and substitution rate has been demonstrated for dairy cows (Meijs & Hoeskstra 1984; Grainger & Matthews 1989) and in beef cattle (French et al. 2001b).

The pre- and post-grazing difference method consistently overestimated herbage intake when the n-alkane & 13C method was taken as a reference (Table 2), a result which is in agreement with previous findings (Reeves et al. 1996; Garcia 2000). These authors mentioned herbage treading losses as one of the likely causes for overestimation of intake from herbage measurements. The n-alkane & 13C intake method was considered a better indicator of intake than the pre- and post-grazing difference method. The ME eaten (MJ ME d⁻¹) estimated by n-alkane & 13C was in very close agreement with the ME requirement predicted (AFRC 1993) from recorded LWG and animal liveweight during the study, whereas sward-

based estimates were consistently 37% higher than that estimated from ME requirements predicted.

A direct effect of maize supplementation was to reduce grazing time and increase idling time, which is in agreement with most research (Allden 1981; Leaver 1986; Gekara et al. 2002). The decline in grazing time of 57 min kg DM maize⁻¹ in this study is much higher than the 7.5 min kg DM supp.⁻¹ estimated from a linear adjustment after Gekara et al. (2002), and the 3-30 and the 20-23 min. kg DM supp.⁻¹ found by Leaver (1986) and Mayne (1988), respectively. Reasons for such a high depression in this trial are not clear. The linear decline in grazing time was evident at all times of the day, but effects were more marked during daylight hours and particularly in the afternoon (after supplement feeding), with slopes of -37 and -21 min. kg DM maize⁻¹ respectively (Table 3). This behaviour could be associated with the induction of a satiety-regulating mechanism as suggested by Baile & McLaughlin (1987), hence decreasing the drive for grazing although there was herbage available for the animals.

Digestibility of total diet increased linearly with increasing maize level fed, which is in agreement with the experiment 2 of Robaina et al. (1998), who fed dairy cows 0 or 6.7 kg of a barley-based supplement at two herbage allowances. Since grain was more digestible than herbage (Table 1), this response was expected (Dixon & Stockdale 1999).

Liveweight gains increased linearly with increasing level of maize fed, with an increment above unsupplemented control of 0.3 kg LWG d⁻¹ kg DM maize⁻¹ for both LHA-M₁ and LHA-M₂. This is similar to the mean of 0.22 kg LWG d⁻¹ kg DM maize⁻¹ found by Boom & Sheath (1998), when 1 to 2 kg of maize was fed to steers during summer and winter, and the 0.23 kg LWG d⁻¹ kg DM maize⁻¹ estimated from Aiken (2002), and higher than the 0.1 kg LWG d⁻¹ kg DM maize⁻¹ estimated from Lake et al. (1974). Although more complex mechanisms involving sites of digestion and rumen energy and protein asynchronies may be operating (Horn & McCollum 1987; Dixon & Stockdale 1999), it is likely that the degree of improvement in the various trials is mostly related to how the animals were performing without grain feeding (Reardon 1975). A productive response to grain feeding in this trial is likely to be

associated with at least four factors. Firstly, the decline in grazing time may lead to a decrease in energy expenditure (Caton & Dhuyvetter 1997) that is potentially related to liveweight gain. The decline in grazing time is also associated with a less than proportional decline in herbage intake, meaning that the efficiency of harvesting the forage, expressed in g DM eaten kg LW⁻¹ min. spent grazing⁻¹ (Krysl & Hess 1993), significantly increased (Table 3). Secondly, there was a linear increase in total ME eaten. Thirdly, the ME provided by the grain may increase the overall efficiency of energy use (NRC 2000). Fourthly, heifers in the present trial were dosed with a progesterone anabolic to avoid grazing behaviour disturbance and this may have increased LWG. Improvement in LWG of around 5% could be expected from using this compound (Duckett & Andrae 2001).

Treatment MHA resulted in the highest herbage intake, which led to an extra LWG of 0.23 kg LWG d⁻¹ kg DM extra herbage⁻¹. However, MHA was used in this study as a positive control, rather than a real option for the farmer in a season where forage scarcity is frequent. The reduction of forage intake (and increase of herbage residuals) when supplements are fed is not necessarily undesirable depending on the situation, i.e. when the objective is to extend the use of existing herbage in the paddocks (Horn & McCollum 1987). The quantitative effect of extra residual herbage mass on herbage production during autumn and winter has been estimated by Matthew et al. (1995) under New Zealand conditions as 2 kg DM ha⁻¹ d⁻¹ for every 100 kg DM ha⁻¹ increase in herbage residual, over the range 1000-2000 kg DM ha⁻¹.

Individual maize intake under group fed conditions resulted in coefficients of variation of 36.4 % in LHA-M₁ and 24.8 % in LHA-M₂. The recorded variation is in agreement with the 36% CV reported by Garcia et al. (2000) for dairy cows. The variability of individual intake of supplements within each treatment was linearly associated to final LWG (average of R²=0.69, P<0.05). The improved feeding conditions resulting from maize supplementation or by increasing herbage allowance to a level of 5% LW, tended to decrease the variability in animal LWG. A CV in LWG of up to 86% during winter in intensive beef systems has been reported (Cosgrove et al. 2003). Current changes in market characteristics where the value of high carcass grading and timeliness of supply are increasing,

emphasize the importance of consistency and predictability of performance (McRae 2003). Winter grain feeding allows the maintenance of a high stocking rate, that contributes to a high herbage utilization during the spring period (Rearte & Pieroni 2001), and the advantages of reducing LWG variation by grain feeding should be taken into account for whole system evaluation.

Increasing the level of concentrates fed has caused lower shrunk liveweight losses in steers (Machado et al. 2001) and lambs (Karnazos et al. 1994). However no effects were found in the present trial. Animals grazing LHA had lower shrunk live weight losses than animals in MHA. This is likely to be associated to the differences in herbage intakes (Table 2), as higher forage intake increases digesta volume (Luginbuhl et al. 1994).

5. Conclusions and implications

Including maize grain up to a level of 1.0 % LW per day (DM) in animals grazing a low herbage DM allowance (2.5 % LW d⁻¹), resulted in consistent substitution rates (0.36 kg DM herbage kg DM maize⁻¹) and a linear increase in LWG. When animals grazed a moderate herbage DM allowance (5.0 % LW d⁻¹), animal performance was equivalent to the feeding of low-level maize DM supplementation (0.5 % LW d⁻¹) on a low herbage allowance. Prediction of ME intake from the alkane & 13C technique gave similar results to the theoretical energy requirements for the animal performance achieved, and allowed (without the need of adding others markers) identification of an important within-group variability in maize intake, which associated positively with LWG. Feeding maize also tended to decrease LWG variability. The results support evidence from the literature that supplements fed to grazing animals usually depress herbage intake and grazing time, increase animal performance and decrease LWG variability.

References

- AFRC. 1993: Energy and protein requirements of ruminants. *Published by the AFRC Technical Committee on Response to Nutrients*:176 p.
- Aiken G. E. 2002: Cost of steer weight gain to rate of supplementation with ground

- corn. *Agronomy Journal* 94:1387-1392.
- Allden W. G. 1981: Energy and protein supplements for grazing livestock. *In: Morley, F.H.W. Ed. World Animal Science, B.I. Grazing Animals*. Elsevier Science Publishers:289-307 .
- Baile C. A.; McLaughlin C. L. 1987: Mechanisms controlling feeding intake in ruminants. *Journal of Animal Science* 64:915-922.
- Boom C. J.; Sheath G. W. 1998: Grain supplementation of finishing beef cattle. *Proceedings of the New Zealand Society of Animal Production* 58:239-242.
- Bowman J. G. P.; Sowell B. F. 1997: Delivery method and supplement consumption by grazing ruminants: a review. *Journal of Animal Science* 75:543-550.
- Caton J.; Dhuyvetter D. 1997: Influence of energy supplementation on grazing ruminants: requirements and responses. *Journal of Animal Science* 75:533-542.
- Cosgrove G. P.; Clark D. A.; Lambert M. G. 2003: High production dairy-beef cattle grazing systems: a review of research in the Manawatu. *Proceedings of the New Zealand Grassland Association* 65:17-20.
- Curtis K. M. S.; Holst P. J.; Murray P. J. 1994: Measuring supplement intake in the field using ytterbium as a marker. *Australian Journal of Experimental Agriculture* 34:339-343.
- Dixon R. M.; Stockdale R. C. 1999: Associative effects between forages and grains: consequences for feed utilisation. *Australian Journal of Agricultural Research* 50:757-753.
- Dove H. 1996: Constraints to the modelling of diet selection and intake in the grazing ruminant. *Australian Journal of Agricultural Research* 47:257-275.
- Dove H.; Mayes R. 1991: The use of wax alkanes as marker substances in studies of the nutrition of herbivores: a review. *Australian Journal of Agricultural Research* 42:913-952.

- Dove H.; Mayes R. W. 1996: Plant wax components: a new approach to estimating intake and diet composition in herbivores: a review. *Journal of Nutrition* 126:13-26.
- Duckett S. K.; Andrae J. G. 2001: Implant strategies in an integrated beef production system. *Journal of Animal Science* 79 (E.Suppl):E110-E117.
- Earle D.; McGowan A. 1979: Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19:337-343.
- Elizalde J. C.; Merchen N. R.; Faulkner D. B. 1999: Supplemental cracked corn for steers fed fresh alfalfa: I. Effects on digestion of organic matter, fiber, and starch. *Journal of Animal Science* 77:457-466.
- Frame J. 1981: Herbage Mass. In: Hodgson, J.; Baker R.D; Davis, A.; Laidlaw, A.S. ; Leaver, J.D. Eds. *Sward Measurement Handbook*. British Grassland Society: Berkshire, UK. 35-70.
- French P.; O'Riordan M. A.; O'Kiely P. O.; Caffrey P. J. 2001a: Effects of concentrate level and grazing system on the performance of beef cattle grazing autumn herbage. *Irish Journal of Agricultural and Food Research* 40: 33-44.
- French P.; O'Riordan M. A.; O'Kiely P. O.; Caffrey P. J.; Moloney A. P. 2001b: Intake and growth of steers offered different allowances of autumn grass and concentrates. *Animal Science* 72:129-138.
- Garcia S. C. 2000: System, component, and modelling studies of pasture-based dairy systems in which the cows calve at different times of the year. *PhD Thesis. Massey University, New Zealand*: 203 p.
- Garcia S. C.; Holmes C. W.; Hodgson J.; MacDonald K. A. 2000: The combination of the n-alkanes and ^{13}C techniques to estimate individual dry matter intakes of pasture and maize silage by grazing dairy cows. *Journal of Agricultural Science, Cambridge* 135: 47-55.
- Gekara O. J.; Prigge E. C.; Bryan W. B.; Schettini M.; Nestor E. L.; Townsend E. C.

- 2002: Influence of pasture sward height and concentrate supplementation on intake, digestibility, and grazing time of lactating beef cows. *Journal of Animal Science* 79:745-752.
- Grainger C.; Matthews G. L. 1989: Positive relation between substitution rate and pasture allowance for cows receiving concentrates. *Australian Journal of Experimental Agriculture* 29:355-360.
- Hodgson J. 1982: Ingestive behaviour. In: Leaver, J. Ed. *Herbage Intake Handbook*. British Grassland Society. Hurley, United Kingdom. 113-139.
- Hodgson J. 1984: Sward conditions, herbage allowance and animal production. *Proceedings of the New Zealand Society of Animal Production* 44: 99-104.
- Hodgson J.; Brookes I. M. 1999: Nutrition of grazing animals. In: White, J. & Hodgson, J. Eds. *New Zealand Pasture and Crop Science*. Oxford University press. 117-132.
- Horn G. W.; McCollum F. T. 1987: Energy supplementation of grazing ruminants, July 23-24. *Proceedings of the Grazing Livestock Nutrition Conference*:125-136.
- Jones R. J.; Ludlow M. M.; Troughton J. H.; Blunt C. G. 1979: Estimation of the proportion of C³ and C⁴ plant species in the diet of animals from the ratio of natural ¹²C and ¹³C isotopes in the faeces. *Journal of Agricultural Science, Cambridge* 92:91-100.
- Karnezos T. P.; Matches A. G.; Preston R. L.; Brown C. P. 1994: Corn supplementation of lambs grazing alfalfa. *Journal of Animal Science* 72:783-789.
- Krysl L. J.; Hess B. W. 1993: Influence of supplementation on behavior of grazing cattle. *Journal of Animal Science* 71:2546-2555.
- Lake R. P.; Hildebrand R. L.; Clanton D. C.; Jones L. E. 1974: Limited energy supplementation of yearling steers grazing irrigated pasture and subsequent feedlot performance. *Journal of Animal Science* 39:5:827-833.

- Leaver J. D. 1986: Effect of supplements on herbage intake and performance. *In: J. Frame Ed. Grazing Occasional Symposium. No.19, British Grassland Society, Berkshire, UK. 79-88.*
- Littell R. C.; Henry P. R.; Ammerman C. B. 1998: Statistical analysis of repeated measures data using SAS procedures. *Journal of Animal Science 76:1216-1231.*
- Luginbuhl J.-M.; Pond K. R.; Burns J. C. 1994: Whole-tract digesta kinetics and comparison of techniques for the estimation of fecal output in steers fed coastal bermudagrass hay at four level of intake. *J. Anim. Sci. 72:201-211.*
- Machado C.; Striebeck G.; Vasolo V.; Di Croce F.; Gonzalez F.; Duhalde J.; Parente M.; Auza N. 2001: Suplementación de grano de maíz en pastoreo y a corral como alternativas de terminación de novillos en el verano. *Avances En Producción Animal 26:139-146.*
- Matthew C.; Hodgson J.; Matthews P. N. 1995: Growth of pastures principles and their application. *Dairyfarming Annual, Massey University 47:122-129.*
- Mayer D. G.; Butler D. G. 1993: Statistical validation. *Ecological Modelling 68:21-32.*
- Mayes R.; Lamb C.; Colgrove P. 1986: The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. *Journal of Agricultural Science, Cambridge 107:161-170.*
- Mayne C. S. 1988: Effects of supplementation on the performance of both growing and lactating cattle at pasture. *In: Frame, J. Ed. Efficient Beef Production from Grass. Occasional Symposium. No.25, British Grassland Society, Berkshire, UK. 55-71.*
- McRae A. F. 2003: Historical and practical aspects of profitability in commercial beef production systems. *Proceedings of the New Zealand Grassland Association 65:29-34.*
- Meijs J. A. C.; Hoeskstra J. A. 1984: Concentrate supplementation of grazing dairy cows. 1. Effects of concentrate intake and herbage allowance on herbage

- intake. *Grass and Forage Science* 39:59-66.
- Morris S. T.; Parker W. J.; Grant D. A. 1993: Herbage intake, liveweight gain, and grazing behavior of Friesian, Piedmontese x Friesian, and Belgian Blue x Friesian bulls. *New Zealand Journal of Agricultural Research* 36:231-236.
- Moshtaghi Nia S. A.; Wittenenberk K. M. 2002: Evaluation of n-alkanes as markers for estimation of dry matter intake and digestibility in steers consuming all-forage or forage-concentrate diets. *Canadian Journal of Animal Science* 82:419-425.
- NRC. 2000: Nutrient requirements of beef cattle. *National Research Council. National Academy Press. Washington, D.C.*
- Opatpatanakit Y.; Kellaway R. C.; Lean I. J. 1993: Substitution effects of feeding rolled barley grain to grazing dairy cows. *Animal Feed Science and Technology* 4:25-38.
- Petchey A. M.; Broadbent P. J. 1980: The performance of fattening cattle offered barley and grass silage in various proportions either as discrete feeds or as a complete diet. *Animal Production* 31:251-257.
- Reardon T. F. 1975: Summer feeding of beef cattle. *Proceedings of the Ruakura Farmers' Conference* 27:14-18.
- Rearte D. 1998: Beef cattle production and meat quality on grazing system in temperate regions. *Revista Argentina De Producción Animal* 18:129-142.
- Rearte D.; Pieroni G. A. 2001: Supplementation of temperate pastures. *Proceedings of the XV International Grassland Congress*:679-691.
- Reeves M.; Fulkerson W.; Kellaway R.; Dove H. 1996: A comparison of three techniques to determine the herbage intake of dairy cows grazing kikuyu (*Pennisetum clandestinum*) pasture. *Australian Journal of Experimental Agriculture* 36: 23-30.
- Robaina A. C.; Grainger C.; Moate P.; Taylor J.; Steward J. 1998: Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental*

Agriculture 38:541-549.

SAS/STAT. 2001: Release. 8 SAS. *Inst. Inc., Cary, NC.*

Steel R. G. D.; Torrie J. H. 1980: *Principles and Procedures of Statistics: A Biometrical Approach*. 2nd Ed. McGraw-Hill Publishing Co., New York. 631p.

Tilley J. M. A.; Terry R. A. 1962: two-stage technique for the in vitro digestion of forage crops. *Journal of the British Grassland Society* 18:104-111.

**Effects of herbage allowance and maize grain on
herbage and grain intake, and performance of
Angus steers in late spring**

Abstract

Fifty-four Angus steers (281 ± 22 kg LW) were allocated during late spring (2 November to 29 December) to six replicated treatments in groups of four or five animals in a 3x2 factorial design in a fescue-white clover pasture for 57 days. There were three herbage DM allowances, LHA (2.5% LW d^{-1}), MHA (5% LW d^{-1}) and HHA (7.5% LW d^{-1}), and two levels of group-fed DM maize grain M_0 (0% LW d^{-1}) and M_1 (0.5% LW d^{-1}). Animals were weighed unfasted fortnightly and after a 15-h fast at the end of the trial. Estimates of herbage and maize intake were obtained using the difference between feed offered and feed residuals and with a method combining n-alkane capsules (Captec®) and ^{13}C . Herbage residuals increased linearly ($P < 0.01$) when herbage allowance increased (from 1240 to 1710 kg DM ha^{-1} for LHA to HHA, respectively) and when maize was fed ($P < 0.05$). Herbage and total intake and ME eaten estimated from n-alkane & ^{13}C method increased ($P < 0.01$) with increasing herbage allowance. *In vivo* dry matter digestibility of the total diet was higher ($P < 0.05$) when maize grain was fed (71 and 77 % for control and maize supplemented treatments, respectively), and increased linearly according to the herbage allowance level. Maize grain intake had an overall mean of 1.2 kg DM d^{-1} , with a coefficient of variation (CV) between individual animals of 41 %. The substitution rate (SR) was quadratically increased by increased levels of herbage allowance from 0.38 to 0.87 when the alkane & ^{13}C method was used. Differences between methods used to estimate SR were detected. The predicted ME requirements from observed animal liveweights and LWG (ME-req), were similar ($P < 0.05$) to ME intake estimated from *in vivo* digestibility and DM intake obtained from the alkane & ^{13}C method. Final liveweight and liveweight gains increased quadratically ($P < 0.05$) with the level of herbage allowance (from 268 kg LW and 0.16 kg d^{-1} at LHA to 291 kg LW and 0.69 kg d^{-1} at HHA, respectively) and maize feeding level increased ($P < 0.05$) LWG by 0.09 kg d^{-1} . The fasting liveweight losses increased significantly ($P < 0.05$) with the level of herbage allowance, with no significant effect of maize feeding. The coefficient of variation of LWG declined with the level of herbage allowance, with values of 107, 34 and 23% for LHA, MHA and HHA, respectively. These findings were compared with the results of Chapters 2 and 3, and the implications of these generalizations discussed.

Keywords: n-alkanes; herbage allowance; feed-intake; maize; liveweight gain; Angus steer

1. Introduction

Direct utilization of the sward by grazing is usually the cheapest option for feeding ruminants. The greater the control the livestock producer exerts over forage production, consumption and matching animal requirements to seasonal forage production cycles, the better are the chances that the operation will be profitable (Forbes 1988). In those systems where grain may be fed profitably in grazing conditions, a productive and efficient use of this resource requires a better understanding of interactions occurring at the plant-animal interface (Dove 1996).

Herbage allowance has been used successfully in rotational grazing systems as an experimental variable to control animal performance (Reardon 1977; Jamieson & Hodgson 1979; Baker et al. 1981; Reid 1986). Animal performance usually increases at a steadily decreasing rate towards a maximum value as herbage allowance (HA) increases, reflecting the effect of HA on herbage intake (Hodgson 1984). Recently, the interest in this variable has been renewed, incorporating more detailed sward descriptions (Dougherty et al. 1989; Kim et al. 1995; Okajima et al. 1996) and estimating herbage intake with n-alkanes (French et al. 2001) or other external markers (Redmon et al. 1995; Delagarde et al. 2000).

The effects of grazing system and levels of herbage allowance on herbage intake, animal performance and herbage utilisation have been studied in beef cattle finishing systems in Argentina (Kloster et al. 2000). In such grazing-based beef cattle finishing systems, grain is frequently used (Rearte 1998; Martinez Ferrer et al. 2002), so it is important to establish some indications of the pattern and logic of the relationship between herbage allowance, grain feeding and animal performance over a wide range of levels. The limited availability of such information usually constrains the development of models (Dove 1996), which are useful when exploring the benefits of alternative grazing systems. Short-term trials were developed to evaluate two levels of herbage allowance (Chapter 2) and repeated including three levels of maize grain fed (Chapter 3). Substitution rate did not

change with the level of grain fed at a herbage allowance of 2.5% LW d⁻¹ (average of 0.36 kg herbage DM kg maize DM⁻¹), and a large variation in the level of individual grain intake (31 % CV) when fed as a group was demonstrated (Chapter 3). This chapter reports the results of a further study on the effect of three levels of herbage allowance in late spring on herbage intake and animal performance of Angus steers group-fed with and without maize grain.

2. Material and Methods

2.1. Treatments

Fifty-four Angus steers (281±22 kg LW) were allocated to six replicated treatments in a 3x2 factorial design in a fescue-white clover pasture for 57 days in late spring. There were three herbage DM allowances, LHA (2.5% LW d⁻¹), MHA (5% LW d⁻¹) and HHA (7.5% LW d⁻¹), and two levels of group-fed DM maize grain, M₀ (0 % LW d⁻¹) and M₁ (0.5 % LW d⁻¹). Each treatment was replicated twice with four to five animals in each replicate group and herbage allowance was expressed as herbage DM mass to ground level as percentage of animal liveweight (Hodgson 1984). The trial was carried out on a commercial farm at Chillar, Azul (37° 19'S 59° 59'W) during late spring (2 November to 29 December) with 15 pre-experimental and 42 experimental days. A uniform pasture was used containing predominantly tall fescue (*Festuca arundinacea*) and white clover (*Trifolium repens*), which was rested in advance for five weeks and received no fertiliser. The paddock was partially flooded during rest, which delayed the start of the study, so the sward was topped at 20 cm height before the experimental period (25 cm before topping). Animals were strip-grazed and moved daily (at 12:00 am) to a fresh strip with no back-grazing of experimental areas. Cracked maize grain was used and it was stored in 45-kg bags, from where the amount needed was extracted daily.

2.2. Measurements

Thirty measurements of pre- and post-grazing herbage mass were taken daily in each replicate using a calibrated rising plate meter and a double sampling procedure (Earle & McGowan 1979). From the pre-grazing estimations of herbage mass, daily herbage allowances were allocated by adjusting the grazing area. Group herbage intake was calculated from the difference between pre- and post-

grazing estimations of herbage mass (Frame 1981).

Animals were de-wormed with ivermectin (Ivomec™) 48 h prior to allocation to treatments and at day 30 of the study. Maize was fed to the supplemented groups at 1:00 pm. A trough space of 80 cm per animal was assigned, and residual concentrates left after feeding (if any) were weighed and sampled for DM estimation (oven-dried at 60 °C for 48 h until constant weight). Group maize DM intake was estimated as the difference between amount offered and refusals.

Animals were weighed unfasted (within 1 h of removal from grazing) fortnightly and after a 15-h fast at the end of the trial. Fortnightly animal live weights were used to adjust herbage and concentrate allowances. On day 40 n-alkane capsules (Captec® 300-650 kg LW) containing dotriacontane (C₃₂) and hexatriacontane (C₃₆) with a constant release rate for each n-alkane of 400 mg d⁻¹ were administered to all animals. Routines for sampling and estimation of individual herbage intake and digestibility were carried out as described by Dove and Mayes (1991). Faeces collections for intake estimation were made between days 48 and 52 (8-12 days post-application). Faecal samples were collected daily during morning and evening observation (2-h periods) of animals defecating (Morris et al. 1993). Samples were freeze-stored and compounded within each animal over the period of collection. After defreezing, they were ground through a mill (1 mm) and analysed for n-alkane composition by gas chromatography (Mayes et al. 1986). The ¹³C was estimated from organic matter content by mass spectrometry (Finnigan Mat DeltaS, Laboratory of isotopes, INGEIS-UBA).

Individual herbage and maize intakes were estimated by using the iterative alkane & ¹³C method (Garcia et al. 2000). In unreplicated supplementation trials the grazing only group acts as the control for estimating the substitution rate. In the current trial, to estimate individual substitution rates associated with maize intake, an average “basal” herbage intake was calculated from animals allocated to both replicates of the “grazing only” treatments at each level of herbage allowance, and individual differences from these basal levels were calculated for supplemented animals. From these differences and maize intakes individual substitution rates were estimated.

During the intake measurement period, thirty hand-plucked herbage samples representing the diet for each replicated plot were obtained daily. Herbage samples were pooled within each replicate by sampling period as described by Garcia et al. (2000). Samples were sealed in polythene bags and taken to the laboratory in an icebox. Part of the sample was freeze-dried, ground (1 mm screen) and divided into two sub-samples. The first was analysed for n-alkane composition, and the second analyzed for dry matter *in vitro* digestibility (Dig %) (Tilley & Terry 1962) and crude protein (CP %) by Micro Kjeldhal (A.O.A.C. 1960). To determine the organic matter (OM) fraction the dry matter was subsequently ashed in a muffle furnace at 550 C°. The second part of the pooled sample was divided into two. The first was completely sorted by hand into tall fescue and white clover, and then into their component parts, i.e. lamina, sheath plus stem and dead (tall fescue) and leaflet, petiole plus stolon and dead in white clover. These components were dried in an oven until constant weight (60 °C for 48 h) and expressed as fraction of dry matter. The rest of the sample was also oven dried and preserved for ¹³C determination.

2.3. Statistical analysis

A factorial design was used to analyse sward measurements, using treatment replicates (grazing plots) as experimental units. Pre-planned contrasts included linear and quadratic contrasts for herbage allowance level. The other variables were analysed with the animal as experimental unit using PROC GLM as $Y_{ijk} = \mu + HA_i + M_j + HA_i \times M_j + \text{paddock}(HA_i \times M_j) + e_{ijk}$. Where Y_{ijk} is the response variable being modelled (individual herbage, maize and total intakes, SR, LWG, ME eaten daily and *in vivo* digestibility of the whole diet), HA_i is the effect of herbage allowance, M_j is the effect of maize supplementation, $HA_i \times M_j$ is the effect of the interaction between herbage allowance and maize supplementation and $\text{Paddock}(HA_i \times M_j)$ represents the error term effect of the replicated paddock. e_{ijk} is the model residual. The pre-planned contrasts were as stated above. Following a significant F-test ($P < 0.05$), least squares means were separated using least significant differences (Steel & Torrie 1980). All analyses were performed using SAS/STAT (2001).

3. Results

Chemical composition, concentration of dominant n-alkanes and $\delta^{13}\text{C}$ in herbage and grain fed are presented in Table 1. No interactions were found between herbage allowance and maize supplementation effects in any of the studied variables, so main effects are presented separately. The sward was composed (as fractions and standard deviations of the whole canopy), by 0.29 ± 0.09 of grass stem, 0.19 ± 0.05 of grass lamina, 0.10 ± 0.08 of clover leaflet, 0.14 ± 0.04 of clover stem&stolon and 0.28 ± 0.11 of dead material.

Table 1. Chemical composition, concentration of dominant n-alkanes and concentration of ^{13}C in the forages utilised.

Forage	DM	CP	Dig	OM	C ₂₉	C ₃₁	C ₃₃	$\delta^{13}\text{C}$
	%				mg 100 g DM ⁻¹			‰
Herbage	33.6	15.6	68.2	89.6	156.2	333.1	75.2	-27.9
Maize grain	88.7	9.7	83.2	96.5	1.1	0.8	0.6	-11.1

DM=dry matter, CP= crude protein, Dig=in vitro DM Digestibility, OM= organic matter, C₂₉=nonacosane, C₃₁= hentriacontane, C₃₃= tritriacontane and $\delta^{13}\text{C}$ =abundance of ^{13}C relative to a carbonate standard.

Final liveweight and liveweight gains in LHA were lower ($P<0.05$) than in MHA and HHA, and increased quadratically ($P<0.05$) with the level of herbage allowance. Level of maize fed increased significantly ($P<0.05$) LWG by 0.09 kg d^{-1} (Table 2). A quadratic function adjusted significantly to predict LWG from herbage allowance (Figure 1). The fasting liveweight losses increased significantly ($P<0.05$) with the level of herbage allowance, with no significant effect of maize feeding level (Table 2). The coefficient of variation of LWG declined with the level of herbage allowance, with values of 107, 34 and 23% for LHA, MHA and HHA, respectively.

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.

	LHA	MHA	HHA	PSE- HA	M ₀	M ₁	PSE- M	HA	M	HA- Quadratic
Final LW (kg)	268 ^a	287 ^b	291 ^b	1.62	280 ^a	284 ^b	1.3	**	*	*
LWG (kg d ⁻¹)	0.16 ^a	0.61 ^b	0.69 ^b	0.04	0.44 ^a	0.53 ^b	0.03	**	* [•]	*
Fasted-Loss (% full LW)	6.0 ^a	7.0 ^{ab}	7.2 ^b	0.003	6.3	6.9	0.3	* [•]	NS	NS

LHA= 2.5 % LW d⁻¹, LHA=5.0 % LW d⁻¹, HHA=7.5 % LW d⁻¹, M₀ = 0% d⁻¹ maize grain, M₁ = 0.5% d⁻¹ maize grain, HA= herbage DM allowance effect, M= DM Maize effect, PSE-HA and PSE-M= pooled standard errors of HA and M effects, HA-^{Quadratic}= contrast for quadratic effects of herbage DM allowance level, different letters in a row within effects (HA and M) indicate significant differences ($P<0.05$), NS= non significant differences ($P>0.1$), *= $P<0.05$ and **= $P<0.01$.

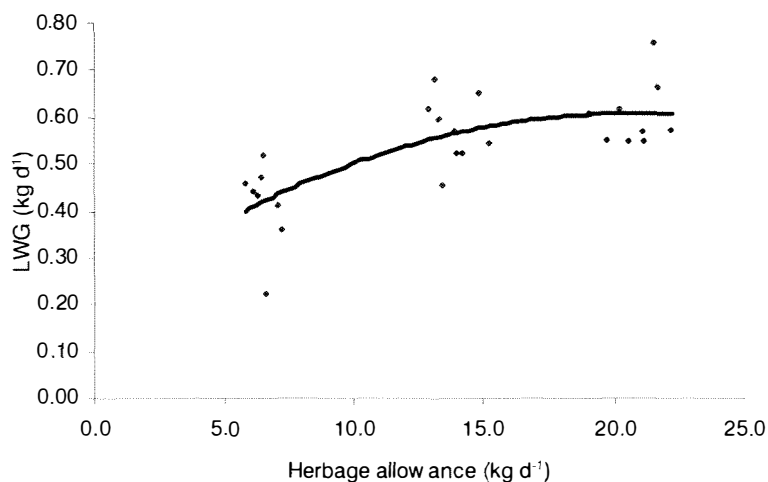


Figure 1. Relationship between herbage DM allowance (X) in kg d⁻¹ and individual liveweight gain (Y) in kg d⁻¹.

For the fitted quadratic curve, $Y = 0.21 \pm 0.10 + 0.03 \pm 0.017X - 0.0009 \pm 0.0006X^2$; $R^2 = 0.51$, $P < 0.001$, Residual SS = 0.14 and $n = 26$.

Pre-grazing herbage mass was similar between treatments (Table 3), and residuals increased when herbage allowance increased ($P < 0.01$), and when maize was fed ($P < 0.05$). When pre- and post-grazing measurements were used to estimate herbage and total intake (Table 3), both variables increased linearly ($P < 0.01$) as herbage allowance increased, with significant differences ($P < 0.01$) between LHA, MHA and HHA. Using this method, substitution rate was not significantly affected ($P > 0.05$) by herbage allowance.

Herbage, total intake and ME eaten increased ($P < 0.01$) with increasing herbage allowance, when the n-alkane & ¹³C method was used (Table 3), fitting significantly ($P < 0.001$) to a quadratic curve (Figure 2). The treatment LHA was significantly lower ($P < 0.05$) than MHA and HHA in the three previously mentioned variables. *In vivo* dry matter digestibility of the total diet was higher ($P < 0.05$) when maize grain was fed, and increased linearly according to the herbage allowance level. Maize grain intake had a mean of 1.2 kg DM d⁻¹, with a coefficient of variation (CV) between individual animals of 41 %. Within each supplemented treatment, individual LWG was predicted linearly ($P < 0.05$) from maize intake (R^2 of 0.42, 0.47 and 0.58 for LHA-M, MHA-M and HHA-M, respectively), but no significant relationship could be established with herbage intake or substitution rate.

Table 3. Sward and animal parameters of Angus steers fed at three herbage allowances and two maize grain levels during late spring.

	LHA	MHA	HHA	PSE- HA	M ₀	M ₁	PSE- M	HA	M	HA- Linear
Pre-grazing herbage mass (kg ha ⁻¹)	2350	2490	2480	76	2420	2470	65	NS	NS	NS
Post-grazing herbage mass (kg ha ⁻¹)	1240 ^a	1640 ^{ab}	1710 ^b	67	1470 ^a	1590 ^b	39	•	*	**
<u>DM disappearance</u>										
Herbage DM intake (kg d ⁻¹)	3.3 ^a	5.7 ^b	7.6 ^c	0.71	5.9	5.2	0.58	**	NS	**
Total DM intake (kg d ⁻¹)	3.9 ^a	6.4 ^b	8.5 ^c	0.71	5.9	6.6	0.58	**	NS	**
Maize intake ((kg d ⁻¹)	1.3	1.5	1.4	0.13	--	1.4	0.2	NS	--	NS
Substitution rate (kg DM herbage kg DM maize grain ⁻¹)	0.54	0.82	0.38	0.53	--	0.58	0.30	NS	--	NS
<u>n-alkane & δ¹³C</u>										
Herbage DM intake (kg d ⁻¹)	3.6 ^a	4.6 ^b	4.7 ^b	0.26	4.8 ^b	3.9 ^a	0.21	**	**	**
Total DM intake (kg d ⁻¹)	4.2 ^a	5.2 ^b	5.3 ^b	0.28	4.8	5.1	0.23	**	NS	**
Diet digestibility (%)	72 ^a	75 ^{ab}	76 ^b	1.2	71 ^a	77 ^b	0.9	**	**	•
Energy intake (MJ ME d ⁻¹)	45.7 ^a	60.1 ^b	61.1 ^b	3.5	52.1	59.2	2.9	**	+	**
Maize DM intake (kg d ⁻¹)	1.0	1.2	1.3	0.19	--	1.2	0.1	NS	--	NS
Maize DM intake (% LW d ⁻¹)	0.42	0.47	0.49	0.06	--	0.46	0.04	NS	--	NS
Substitution rate (kg DM herbage kg DM maize grain ⁻¹)	0.38 ^a	0.83 ^{ab}	0.87 ^b	0.16	--	0.70	0.09	•	--	•

LHA= 2.5 % LW d⁻¹, MHA=5.0 % LW d⁻¹, HHA=7.5 % LW d⁻¹, M₀ = 0 % d⁻¹ maize grain,

M₁ = 0.5 % d⁻¹ maize grain, HA= herbage DM allowance effect, M= Maize DM effect,

PSE-HA and PSE-M= pooled standard error of HA and M effects,

HA_{Linear} = contrast for linear effect of herbage DM allowance level, different letters in a row within effects (HA and M) indicate significant differences (P<0.05), DM disappearance= pre- and post-grazing dry matter difference, NS= non significant differences (P>0.1), +=P<0.1, *=P<0.05 and **=P<0.01.

Supplemented animals had an overall SR of 0.70 kg herbage kg maize grain⁻¹ (Table 3). The linear contrast for SR associated with increased levels of herbage allowance was significant at P<0.05 but a quadratic term was not significant. However, a separate regression analysis based on individual values expressed in kg DM d⁻¹ fitted to a quadratic function (Figure 3).

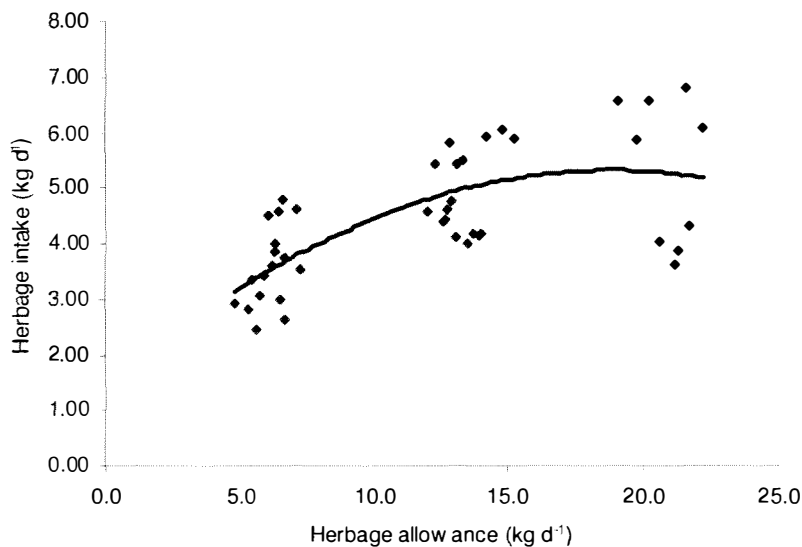


Figure 2. Relationship between herbage allowance (X) in kg DM d⁻¹ and individual herbage intake (Y) in kg DM d⁻¹.

For the fitted quadratic curve, $Y = 1.4 \pm 0.73 + 0.41 \pm 0.12 X - 0.01 \pm 0.004 X^2$; $R^2 = 0.47$, $P < 0.001$, Residual SS = 0.56 and $n = 25$.

Estimates of herbage intake in LHA were similar from sward measurements and the alkane & ¹³C method, but pasture estimates exceeded alkane estimation at higher herbage allowances (23 and 63 % higher in MHA and HHA). In the case of maize grain intake, both methods were similar with an overall higher estimation of 7% when the method of pre- and post-feeding difference was used. The achieved level of maize DM feeding (overall mean of 0.46 % LW d⁻¹) was slightly lower than originally planned (0.6 % LW d⁻¹).

The accuracy and precision of the the alkane & ¹³C method (ME-alk) and the pre- and post-grazing difference method with feed digestibilities (ME-diff) were tested against metabolisable energy requirements for the level of performance attained (ME-req) with the method described in Chapter 3 (Mayer & Butler 1993). Linear regressions fitted significantly for ME-alk ($R^2 = 0.88$, RMSE=3.3 $P < 0.01$) and ME-diff ($R^2 = 0.62$, RMSE=15.3 $P < 0.1$), and the intercepts were not significantly different from zero ($P > 0.05$). Regressions forced through the origin were significant at $P < 0.01$ (ME-alk $R^2 = 0.99$, RMSE=4.4 and ME-diff $R^2 = 0.96$, RMSE=10.6), but only the slope of ME-alk (1.09 ± 0.03) was not different from unity ($P > 0.05$), which leads to $ME-alk \approx ME-req$ ($P < 0.05$). The ME-diff had a slope coefficient of 0.73 ± 0.01 , which was significantly lower than 1.0 ($P < 0.05$).

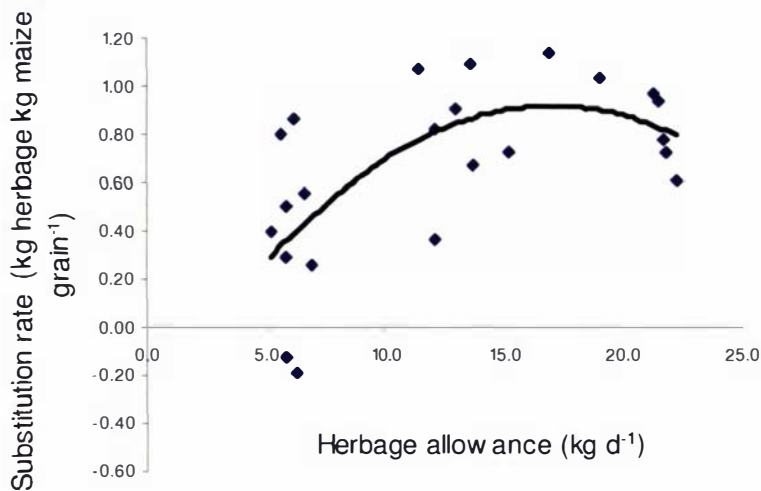


Figure 3. Relationship between herbage allowance (X) in kg DM d⁻¹ and individual substitution rate (Y) in kg herbage kg DM maize grain⁻¹.

For the fitted quadratic $Y = -0.39 \pm 0.37 + 0.15 \pm 0.06X - 0.004 \pm 0.002X^2$, $R^2 = 0.39$, $P < 0.01$, Residual SS = 2.03 and $n = 22$.

There was also significant quadratic relationship between herbage intake (X) in kg DM d⁻¹ and liveweight gain (Y) kg d⁻¹:

($Y = -0.078 \pm 0.29 + 0.19 \pm 0.12X - 0.012 \pm 0.012X^2$; $R^2 = 0.51$, $P < 0.01$, Residual SS = 0.15 and $n = 25$).

4. Discussion

One of the objectives of the thesis was to provide information on herbage allowance-intake functions and the effects on animal performance when maize grain is supplemented in beef cattle finishing systems. A series of experiments were designed to adjust locally the methodologies and obtain preliminary information (Chapter 2), to study the effects of increasing levels of maize grain (Chapter 3) and the study of increasing level of herbage allowance (present study). The discussion developed here involves evaluation of the observed results in this chapter, but also a comparative assessment with Chapters 2 and 3, exploring the possibilities of generalized relationships within the studies relating herbage allowance to LWG and herbage intake. Additionally, brief comments are made about the grazing methodologies used.

4.1. Present study

The results indicated an asymptotic relationship between herbage allowance and liveweight gain (Table 2 and Figure 1). This is in agreement with other studies (Reid 1986; Redmon et al. 1995). The maximum LWG achieved ($0.69 \text{ kg LWG d}^{-1}$) at $7.5 \% \text{ LW d}^{-1}$ is similar to the 0.63 kg d^{-1} observed during summer in steer calves at the same allowance (Marsh 1977) but lower than the results of Reid (1986) during spring with Angus steers of similar weights, who observed an asymptote of $1.09 \text{ kg LWG d}^{-1}$ at a herbage allowance higher than $6.5 \% \text{ LW d}^{-1}$.

Increasing herbage allowance significantly increased herbage intake estimated by both methods (Table 3), and increased herbage residuals which is in agreement with the literature (Hodgson 1984; Reid 1986). Similarly, associated to the observed substitution rates, grain feeding increased the herbage residuals significantly, as reported by Meijs & Hoekstra (1984), Grainger & Matthews (1989) and in Chapter 3.

The better estimation of herbage intake by the alkane & ^{13}C method than from sward measurements is in agreement with the observations of Garcia et al. (2000) and the results of Chapter 3. Estimates of herbage intake from sward measurements exceeded alkane estimations at higher herbage allowances (Table 3), similarly to the observation in Chapter 3, but not in Chapter 2. Flooding of the experimental area caused a delay in grazing of 14 days, which affected sward condition so it was necessary to top the sward to limit heading. Some reproductive stems were observed to be trodden into the soil surface (particularly at higher herbage allowances), which were likely to be undetected by the measurement of herbage residuals using the rising plate meter. This situation was described by Robaina et al. (1998), who observed that the estimation of herbage intake on late spring-summer pastures using sward sampling techniques is often difficult when pasture is clumpy and may contain a mixture of dry stem material and green herbage. The alkane & ^{13}C procedure is clearly the method of choice in these studies, and appeared to give reliable estimates of both herbage and maize consumption.

The effect of increasing herbage allowance on LWG is likely to be associated with at least two main factors, increased diet quality and increased herbage intake.

Quality of the diet expressed as *in vivo* DM digestibility increased as herbage allowance increased (Table 2), which is in agreement with other authors measuring *in vivo* OM digestibility (French et al. 2001) and *in vitro* OM digestibility from oesophageal fistulates (Jamieson & Hodgson 1979; Redmon et al. 1995). The functional response of *in vivo* DM digestibility was affected clearly by herbage DM allowance in this study. However, between 2.5 and 5.0 % LW d⁻¹ (LHA and MHA respectively) values were not different, in coincidence with the results in Chapter 2 and 3 at the same levels of allowance. This indicates the value of a wider range of allowances as was used in this study. The observed level of crude protein in the pasture (15.6 % CP) could appear marginal when some part is replaced by maize grain (9.8 % CP) in terms of the minimum recommended level of 15 % for young cattle (Hodgson & Brookes 1999). However, it is likely that selective grazing (as indicated by a difference of 9 % in the DM digestibility of the sward and the diet selected from it) in unsupplemented treatments (Tables 1 and 3), would have also enhanced the protein content of the diet.

The pattern of LWG observed here at increased herbage allowance (Figure 1) was clearly associated with the intake estimated with the alkane & 13C method (Figure 2), which became in this case the most relevant driver in terms of LWG response. The asymptotic value of herbage intake (and LWG) was reached at lower allowance than the 9 to 12 % LW d⁻¹ suggested by Hodgson (1984). Animals were not likely to express their potential LWG (above 1 kg d⁻¹ in feedlot conditions, Machado et al. 1997), nevertheless they had an asymptotic pattern of herbage intake and LWG at a herbage allowance of above 5 % LW. If it is assumed that herbage quality was not a constraint to LWG, sward structure was likely to play a role in the restricted intake and performance, as indicated by Pearson (1997).

Increasing the herbage allowance increased the substitution rate (Figure 3), in accord with previous studies (Meijs & Hoekstra 1984; French et al. 2001). The substitution rate at a herbage allowance of 2.5 % LW (0.38 kg DM herbage kg DM maize grain⁻¹), was the same as that observed in Chapter 3 (0.39 kg DM herbage

kg DM maize grain⁻¹) at the same herbage allowance and level of supplementation.

Although maize feeding depressed herbage intake (overall SR of 0.70 kg herbage kg maize grain⁻¹), it also increased LWG significantly by 0.09 kg d⁻¹ due to higher total DM intake and the higher ME content of the maize. The conversion of 0.13 kg LWG kg maize grain⁻¹ is close to the overall values of 0.17 kg LWG kg maize grain⁻¹ observed by Boom and Sheath (1998) and the 0.12 kg LWG kg supplement⁻¹ observed by Boom and Sheath (1999), but lower than the 0.3 kg LWG kg maize grain⁻¹ observed in Chapter 3. The importance of the actual animal performance under unsupplemented conditions to predict potential response was emphasised in Chapter 1. Unsupplemented animals in the present study were gaining 0.44 kg d⁻¹ (average over all herbage allowances), whereas in Chapter 3 the control group had a LWG of 0.25 kg d⁻¹. Maize feeding improved ($P < 0.01$) *in vivo* diet digestibility by 8 %, in concordance with other studies that fed starch grains (French et al. 2001), which is a common finding when the digestibility of the grain is higher than that of the herbage (Table 1), as stated by Dixon & Stockdale (1999).

4.2. Generalised comparison of grazing experiments

In Figures 4 and 5 the observations of LWG and herbage intake of unsupplemented animals at different herbage allowances studied in Chapter 2, 3 and the present study are presented. Although experimental conditions differed (season, animal sex and herbage quality), in both figures a general trend could be observed and fitted significantly ($P < 0.01$) to quadratic functions. However, observations from Chapter 2 behaved as outliers at pooling, and finally were not included in the combined regression equations shown in Figures 4 and 5. All experiments grazed simple legume-grass pastures, however, in the case of the study reported in Chapter 2, pasture was dominated by clover (0.72 ± 0.02 , as fraction of green component), whereas the clover content of the sward in Chapter 3 and the present chapter were 0.33 and 0.03 as fraction of green component, respectively. A higher ingestibility of legumes in comparison with grasses has been observed (Freer & Jones 1984), which is likely to explain partially the higher intake and consequently the higher LWG observed in Chapter 2.

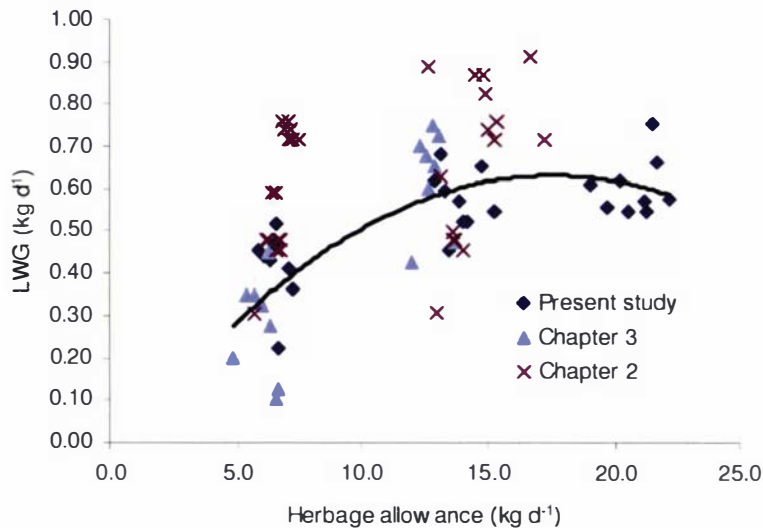


Figure 4. Relationship between herbage allowance (X) in kg d^{-1} and individual liveweight gain (Y), condensing information between Chapters 2, 3 and 4.

For the fitted quadratic curve (including observations from Chapters 3 and 4) $Y = -0.109 \pm 0.001 - 0.08 \pm 0.0006X - 0.002 \pm 0.102X^2$, $R^2 = 0.58$, $P < 0.001$, Residual SS = 0.56 and $n = 42$.

The relationship between herbage intake and LWG from this study (spring) and from Chapter 3 (winter), were relatively consistent (Figure 4 and 5). This was unexpected as season can have a strong influence on the relationship between herbage allowance and LWG (Reid 1986). However, this finding could be associated with the herbage nutritive values in the studies, which were moderate and similar as shown in Table 1 (Chapter 3) and in Table 1 (this Chapter).

In Figure 6 the relationship between observations of LWG and herbage intake for unsupplemented animals in Chapter 2, 3 and the present study are presented. Chapter 2 information was consistent to the general pattern, therefore was included in the equation fitting. This significant relationship agrees with the suggestion of Hodgson (1984) that the effect of herbage allowance on LWG mostly reflects the effect of HA on herbage intake.

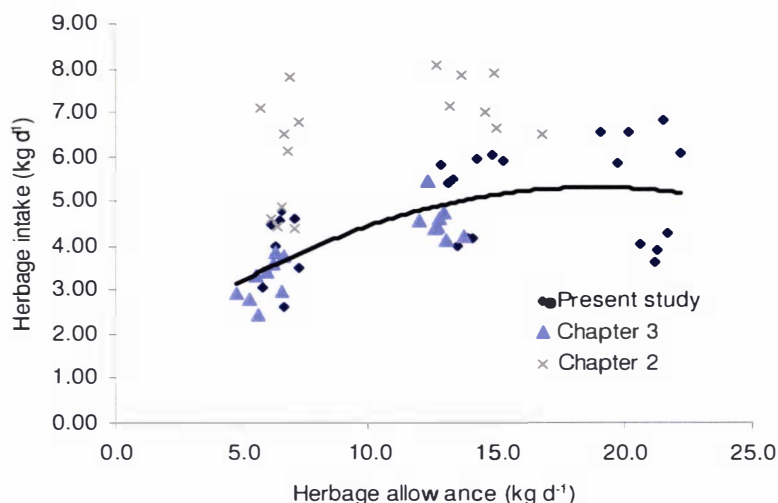


Figure 5. Relationship between herbage allowance (X) in kg DM d⁻¹ and individual herbage intake (Y) in kg DM d⁻¹, condensing information between Chapters 2, 3 and 4.

For the fitted quadratic curve including observations from Chapters 3 and 4, $Y = -1.37 \pm 0.73 + 0.42 \pm 0.12X - 0.011 \pm 0.005X^2$, $R^2 = 0.47$, $P < 0.001$, Residual SS = 28 and $n = 42$.

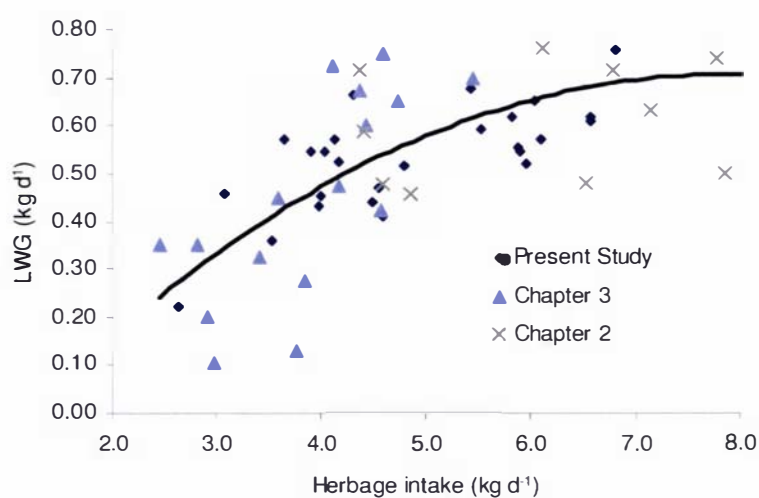


Figure 6. Relationship between individual herbage intake (X) in kg DM d⁻¹ and liveweight gain (Y) in kg DM d⁻¹, condensing information between Chapters 3 and present study.

For the fitted quadratic curve (including observations from Chapters 2, 3 and 4) $Y = -0.27 \pm 0.22 + 0.25 \pm 0.09X - 0.16 \pm 0.008X^2$, $R^2 = 0.46$, $P < 0.001$, Residual SS = 1.03 and $n = 55$.

Caution is necessary in making SR comparisons, as estimates of substitution rates were affected by the method used for its calculation (Table 3), which is in

agreement with Robaina et al. (1998) and the findings of Chapter 3. Additionally, If herbage intake is expressed as kg DM kg LW⁻¹ d⁻¹ instead of kg DM d⁻¹ and is used for SR estimations to avoid any bias from the different liveweights (i.e. unsupplemented animals were lighter), substitution rates of 0.40, 0.63 and 1.01 (± 0.2 PSE) were obtained for LHA-M, MHA-M and HHA-M, respectively. Similarly to the observations in Chapter 3, substitution rate values expressed per kg LW differ slightly from those estimated using the absolute herbage intakes (Table 3), but it would be expected that these differences could increase in longer duration supplementation trials.

Maize grain intake in the present study had an overall coefficient of variation (CV) of 41 % between individual animals, which is in agreement with the 36% CV reported by Garcia et al. (2000), and slightly higher than the mean value observed (31 %) in Chapter 3. Boom & Sheath (1998) reported from individual visual observation of beef steers eating maize grain at levels between 2 and 6 kg d⁻¹, that on any day 20 % of the animals were not consuming grain. Although the actual range in maize intake was high between animals in this study (between 0.56 and 2.15 kg DM d⁻¹) and in Chapter 3 (between 0.46 and 1.81 and between 1.67 and 3.28 kg DM d⁻¹ in LHA-M₁ and LHA-M₂, respectively), all animals were eating some maize. However, considering that the estimates of intake of maize (and also herbage intake) represent a pooled five-day period, it is likely the variability in maize intake between animals within days would be even higher than the values quoted above. Similarly, the same constraint of time scale affects the significant linear relationships between individual maize grain intake and LWG within each treatment, in this study and in Chapter 3 (average R²=0.59). With this caution, and considering that there is no technique available for estimation of the daily individual grain intake in free-grazing animals supplemented in groups, the association with animal performance may have practical implications, given that the high variability in animal LWG in response to grain feeding is well recognised (Horn & McCollum 1987).

4.3. Grazing methodologies used in the studies

There is a broad range of methodological approaches to study herbivore foraging, but their reliability and limitations of experimental results in terms of management

purposes have been highlighted (Dumont & Iason 2000). The n-alkane method used in this thesis has proven to be an effective alternative for individual herbage intake estimation, but it had not been tested previously in Argentina when this project was designed. The use of controlled-release devices (CRD, Captec®) inserted into the rumen of the animals was preferred in this thesis, since it minimised interference with normal animal behaviour and management. One of the key issues about the CRD is the assumption of a relatively constant release rate of dotriacontane (C₃₂) and hexatriacontane (C₃₆) after a stabilization period of seven days. Specific studies to test the accuracy of CRD or compare it with other methods, has shown that this device provides a satisfactory means of delivering an accurate, daily dose of n-alkanes (Dove et al. 2002; Hendricksen et al. 2003; Molina et al. 2004). Though a local calibration with total faecal collection when possible is advisable, some studies were based in the release rate provided by CRD manufacturers (Realini et al. 1999; Garcia et al. 2000; Kennedy et al. 2003). At least two findings seem to indicate an adequate performance of the method in this thesis. Firstly, close agreement with the theoretical energy requirement for the actual level of performance (Chapter 3 and present study), and secondly, a similar release rate to that suggested by manufacturers and the estimation from a single test with CRD inserted in a rumen fistulated animal (Chapter 2).

The main objective of the grazing experimentation was to study the daily herbage intake and its relationship to sward characteristics, maize grain feeding and animal performance. However, different indicators of diet characteristics were also used. These included micro-histological evaluations of faeces and differences in nutrient and component selection indexes (computed by pre- and post-grazing sward measurements) in Chapter 2. The n-alkane method was also tested for diet composition with no feasible solutions (Chapter 2). Results were not reliable enough, and they represented a substantial increase of research costs and increased workload, practically unmanageable under commercial farm conditions. The decision to concentrate effort on herbage intake in Chapter 3 and Chapter 4 (with eight and twelve animal groups, respectively), seemed adequate as a close relationship between herbage intake and animal performance was obtained (Figure 6). However, it is recognised that further research on diet composition under changing grazing conditions is needed, and information obtained from a low time-

space scale (i.e. bite scale as reported by Cangiano et al. 2002) with daily grazing activities needs to be investigated.

Visual measurements of ingestive behaviour in Chapter 2 and 3 provided additional insights about animal responses. It was demonstrated that maize feeding significantly increased the harvesting rate in a linear fashion (Chapter 3), expressed as g DM eaten kg LW⁻¹ min. spent grazing⁻¹ (Krysl & Hess 1993). The use of automatic recording equipment (Rutter et al. 1997) could make it possible to enhance the detail of behavioural responses. Automated observations were made on animals in the study described in Chapter 4 as part of another postgraduate project (Sacido M., unpublished), and are not reported here.

5. Implications and conclusions

The n-alkane & ¹³C method proved to be reliable, at least for quantitative estimates of herbage and grain intakes, and allowed the estimates of important variation in individual grain intake when animals are supplemented in groups. The benefits that differences observed in herbage intake and substitution rate estimations depend on the method used, highlights the importance of standardisation, and caution in comparing results.

The results from this series of short-term studies showed consistency in the comparison of the effects of increasing herbage allowance and supplementation on herbage intake and animal LWG. Although their applicability in terms of practical grazing management is limited and needs further confirmation, they have potential to help the development of grazing models as sward description is available, and therefore to expand the understanding of the effects of manipulating herbage DM allowance and grain feeding in a systems context. Data summarized in this chapter will be used for model evaluation in Chapter 7.

References

A.O.A.C. 1960: *Official Methods of Analysis*. 9th ed. AOAC. Washington:957 p.

- Baker R. D.; Alvarez F.; Le Du L. P. 1981: The effect of herbage allowance upon the herbage intake and performance of suckler cows and calves. *Grass and Forage Science* 36:189-199.
- Boom C. J.; Sheath G. W. 1998: Grain supplementation of finishing beef cattle. *Proceedings of the New Zealand Society of Animal Production* 58:239-242.
- Boom C. J.; Sheath G. W. 1999: Tactical supplementation of beef finishing cattle. *Proceedings of the New Zealand Society of Animal Production* 59:162-165.
- Cangiano C. A.; Galli J. R.; Pece M. A.; Dichio L.; Rozsypalek S. H. 2002: Effect of liveweight and pasture height on cattle bite dimensions during progressive defoliation. *Australian Journal of Agricultural Research* 53:541-549.
- Delagarde R.; Peyraud J.; Delaby L. 2000: Influence of herbage allowance on intake and behaviour of dairy cows grazing perennial ryegrass swards in autumn. In: Rook, A.J. & Penning, P. D. Eds. *The Principles and Practice of Grazing, for Profit and Environmental Gain, Within Temperate Grasslands Systems*. Occasional Symposium No 34, British Grassland Society 34:101-102.
- Dixon R. M.; Stockdale R. C. 1999: Associative effects between forages and grains: consequences for feed utilisation. *Australian Journal of Agricultural Research* 50:757-753.
- Dougherty C. T.; Bradley N. W.; Lauriault L. M.; Arias J. E.; Cornelius P. L. 1989: Herbage allowance and intake of cattle. *Journal of Agricultural Science, Cambridge* 112:395-401.
- Dove H. 1996: Constraints to the modelling of diet selection and intake in the grazing ruminant. *Australian Journal of Agricultural Research* 47:257-275.
- Dove H.; Mayes R. 1991: The use of wax alkanes as marker substances in studies of the nutrition of herbivores: a review. *Australian Journal of Agricultural Research* 42:913-952.
- Dove H.; Mayes R. W.; Lamb C. S.; Ellis K. J. 2002: Factors influencing the release rate of alkanes from an intra-ruminal, controlled-release device, and the

- resultant accuracy of intake estimation in sheep. *Australian Journal of Agricultural Research* 53:681-696.
- Dumont B.; Iason G. R. 2000: Can we believe the results of grazing experiments? Issues and limitation in methodology. In: Rook, A.J. & Penning, P.D. Eds. *The Principles and Practice of Grazing, for Profit and Environmental Gain, Within Temperate Grasslands Systems. Occasional Symposium British Grassland Society* 34 :171-180.
- Earle D.; McGowan A. 1979: Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19:337-343.
- Forbes T. D. A. 1988: Researching the plant-animal interface: the investigation of ingestive behavior in grazing animals. *Journal of Animal Science* 66:2369-2379.
- Frame J. 1981: Herbage Mass. In: Hodgson, J.; Baker R.D; Davis, A.; Laidlaw, A.S. ; Leaver, J.D. Eds. *Sward Measurement Handbook*. British Grassland Society: Berkshire, UK. 35-70.
- Freer M.; Jones D. B. 1984: Feeding value of subterranean clover, lucerne, phalaris and Wimmera ryegrass for lambs. *Australian Journal of Experimental Agriculture and Animal Husbandry* 24:156-156.
- French P.; O'Riordan M. A.; O'Kiely P. O.; Caffrey P. J.; Moloney A. P. 2001: Intake and growth of steers offered different allowances of autumn grass and concentrates. *Animal Science* 72:129-138.
- Garcia S. C.; Holmes C. W.; Hodgson J.; MacDonald K. A. 2000: The combination of the n-alkanes and ¹³C techniques to estimate individual dry matter intakes of pasture and maize silage by grazing dairy cows. *Journal of Agricultural Science, Cambridge* 135: 47-55.
- Grainger C.; Matthews G. L. 1989: Positive relation between substitution rate and pasture allowance for cows receiving concentrates. *Australian Journal of Experimental Agriculture* 29:355-360.

- Hendricksen R. E.; Gazzola C.; Reich M. M.; Robertson R. F.; Reid D. J.; Hill R. A. 2003: Using molasses as an alternative to controlled release devices for administering n-alkane markers to cattle. *Animal Science* 76:471-480.
- Hodgson J. 1984: Sward conditions, herbage allowance and animal production. *Proceedings of the New Zealand Society of Animal Production* 44: 99-104.
- Hodgson J.; Brookes I. M. 1999: Nutrition of grazing animals. In: White, J. & Hodgson, J. Eds. *New Zealand Pasture and Crop Science*. Oxford University press. 117-132.
- Horn G. W.; McCollum F. T. 1987: Energy supplementation of grazing ruminants, July 23-24. *Proceedings of the Grazing Livestock Nutrition Conference* :125-136.
- Jamieson W. S.; Hodgson J. 1979: The effect of daily herbage allowance and sward characteristics upon the ingestive behavior and herbage intake of calves under strip-grazing management. *Grass and Forage Science* 34:261-271.
- Kennedy J.; Dillon P.; Faverdin P.; Stakelum G. 2003: Effect of genetic merit and concentrate supplementation on grass intake and milk production with Holstein Friesian dairy cows. *Journal of Dairy Science* 86:610-621.
- Kim T. H.; An K. W.; Jung W. J. 1995: Effects of daily herbage allowance on sward structure, herbage intake and milk production by dairy cows grazing a pure perennial ryegrass sward. *Asian-Australasian Journal of Animal Sciences* 14:1383-1388.
- Kloster A. M.; Latimori N. J.; Amigone M. A. 2000: Evaluación de dos sistemas de pastoreo rotativo a dos niveles de asignación de forraje en una pastura de alfalfa y gramíneas. *Revista Argentina De Producción Animal* 20:187-198.
- Krysl L. J.; Hess B. W. 1993: Influence of supplementation on behavior of grazing cattle. *Journal of Animal Science* 71:2546-2555.
- Machado C.; Matoso H.; Auza N. 1997: A note of productive performance of feedlot heifer-calves fed on two daily feeding frequencies. *Journal of Animal and*

Feed Sciences 6:81-85.

Marsh R. 1977: The effect of level of herbage dry matter per animal on efficiency of utilization of pasture by young Friesian cattle. *Proceedings of the New Zealand Society of Animal Production* 37:62-66.

Martinez Ferrer J.; Simondi J.; Brunetti M. A.; Ustarroz E.; De Leon M.; Spada M.; Gonzalez Palau C.; Ramos C.; Garcia Astrada A.; Faya F. 2002: Asignación forrajera y suplementación energética en invernadas pastoriles. 1. Consumo de forraje, consumo total y eficiencia de utilización de la pastura. *Revista Argentina De Producción Animal* 22:8-9.

Mayer D. G.; Butler D. G. 1993: Statistical validation. *Ecological Modelling* 68:21-32.

Mayes R.; Lamb C.; Colgrove P. 1986: The use of dosed and herbage n-alkanes as markers for the determination of herbage intake. *Journal of Agricultural Science, Cambridge* 107:161-170.

Meijs J. A. C.; Hoeskstra J. A. 1984: Concentrate supplementation of grazing dairy cows. 1. Effects of concentrate intake and herbage allowance on herbage intake. *Grass and Forage Science* 39:59-66.

Molina D. O.; Matamoros I.; Pell I. N. 2004: Accuracy of estimates of herbage intake of lactating cows using alkanes: comparison of two types of capsules. *Animal Feed Science and Technology* 114:241-260.

Morris S. T.; Parker W. J.; Grant D. A. 1993: Herbage intake, liveweight gain, and grazing behavior of Friesian, Piedmontese x Friesian, and Belgian Blue x Friesian bulls. *New Zealand Journal of Agricultural Research* 36:231-236.

Okajima T.; Kamijoh T.; Yokota H.; Ohshima M. 1996: Relationships between daily herbage intake of grazing cattle with daily herbage allowance and leafiness. *Asian-Australasian Journal of Animal Sciences* 9:577-582.

Pearson C. J. 1997: *Agronomy of Grassland Systems*. 2nd Ed. Cambridge [England]; New York, NY, USA. Cambridge University Press:222 p.

- Realini C.; Hodgson J.; Morris S. T. 1999: Effect of sward surface height on herbage intake and performance of finishing beef cattle. *New Zealand Journal of Agricultural Research* 42:155-154.
- Reardon T. F. 1977: Effect of herbage per unit area and herbage allowance on dry matter intake by steers. *Proceedings of the New Zealand Society of Animal Production* 37: 58-61.
- Rearte D. 1998: Beef cattle production and meat quality on grazing system in temperate regions. *Revista Argentina De Producción Animal* 18:129-142.
- Redmon L.; McCollum T.; Horn G.; Matthew D.; Cravey S.; Gunter P.; Beck J.; Mieres M.; San Julian R. 1995: Forage intake by beef steers grazing winter wheat with varied herbage allowances. *Journal of Range Management* 48:198-201.
- Reid T. 1986: Comparison of autumn/winter with spring pasture for growing beef cattle. *Proceedings of the New Zealand Society of Animal Production* 46:145-147.
- Robaina A. C.; Grainger C.; Moate P.; Taylor J.; Steward J. 1998: Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* 38:541-549.
- Rutter S. M.; Champion R. A.; Penning P. D. 1997: An automatic system to record foraging behavior in free-ranging ruminants. *Applied Animal Behavior Science* 54:185-195.
- Steel R. G. D.; Torrie J. H. 1980: *Principles and Procedures of Statistics: A Biometrical Approach*. 2nd Ed. McGraw-Hill Publishing Co., New York. 631p.
- Tilley J. M. A.; Terry R. A. 1962: two-stage technique for the in vitro digestion of forage crops. *Journal of the British Grassland Society* 18:104-111.

Herbage quality

**Seasonal variation in the quality of an alfalfa-based
pasture and its relationship with morphological and
maturity estimates**

Abstract

To monitor seasonal change of herbage quality of an alfalfa-based pasture (*Medicago sativa*, *Dactylis glomerata* and *Bromus willdenowii*) at the Chacra Barrow Experimental Station- Argentina (38° 20' S, 60° 13' W, 120 m.a.s), was sampled fortnightly for 28 months. The pasture was strip-grazed and samples were taken from the re-growth of a previously grazed paddock, which was ready for re-grazing. At each sampling time, herbage mass was estimated with a fortnightly calibrated rising plate meter. Twenty herbage samples were cut to 4 cm above ground level and immediately bulked and refrigerated. In the laboratory, a subsample (0.4 kg) was taken and divided into two parts; one was freeze-dried and analyzed for IVDM Digestibility, CP%, NDF% and NSC %, and the second fraction was quickly sorted out into dead and green components. The green pool was separated into grass and alfalfa, and later into lamina plus leaflet and stem plus pseudostem fractions. These fractions were oven dried (48 h at 60°C), weighed and expressed as DM %. At each sampling date, the quantitative maturity (mean stage by count and mean stage by weight) of fifty tillers per grass species and fifty alfalfa shoots were recorded. There was a decline in DM digestibility (and consequently ME) during autumn (71.7 % and 10.8 MJ ME kg DM⁻¹, respectively) and in CP during summer (17.3 %), although herbage quality was consistently high throughout the year (overall average of 11.5 MJ ME kg DM⁻¹ and 20.6 %, for metabolisable energy content and crude protein level, respectively). During summer and autumn, the sward had the highest proportion of legume and dry matter (averages of 59.3 and 28.0 %, respectively), with the lowest leaf to stem ratio (1.25) and green content (82.6%). Grasses had the highest maturity state during spring and summer and *M. sativa* was more mature during summer-autumn. Morphological and maturity estimates predicted satisfactorily the changes in the main nutritional variables. Although promising in terms of gaining understanding of the seasonal change of herbage quality, these relationships require further investigation to determine their implications under practical conditions.

Key-words: herbage quality; seasonal change; alfalfa/grass; maturity

1. Introduction

Herbage nutritional quality at any time is the weighted average of the proportions of plant components and their nutrient content. Sward quality changes seasonally and dynamically when physiological changes take place in the plants, and grazing or harvesting conditions interact with those changes (Nelson & Moser 1994).

Matching herbage mass and quality with the nutritional requirements of grazing animals is one of the key challenges facing graziers. Tactical decisions within grazing systems are often based on scant information about herbage quality, in spite of its importance in influencing herbage intake and animal performance (Pearson 1997). More recently, some dairy cattle studies have concentrated on herbage quality (Moller 1997; Cosgrove et al. 1998) and systematic characterisation of herbage quality for different sheep and beef cattle farms in four regions of New Zealand has been undertaken (Litherland et al. 2002).

The need for a low cost and less time-consuming method of estimating herbage quality is well recognized by pastoral researchers all around the world. A strategy to lower the costs has been to derive one nutritional variable from another. Neutral detergent fiber content (NDF) has been shown to be a good predictor of *in vitro* digestibility for alfalfa, alfalfa-grass pastures and winter and summer fodder crops (Pagella et al. 1996). Another alternative has been use of faster analytical methods than the traditional laboratory analysis, such as near infra-red reflectance spectroscopy (Corson et al. 1999). Others have established quantitative relationships between maturity stages and herbage quality in non-defoliated grasses (Sanderson & Wedin 1889; Berg & Hill 1989; Sanderson 1992; Elizalde et al. 1999) and legumes (Hintz & Albrecth 1991; Owens et al. 1995; Sulc et al. 1997) and less frequently in grazed pastures (Smart et al. 2001). Similarly the relationships between maturity and accumulated degree days (Frank & Hofmann 1989; Smart et al. 2001) and water stress (Lynk et al. 1990) have been reported. It is worth noting that these attempts to predict pasture quality are dependent on chemical analysis for validation, and their usefulness is restricted to those short-term tactical circumstances where forage testing is not feasible (Fick et al. 1994).

As forage matures, the general trend is for decreasing leaf to stem ratio (Nelson & Moser 1994) both in grasses and legumes. The higher contribution of stems and the decrease in their quality and digestibility, is associated with an increase of NDF within the herbage (Sanderson & Wedin 1889). However, maturity is not a clear concept in multispecies pastures, as different maturation patterns have been widely reported for different plant species under similar climatic conditions (Sanderson 1992). Herbage quality is affected by grazing management (Saul et al. 1999; Schlegel et al. 2000; Frame et al. 2002), and intensive grazing is a key tool to maintain nutritional value of pastures, by keeping the sward immature with a greater leaf:stem ratio (Nelson & Moser 1994; Clark 1995; Smart et al. 2001) by preventing the development of structural tissue which leads to a decline of readily digestible cell contents (Hodgson & Brookes 1999).

The relationships cited are mainly developed for timing of harvesting events when monophytic stands grow uninterrupted, but not when forage maturity of mixed pastures is prevented under an intensive grazing management. Therefore, the main objective of this experiment was to study the seasonal variation of pasture quality in an alfalfa-based pasture, under an intensive beef cattle grazing system. Secondly, the relationship between nutritional variables and potential predictors from morphological and maturity variables was explored quantitatively. The experiment described in this Chapter was designed taken into account a preliminary study of the seasonal variation on herbage quality of hand-plucked pre-grazing herbage samples over three years from a New Zealand Friesian bull beef production system. Details of this preliminary study are given in Annex B.

2. Materials and methods

On a fortnightly basis between March 2000 and July 2002, herbage samples were taken from an alfalfa-based pasture (*Medicago sativa*, *Bromus willdenowii* and *Dactylis glomerata*) in its second year of production at the Chacra Barrow Experimental Station, Argentina (38°20'S, 60°13'W, 120 m.a.s). The pasture was strip-grazed regularly by British bred cattle, and herbage samples were taken from strips prior to grazing. Rainfall, temperature and evapotranspiration were recorded daily at an observation station within the experimental site.

At each sampling time, herbage mass ($\text{kg dry matter ha}^{-1}$) was estimated with a rising plate meter (Filip's folding plate meter, New Zealand), calibrated against herbage height and herbage cutting (above 4 cm ground level) for the same period and experimental site (Machado et al. 2003) according to Earle & McGowan (1979). Fifty herbage samples (1.0 kg approx.) were cut to 4 cm above ground level using a knife, and they were bulked in a plastic bag and refrigerated immediately. Once in the laboratory, a sub-sample (0.4 kg) was taken and divided into two parts. The first was sorted into dead, green and weed components. Subsequently, the green pool was separated into grasses and alfalfa, then divided into grass lamina, legume leaf, grass sheath & stem and legume stem fractions. These fractions were oven dried until constant weight (48 h at 60°C), weighed and expressed as dry matter percentage (DM%). The other fraction was subdivided into two sub-fractions: one was freeze-dried and analysed for *in vitro* digestibility (Dig %) (Tilley & Terry 1962); crude protein (CP %) determined by multiplying the N concentration (the Micro Kjeldhal method (A.O.A.C. 1960) by 62.5, neutral detergent fiber (NDF %) (Goering & Van Soest 1970) and non structural carbohydrates (NSC) by the anthrone method (Pichard & Alcalde 1990). The other sub fraction was sorted into components as previously described, but samples were freeze-dried instead. In order to obtain an estimation of their quality variation over seasons, five samples per season of each component were randomly selected from the whole set of samples and analysed for *in vitro* digestibility and crude protein.

At each sampling date, fifty tillers per grass species and fifty alfalfa shoots were collected at the same sampling site. Descriptions of morphological stages of development were used for alfalfa (from 0-9 Fick & Mueller 1989), and grasses (from 21-93, Simon & Park 1983). Values for each tiller and shoot were recorded and a mean arithmetic stage by count (MSC) per species was estimated. Additionally, tillers and shoots were oven-dried (48 h at 60°C until constant weight) for each stage of development to estimate a mean stage corrected by weight (MSW). A regression analysis was performed between MSC and MSW for each species.

The dataset was grouped into nutritional variables (Dig, CP, NDF and NSC) and

morphological and maturity variables (herbage mass, dry matter content, green content, leaf:stem ratio, mean stage by count or weighing for each of the three species). Analyses of variance by season for both groups of variables were carried out using year as a block. Multiple regression analyses ('stepwise' model selection, Alpha=0.15) were performed for each season, using alternatively mean stage by counting and mean stage by weighing as the maturity predictor. In order to study the overall relationship between nutritional and morphological-maturity variables, a multivariate canonical correlation analysis was applied (Matthew et al. 1994). Crude protein and ME of plant components were analysed with a completely random design between seasons. Following a significant F-test ($P < 0.05$), least squares means were separated using least significant differences (Steel & Torrie 1980). All analyses used the SAS statistical analysis system (SAS/STAT 2001).

Additionally, a Bayesian smoothing analysis was applied to the complete data set of ME and Protein using Flexi 3.1 (Wheeler & Upsdell 2003), to reveal possible underlying seasonal trends in herbage ME and Protein. This smoothing technique employs a variance components model to fit a constant term describing the general level of the variable and a correlated random term to describe departures of the curve from this constant. A cycle of 365 days with fluctuating covariance (the cycle is not forced to repeat exactly) and integral equal to 0 were used to model the data as: *Total fit of ME or CP = Seasonal component + long term component + error*. Graphs are presented with the confidence intervals (83 % as default of Flexi) for the fitted curve (Wheeler & Upsdell 2003).

3. Results

3.1. Climatic conditions

The annual means for rainfall, mean daily temperature and hydric balance (difference between rainfall and potential evapotranspiration) recorded during the trial were very similar to the 18-year average (Table 1). However, during the experimental period, February, June and December were drier and August and October were wetter than normal.

3.2. Seasonal change in nutritional quality

DM digestibility (and consequently ME) were lowest ($P < 0.05$) during autumn (Table 2), and for the rest of the year had a fairly stable pattern around 11 MJ kg DM⁻¹ (Table 2 and Figure 1.a). Crude protein was lowest ($P < 0.05$) during summer (Table 2), although variability for the rest of the seasons was greater than for ME content (Figure 1.b), with two peaks occurring at the start of winter and during spring. Non-structural carbohydrate was lower during autumn, whereas NDF content was constant across seasons (Table 2).

Table 1. Means of rainfall, daily temperature and hydric balance recorded over last 18 years and during the trial.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	x
	Historical (18 yrs.)												
Rainfall (mm)	96	78	82	80	58	43	39	47	61	76	98	87	70
Mean daily temp. C	23	21	19	14	11	8	7	9	11	14	18	21	15
Hydric balance* (mm)	-95	-77	-35	9	16	11	3	-11	-18	-35	-53	-108	-33
	During trial												
Rainfall (mm)	111	59	116	90	60	29	43	72	79	139	79	70	79
Mean daily temp. C	23	22	18	14	11	8	6	9	10	14	17	21	14
Hydric balance* (mm)	-89	-134	-4	9	12	-8	7	11	1	59	-67	-161	-30

*difference between rainfall and potential evapotranspiration and X = overall mean of the year.

Table 2. Seasonal variation of nutritional variables in an alfalfa-based pasture.

	Autumn	Winter	Spring	Summer	#PSE
Nutritional variables					
In vitro digestibility (% of dry matter)	71.7 ^a	76.8 ^b	78.8 ^b	75.7 ^{ab}	1.83
Metabolizable energy (MJ ME kg dry matter ⁻¹)	10.8 ^a	11.6 ^b	11.9 ^b	11.4 ^{ab}	0.27
Neutral detergent fiber (% dry matter)	34.5	33.7	33.3	32.2	1.60
Crude protein (% dry matter)	21.5 ^b	22.2 ^b	22.0 ^b	17.3 ^a	1.00
Non structural carbohydrates (% of dry matter)	6.3 ^a	8.8 ^b	10.0 ^b	8.6 ^b	0.58

#PSE= pooled standard error and different letters within rows indicate significant differences between seasons ($P < 0.05$).

Seasonal variations in contents of ME and CP in different sward components are presented in Table 3. The ME of grass parts was significantly lower ($P < 0.05$) in summer, although sheath & stem ME started to decrease during spring. Alfalfa leaf ME decreased during autumn, and legume stem during summer. Dead material had the lowest ME value during autumn. The content of metabolisable energy in leaf fractions (computed mean between legume and grasses) had a trend to lower coefficients of variation (CV) than stem fractions (9.4 and 13.3 % CV, respectively). Legume fractions tended to be more stable in ME than grasses fractions, while the ME of dead components had the highest seasonal variability. Crude protein

content declined significantly ($P < 0.05$) in summer in most of the sward components, but in legume leaflets it was similar throughout the seasons, and in grass stem it was also lower during autumn. Crude protein content was highly variable between seasons in all the components, with an averaged CV of 20.6 %. However, crude protein in the legume leaf was the least variable component (10.6 %).

Table 3. Seasonal variation in contents of metabolisable energy and crude protein in different sward components.

	Autumn	Winter	Spring	Summer	#PSE	*CV
Metabolizable energy (MJ ME kg dry matter⁻¹)						
Grass lamina	10.2 ^{ab}	12.1 ^b	11.8 ^b	9.9 ^a	0.33	10.7
Grass sheath & stem	11.1 ^{ab}	12.7 ^b	10.0 ^a	9.9 ^a	0.53	14.7
Legume leaf	11.3 ^a	12.6 ^b	13.2 ^b	12.3 ^{ab}	0.35	8.1
Legume stem	10.9 ^b	12.8 ^c	10.4 ^{ab}	9.6 ^a	0.29	12.0
Dead	5.2 ^a	7.1 ^b	7.3 ^b	6.0 ^{ab}	0.54	22.2
Crude protein (% of dry matter)						
Grass lamina	22.1	20.1	21.3	18.6	1.90	21.0
Grass sheath & stem	10.8 ^a	15.9 ^b	11.9 ^{ab}	10.0 ^a	1.40	29.0
Legume leaf	32.0 ^b	29.4 ^{ab}	29.5 ^{ab}	26.7 ^a	1.20	10.6
Legume stem	16.0 ^{ab}	19.1 ^b	16.4 ^{ab}	12.6 ^a	1.40	23.0
Dead	8.2 ^{ab}	9.3 ^b	8.6 ^{ab}	7.1 ^a	0.7	19.1

Different letters within rows indicate significant differences between seasons ($P < 0.05$), #PSE pooled standard error and *CV = coefficient of variation.

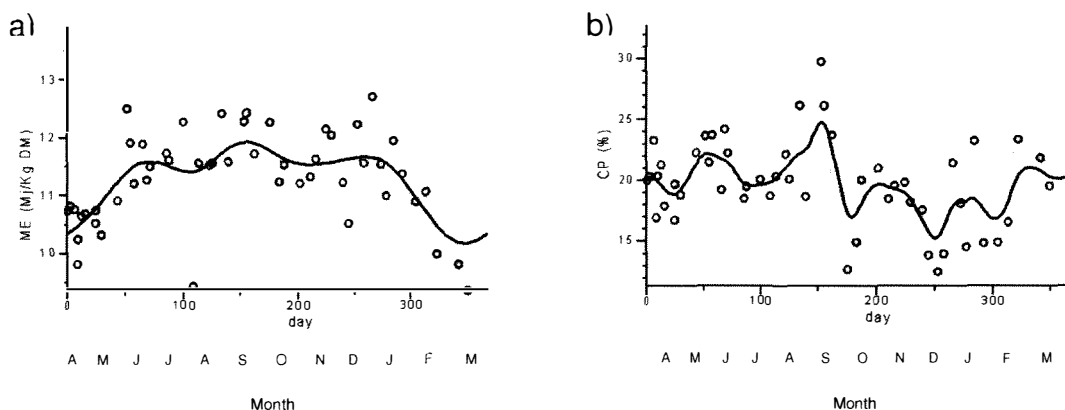


Figure 1. Seasonal change in herbage metabolisable energy (a) and crude protein (b) in pre-grazing samples during the sampling period.

Plotted confidence bands represent 83% probability in the smoothing analysis.

3.3. Seasonal change of morphological and maturity variables

The seasonal variation in morphological and maturity variables in the pasture is shown in Table 4. Herbage mass (>4cm above ground level) was similar through the seasons ($P>0.05$). During summer and autumn, the sward had a higher proportion of legume and dry matter, with lower leaf to stem ratio and green content. This last variable also declined during autumn ($P<0.05$).

Grasses had a higher maturity state during spring and summer, using both MSC and MSW. *M. sativa* was more mature during summer-autumn using MSC. A similar pattern was obtained for MSW but with spring differing also from winter. Mean stages by count and by weight were highly correlated in the three species (with correlation coefficients of 0.93, 0.92 and 0.97 for *M. sativa*, *B. willdenoii* and *D. glomerata*, respectively).

Table 4. Seasonal variation of morphological and maturity variables in an alfalfa-based pasture.

	Autumn	Winter	Spring	Summer	#PSE
Herbage mass (kg dry matter ha ⁻¹ above 4 cm)	1515	1673	1519	1639	149.8
Dry matter content (% of herbage mass)	24.6 ^b	19.6 ^a	17.6 ^a	31.3 ^c	1.29
Green (% of dry matter)	79.2 ^a	84.1 ^a	97.5 ^b	86.0 ^a	2.47
Leaf:stem ratio	1.51 ^{ab}	2.82 ^c	1.98 ^b	1.00 ^a	0.29
Legume (% of Green)	64.2 ^b	43.3 ^a	54.3 ^{ab}	85.1 ^c	6.45
<i>M. sativa</i> (mean stage by counting)+	1.86 ^b	0.61 ^a	1.1 ^a	3.0 ^c	0.20
<i>B. willdenoii</i> (mean stage by counting) *	23.6 ^a	25.8 ^a	47.1 ^b	40.5 ^b	2.82
<i>D. glomerata</i> (mean stage by counting) *	22.2 ^a	25.8 ^a	36.4 ^b	36.6 ^b	2.12
<i>M. sativa</i> (mean stage by weighing) +	2.1 ^b	0.89 ^a	1.6 ^b	3.4 ^c	0.26
<i>B. willdenoii</i> (mean stage by weighing) *	24.5 ^a	26.3 ^a	47.3 ^b	53.2 ^b	3.74
<i>D. glomerata</i> (mean stage by weighing) *	22.7 ^a	25.9 ^a	40.3 ^b	39.6 ^b	2.96

PSE=pooled standard error, + Quantitative scale (Fick & Mueller 1989), * Quantitative scale (Simon & Park 1983) see material and methods for further explanation about scales and different letters within rows indicate significant differences between seasons ($P<0.05$).

3.4. Relationships between variables

Digestibility was significantly correlated with NDF, NSC and Protein (correlation coefficients of -0.62, 0.41 and 0.36, respectively), and NDF content with NSC (-0.32). "Best fit" equations from "step-wise" regression analysis within each season relating herbage quality variables and morphological and maturity variables of the pasture are presented in Table 5. During summer and autumn, nutritional variables were mostly predicted from morphological variables. Protein could not be predicted either in summer or winter, and autumn presented the lower regression coefficient

($R^2=0.54$). The content of non-structural carbohydrates was only predicted significantly in spring. In the cases when maturity corrected by weighing was selected, they could be replaced acceptably by the corresponding mean stage by counting without much loss of prediction capability, except for the case of Dig in winter.

Table 5. Regression equations of herbage quality variables and morphological and maturity variables in an alfalfa-based pasture.

Regression model	Season	R^2	RMSE	p value
Autumn				
Dig = -183 + 0.24 Green - 0.009 HM + 11.23 fDACTw		0.86	3.63	0.00
Dig = -238 - 0.01 HM + 14.7 fDACTc		0.80	3.69	0.00
NDF = 30.7 + 1.23 DM - 0.33 Green		0.65	4.34	0.00
CP = 21.9 - 0.003 HM + 0.06 Legume		0.54	2.36	0.02
Winter				
Dig = 103.9 - 0.006 HM - 4.67 fALFw - 0.44 fBROw		0.54	5.60	0.02
Dig = 87.3 - 0.006 HM		0.27	6.60	0.04
NDF = 24.1 + 5.33 fALFw + 0.003 HM		0.63	3.89	0.02
NDF = 22.1 + 8.37 fALFc + 0.003 HM		0.52	4.41	0.01
Spring				
Dig = 81.6 - 0.003 HM - 0.15 fBROw		0.69	2.26	0.01
Dig = 99.1 - 0.33 fDACTc - 0.16 fBROc		0.78	1.91	0.00
NDF = 24.2 + 0.11 fBROw + 0.002 HM		0.65	1.76	0.01
NDF = 21.6 + 0.13 fBROc + 0.003 HM		0.69	1.63	0.01
CP = 47.3 - 0.004 HM - 0.76 DM - 3.39 fALFw		0.75	3.08	0.01
CP = 47.3 + 0.95 Green - 0.005 HM - 8.9 fALFc		0.87	2.21	0.01
NSC = 7.9 + 0.35 DM - 0.07 fBROw		0.58	1.60	0.03
NSC = 20.4 - 0.06 Legume - 0.153 fBROc		0.59	1.57	0.02
Summer				
Dig = 41.2 + 0.4 Green		0.58	3.10	0.00
NDF = 73.3 - 14.9 Green - 0.3 LeafSt		0.87	2.40	0.00

RMSE=root mean square error, fALFc= Mean stage by counting of *M. sativa*, fALFw= Mean stage by weighing of *M. sativa*, fBROc= Mean stage by counting of *B. wildenowii*, fBROw= Mean stage by weighing of *B. wildenowii*, fDACTc= Mean stage by counting of *D. glomerata*, fDACTw= Mean stage by weighing of *D. glomerata*, HM= herbage mass DM= dry matter percentage, Green=green percentage, Legume= legume percentage and LeafSt=leaf:stem ratio.

The overall relationship between nutritional and morphological-maturity estimates was explored with a canonical correlation analysis. From the possible four pairs of canonical factors (the four nutritional variables constrained by the number of canonical pairs), one pair had significant differences ($P<0.05$) with plant maturity expressed in mean stage by counting or mean stage by weighing, hence both alternatives are shown (Table 6). Within the nutritional variables, Protein and

metabolisable energy contributed the most to their canonical factor. In the case of morphology and maturity variables, maturity stage of *M. sativa*, dry matter content and herbage mass had the highest (and negative) coefficients, followed by a positive coefficient of green content of the dry matter. Comparing both methods of expressing maturity, mean stage by weighing tended to present a slightly higher explanation of the multivariate dispersion ($R^2 = 0.81$) than mean stage by counting ($R^2 = 0.77$).

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.

Correlations between nutritional variables and their canonical variables	Canonical factors	
	CF-MSW ¹	CF-MS ²
Metabolisable energy (MJ ME kg dry matter ⁻¹)	0.77	0.79
Neutral detergent fiber (% of dry matter)	-0.53	-0.51
Crude protein (% of dry matter)	0.85	0.83
Non structural carbohydrates (% of dry matter)	0.36	0.43
Correlations between morphological and maturity variables and their canonical variables		
Herbage mass (kg DM ha ⁻¹ above 4 cm)	-0.56	-0.57
Dry matter content (% of herbage mass)	-0.59	-0.60
Green (% of DM)	0.44	0.49
Leaf:Non leaf ratio	0.30	0.31
Legume (% of Green)	-	-
<i>M. sativa</i> (mean maturity stage)	-0.72	-0.72
<i>B. wildenowii</i> (mean maturity stage)	-	-
<i>D. glomerata</i> (mean maturity stage)	-	-
Summary statistics		
Canonical R ²	0.81	0.77
³ P _{mv}	76.9	69.9
⁴ % Raw var.	26.7	22.6
Significance	**	**

Coefficients less than 0.25 suppressed, ¹ Canonical factor for mean maturity state estimated by weighing, ² Canonical factor for mean maturity state estimated by counting, ³ Proportion of multivariate dispersion explained, ⁴ raw variance of herbage quality variables explained, ** P<0.01 and NS= not significant.

4. Discussion

4.1. Seasonal change in nutritional quality

The herbage quality of bulk harvests was maintained to a high standard throughout the experiment, although protein declined in summer and ME and NSC declined

during autumn. This general pattern is likely to be a consequence of the relatively intensive grazing management carried out during this study. The demonstration of a beef cattle unit of which this trial pasture is a part (Di Nezio et al. 2002), makes intensive use of the pasture area (less than 50% of the beef area, the rest are stubble from cash crops and forage crops) in a combination of cow-calf and beef cattle finishing systems with stocking rate and animal production levels well above the values for the region. Intensive use of pastures is a key tool to keep the sward immature by moderating the development of structural tissue (Nelson & Moser 1994; Clark 1995; Hodgson & Brookes 1999), and these results are also in agreement with the nutritional observations in a New Zealand beef cattle pasture managed intensively (Annex B).

The observed pattern of protein levels throughout the seasons were similar to that obtained with pastures of similar characteristics managed under intensive rotational systems during two years (Kloster et al. 2000), where the authors observed protein values by season of 23.7, 26.0, 25.8 and 23.4 for autumn, winter, spring and summer, respectively. The protein values of the present study clearly exceeded (except for the summer) the recommended protein content of herbage required for very young growing animals, i.e. 15-18% crude protein (Hodgson & Brookes 1999).

The relationships between the quality change of the bulk samples (Table 2) and that of plant parts (Table 3) must be accepted with caution, as sample numbers were not the same. However, they provide some indication of quality changes within the canopy, showing that ME content of grass fractions and alfalfa stem declined during summer, and in the case of grass stem there was some decrease during spring, which is in agreement with the changes in DM digestibility observed by Mowat et al. (1965) in *M. sativa* and Berg & Hill (1989) in *D. glomerata*. Leaf components had a lower coefficient of variation in ME content and less marked variation in protein, in comparison with that observed in stems. In a study carried out during two springs on alfalfa, leaf had 4 and 19 % CV in digestibility and Protein values, respectively, whereas stem presented 23.0 and 40.5 % CV for the same nutrients (Christian et al. 1970).

4.2. Seasonal change of morphological and maturity variables

The higher proportion of alfalfa during summer-autumn (75%) than winter-spring (48%) in this experiment is in agreement with the results of Kloster et al. (2000) in pasture of similar composition (80 and 59 % of alfalfa in canopy DM for spring summer and autumn-winter, respectively). This seasonal pattern is likely to be associated with the different growth patterns of the species and to the different factors for which grass and legume in mixture compete (McKenzie et al. 1999). The intensive sward utilisation moderated the normal maturity process, although leaf to stem ratio declined during summer. High temperature promotes plant maturation with proportionally more stem growth (Buxton & Fales 1994), decreasing the leaf to stem ratio, with a marked decline in the quality of the stems and increased senescence of green material (Christian et al. 1970; Nelson & Moser 1994).

Spring showed the highest level of green percentage, similarly to that observed by Kloster et al. (2000) in an alfalfa-grass pasture under grazing. These authors reported averages of 87.5 and 99.0 of green percentage for autumn-winter and spring-summer, respectively, for two years of measurement. Dry matter content of the pasture increased significantly during summer, which is in agreement with that reported by Christian et al. (1970).

Clearly the combination of species resulted in a spread of pasture maturity. Although the three species were most mature during summer, grasses increased in maturity during the spring, and alfalfa extended maturity to the autumn (Table 4). The effect of increased temperature on plant maturity has been well established (Buxton & Fales 1994), but plant maturity integrates multiple environmental factors and represents the physiological and ecological status of the plant stand (Sanderson 1992).

Although there was a significant seasonal pattern throughout the year, the intensive use of the pasture meant that it was maintained in a relatively immature state. Consideration must be taken of bloat incidence as the relationship between highly immature alfalfa and the problem level has been established (Thompson et al. 2000). However, on the beef cattle unit where this study was developed, bloat

was controlled using different management alternatives (Majak et al. 2001).

There was a very high correlation between MSC and MSW, with an overall correlation between species of $r=0.94$, which is in agreement with that reported by others using alfalfa pasture (Mueller & Fick 1989). However, a better capability of MSW has been mentioned (Fick et al. 1994), but MSC is less time demanding, and is simply the arithmetic average of the quantitative maturity stage of individual tillers and stems. As MSC does not take into account the change in size of the stems and tillers, this could be an important bias when substantial morphological plant changes are occurring. One study under grazing conditions (Smart et al. 2001) reported that MSC became an increasingly poor predictor of leaf to stem ratio as grazing progressed in the growing season of a big bluestem pasture. The prevention of maturity by intensive grazing in this study is likely to have contributed to the higher association between the two used methods for obtaining maturity estimates.

4.3. Relationship between variables

The important correlation between NDF and Dig is in agreement with the observation of Pagella et al. (1996). As expected by the seasonal changes in nutritional variables (Table 2) and morphological and maturity variables (Table 4), nutritional predictors changed seasonally (Table 5). For this reason, no significant predictor could be identified when the overall dataset was used without grouping by season (result not shown). It is worth noting that changes in grasses became important during spring, with earlier maturity than alfalfa (Table 4), where the grass stem plus sheath started to decrease in ME and protein content (Table 3).

Canonical correlation analysis was an interesting tool for exploring the global relationship between the two sets of variables (i.e. morphological-maturity and nutritional indicators). Maturity of *M. Sativa*, and the increase of herbage mass and dry matter percentage affected negatively the ME and protein contents. It is likely that these results may be associated with changes occurring mainly in alfalfa stems. Stems decrease in quality faster than leaves in most forage plants, specially when plants approach maturity (Nelson & Moser 1994), and a close association between MSW and digestibility of alfalfa stem has been demonstrated

(Sanderson & Wedin 1889; Sanderson et al. 1989).

Poor prediction capability of plant maturity indicators has been observed when the herbage is used more intensively, therefore moderating the usual changes that affect herbage quality. The disturbance of the sward structure caused by low herbage allowance, resulted in poor prediction of mean stage by count of leaf:stem ratio, protein and NDF, especially when compared with non-grazed or laxly grazed swards of *Adropogon gerardii* (Smart et al. 2001). However, the combination of estimates of morphological and maturity variable applied here seemed to improve the herbage quality predictors.

Although there was a decline of DM digestibility (and consequently ME) during autumn and of crude protein during summer, herbage quality was consistently high throughout the year. This was in agreement with a NZ pasture (ryegrass and white clover) managed under an intensive system (Annex B). The significant relationships established by different statistical tests between morphological and maturity estimates and herbage nutritional variables in a pasture are promising in terms of gaining understanding of the seasonal change of herbage quality. However, their potential applicability in a wider context is highly restricted at present. Further investigation is required to determine their implication under alternative pasture managements.

References

- A.O.A.C. 1960: *Official Methods of Analysis*. 9th ed. AOAC. Washington:957 p.
- Berg C.; Hill R. 1989: Maturity effect on yield and quality of spring harvested orchardgrass forage. *Crop Science* 29:944-948.
- Buxton D. R.; Fales S. L. 1994: Plant-environment and quality. In: Fahey, G. C. Jr.; Collins, M.; Mertens, D.R.; Moser, L.E. Eds. *Forage Quality, Evaluation, and Utilization*. Published by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. 155-199.
- Christian K. R.; Jones D. B.; Freer M. 1970: Digestibility and chemical composition

- of fractions of lucerne during spring and summer. *Journal of Agricultural Science. Cambridge* 75:213-222.
- Clark E. A. 1995: Maintaining forage quality by intensive management. *Proceedings of the Western Canadian Dairy Seminar* 7: 135-146.
- Corson D. C.; Waghorn G. C.; Ulyatt M. J.; Lee J. 1999: NIRS: Forage analysis and livestock feeding. *Proceeding of the New Zealand Grassland Association* 61:127-132.
- Cosgrove G. P.; Betteridge K.; Thomas V. J.; Corson D. C. 1998: A sampling strategy for estimating dairy pasture quality. *Proceedings of the New Zealand Society of Animal Production* 58:25-28.
- Di Nezio L.; Duhalde J.; Jensen M. y. B. C. 2002: Resultados de la Unidad Ganadera de vacunos para carne en la zona mixta cerealera. *Carpeta De Actualización En Ganadería* :1-4.
- Earle D.; McGowan A. 1979: Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19:337-343.
- Elizalde J. C.; Merchen N. R.; Faulkner D. B. 1999: Fractioning of fiber and crude protein in fresh forages during the spring growth. *Journal of Animal Science* 77:476-484.
- Fick G. W.; Mueller S. C. 1989: Alfalfa: quality, maturity, and mean stage of development. *Information Bulletin Nr.217, College of Agriculture and Life Science, Cornell University, Ithaca, NY.* 13 p.
- Fick G. W.; Wilkens P. W.; Cherney J. H. 1994: Modeling forage quality changes in the growing crop. *In: Fahey, J.R. ed. Forage Quality, Evaluation and Utilization.* American Society of Agronomy, Inc.:757-795.
- Frame H.; Warn L.; McLarty G. 2002: Effects of grazing system and phosphorus application on pasture quality. *Wool Technology and Sheep Breeding* 50:465-470.

- Frank A. B.; Hofmann L. 1989: Relationship among grazing management, growing degree days, and morphological development for native grasses on the Northern Great Plains. *Journal of Range Management* 42:199-202.
- Goering H. K.; Van Soest P. 1970: Forage fiber analysis (apparatus reagents, procedures and some applications). *Agriculture Handbook Nr 379, USDA. Washington, DC.* 20 p.
- Hintz R. W.; Albrecht K. A. 1991: Prediction of alfalfa chemical composition from maturity and plant morphology. *Crop Science* 31:1561-1565.
- Hodgson J.; Brookes I. M. 1999: Nutrition of grazing animals. *In: White, J. & Hodgson, J. Eds. New Zealand Pasture and Crop Science.* Oxford University press. 117-132.
- Kloster A. M.; Latimori N. J.; Amigone M. A. 2000: Evaluación de dos sistemas de pastoreo rotativo a dos niveles de asignación de forraje en una pastura de alfalfa y gramíneas. *Revista Argentina De Producción Animal* 20:187-198.
- Litherland A. J.; Woodward S. J. R.; Stevens D. R.; McDougal D. B.; Boom C. J.; Knight T. L.; Lambert M. G. 2002: Seasonal variations in pasture quality on New Zealand sheep and beef farms. *Proceedings of the New Zealand Society of Animal Production* 62:138-142.
- Lynk S. O.; Gee G. W.; Downs J. L. 1990: The effects of water stress on phenological and ecophysiological characteristics of cheatgrass and Sandberg's bluegrass. *Journal of Range Management* 43:507-513.
- Machado C. F.; Berger H.; Morris S. T.; Hodgson J.; Copes M.; y Duhalde J. 2003: Calibración estacional de mediciones de altura del canopeo con plato y con bastón de altura para estimar la biomasa de forrajera de una pastura base alfalfa. *Revista Argentina De Producción Animal* 23:73-74 (resumen).
- Majak W.; Hall J. W.; McAllister T. A. 2001: Practical measures for reducing risk of alfalfa bloat in cattle. *Journal of Range Management* 54:490-493.
- Matthew C.; Lawoko C. R. O.; Korte C. J.; Smith D. 1994: Application of canonical

- discriminant analysis, principal component analysis, and canonical correlation analysis as a tool for evaluating differences in pasture botanical composition. *New Zealand Journal of Agricultural Research* 37:509-520.
- McKenzie B. A.; Valentine I.; Matthew C.; Harrington K. C. 1999: Plant interactions in pastures and crops. *In: White, J. & Hodgson, J. Eds. New Zealand Pasture and Crop Science*. Oxford University press. 29-44.
- Moller S. N. 1997: An evaluation of major nutrients in dairy pasture in New Zealand and their effects on milk production and herd reproductive performance. *PhD Thesis. Massey University, Palmerston North, New Zealand:342 p.*
- Mowat D. N.; Fulkerson R. S.; Tossell W. E.; Winch J. E. 1965: The in vitro digestibility and protein content of leaf and stem portions of forages. *Canadian Journal of Plant Science* 45: 321-330.
- Mueller S. C.; Fick G. W. 1989: Converting alfalfa development measurements from mean stage by count to mean stage by weight. *Crop Science* 29:416-420.
- Nelson C. J.; Moser L. E. 1994: Plant factors affecting forage quality. *In: Fahey, G. C. Jr.; Collins, M.; Mertens, D.R.; Moser, L.E. Eds. Forage Quality, Evaluation, and Utilization*. American Society of Agronomy:115-154.
- Owens V. N.; Albretch K. A.; Hintz R. W. 1995: A rapid method for predicting alfalfa quality in the field. *Journal of Production Agriculture* 8:491-495.
- Pagella J. H.; Jouve V. V.; Strizler N. P.; Viglizzo E. F. 1996: Estimación de la digestibilidad in vitro de especies forrajeras utilizando parámetros de composición química. *Revista Argentina De Producción Animal* 16:25-34.
- Pearson C. J. 1997: Agronomy of grassland systems. 2nd Ed. Cambridge [England]; New York, NY, USA. Cambridge University Press:222 p.
- Pichard G.; Alcalde J. A. 1990: Determinación de carbohidratos no estructurales. *In: Ruiz, M.E. and Ruiz, A Eds. Nutrición De Rumiantes: Guía metodológica de Investigación*. IICA. San José De Costa Rica:3-20.:3-20.

- Sanderson M. 1992: Morphological development of Switchgrass and Kleingrass. *Agronomy Journal* 84:415-419.
- Sanderson M.; Hornstein J.; Wedin W. 1989: Alfalfa morphological stage and its relation to *in situ* digestibility of detergent fiber fractions of stems. *Crop Science* 29:1315-1319.
- Sanderson M.; Wedin W. 1989: Phenological stage and herbage quality relationship in temperate grasses and legumes. *Agronomy Journal* 81:864-869.
- SAS/STAT. 2001: Release. 8 SAS. *Inst. Inc., Cary, NC.*
- Saul G. R.; Kearney G. A.; Flinn P. C.; Lescun C. L. 1999: Effects of superphosphate fertiliser and stocking rate on the nutritive value of perennial ryegrass and subterranean clover herbage. *Australian Journal of Agricultural Research* 50: 537-545.
- Schlegel M. L.; Wachenheim C. J.; Benson M. E.; Ames N. K.; Rust S. R. 2000: Grazing methods and stocking rates for direct-seeded alfalfa pastures: II. Pasture quality and diet selection. *Journal of Animal Science* 78:2202-2208.
- Simon U.; Park B. 1983: A descriptive scheme for stages of development in perennial forage grasses. *Proceedings of the XIV International Grassland Congress*: 416-418.
- Smart A. J.; Schacht W. H.; Moser L. E. 2001: Predicting leaf/stem ratio and nutritive value in grazed and nongrazed big bluestem. *Agronomy Journal* 93:1243-1249.
- Steel R. G. D.; Torrie J. H. 1980: *Principles and Procedures of Statistics: A Biometrical Approach*. 2nd Ed. McGraw-Hill Publishing Co., New York. 631p.
- Sulc M.; Albrecth K. A.; Cherney J. H.; Hall M. H.; Mueller S. C.; Orloff S. 1997: Field testing a rapid method for estimating alfalfa quality. *Agronomy Journal* 89:952-957.
- Thompson D. J.; Brooke B. M.; Garland G. J.; Hall J. W.; Majak W. 2000: Effect of

stage of growth of alfalfa on the incidence of bloat in cattle. *Canadian Journal of Animal Science* 80:725-727.

Tilley J. M. A.; Terry R. A. 1962: two-stage technique for the in vitro digestion of forage crops. *Journal of the British Grassland Society* 18 :104-111.

Wheeler D. M.; Upsdell M. P. e. 2003: Flexi 3.0. Bayesian Smoother. *Reference Manual* :306 p.

Modelling

Modelling studies of grain feeding in a grazing-based beef finishing operation:

1. Development of a "beef cattle finishing unit" simulator

Abstract

This chapter describes a dynamic "beef cattle finishing unit" simulator (BeefSim) that represents the main biological and some economic indicators for intensively grazed beef cattle systems using strategic grain supplementation. The model is built in Extend packageTM and driven by herbage allowance and stocking rate, with an associated procedure for pasture conservation. The model runs from a day to several years, and can simulate different levels of grain supplementation, stocking rates, and herbage allowances. BeefSim is organised in three modules, biophysical, decision and economic. In the biophysical module daily nutritional and feed budgets are estimated, and from the metabolisable energy and crude protein intake animal performance is computed. The decision module incorporates a monitoring system for pasture cover and mean animal liveweight in relation to pre-defined targets as a basis for management adjustments. The economic module gives a valorization to different physical inputs and outcomes of the model to estimate a gross margin. Three different run modes can be applied, fully interactive (requires the user to take the decision in real time), automatic (decisions are summarized in a user-defined grazing strategy) and automatic plus optimization. It can be concluded that the model contains enough specification for use as a research tool for intensively managed rotational grazing beef cattle finishing systems.

Key-words: Simulator; dynamic; beef cattle finishing; grazing; rotational; grain supplementation

1. Introduction

One challenging and sometimes frustrating issue that must be faced by pastoral researchers, is to demonstrate quantitatively the value of research in a whole-system context. This is relevant for technology transfer to the industry, and also for funding applications. However, in order to have some control, most of the analytical information about grazing systems is obtained at scales of space and time that are smaller than the scales at which it is desired to apply the knowledge (Demment et al. 1995). Consequently, the contribution of simulation in the study of grazing

systems has been recognised (Wright & Dent 1969), and there are many different models available where pastoral-based beef production has been simulated (Doyle et al. 1989; Marshall et al. 1991; Freer et al. 1997; Loewer 1998).

One of the major problems of developing simulation models of grazing systems is the lack of suitable biological data (Wright & Dent 1969; Dove 1996), and this can also apply where there is a need to adapt a model developed for different conditions. In projects of a wider scope and magnitude, this issue has been solved by cooperative research between field researchers and model developers (Cohen et al. 2003). In a more restrictive application, the development of a specific model simultaneous to research, has proved to be a highly effective way to expand the scope of the experimentation (McKinion 1980; Walker et al. 1989; Garcia et al. 2000).

The implications to the animal and to beef cattle systems of "starch" grain supplementation under grazing conditions has been summarised in Chapter 1, and studied in short-term grazing experiments in Chapters 3 and 4. However, a more integral quantification of potential on-farm benefits of this information is not easily predicted. When component information is incorporated into a grazing-based system, often interactions operate in complex ways and may depend on different characteristics of the farm, which highlights the importance of a whole-farm approach to study problems (Pannell 1999). Farmlot-based studies have been shown to be effective for research into beef cattle finishing systems (Garcia et al. 1998; Kloster et al. 2003), but they are costly and limited by the number of treatments, replications and duration of the study. In a sense, the use of a simulation model can be regarded as a whole-farm research approach (Wright & Dent 1969).

The main objective of this chapter was to develop a simulation tool in the shape of a generic "beef cattle finishing unit" simulator (hereafter: BeefSim), to evaluate in a system context the implication of alternative grazing strategies. This task was developed by synthesizing pertinent information for a pasture-based beef cattle finishing system, and this chapter details the rationale and procedures used in the simulator. In this approach, modelling was centred on biological processes to study the impacts of alternative grazing and supplementation strategies involving maize

grain feeding, but economic assessment was included as a necessary constraint in order to ensure that technical efficiency was not pursued at the expense of economic efficiency.

2. Model description

2.1. Specificity, justification and main features

This model represents a rotational grazed beef cattle finishing system, using daily herbage DM allowance as the unit for herbage allocation. “Beefsim” represents intensive beef cattle systems, particularly 12-month systems that use strategic grain supplementation to finish heifers and steers of British breeds (280 and 340-420 kg LW, respectively) before new weaners (150-200 kg LW) enter in the autumn (Arosteguy 1984; Rearte 1999; Machado et al. 2001). To be able to operate at a farm level and different scales of time (i.e. from single day to multiple years) and include nutrient and feed budgeting, different components and procedures have been used directly or adapted from the literature. The possibility of using directly an existing model was evaluated and discarded at an early stage of the study, based on data availability and flexibility to match the objectives of this thesis. The model runs in daily timesteps, which have been adequate in other whole-farm models (Doyle et al. 1989; Herrero et al. 2000; Cros et al. 2003) . Spatially, the lowest level at which the model operates is the grazing strips within a paddock and individual animals within a single mob.

The following processes are modelled: herbage growth, herbage, silage and grain intakes, diet composition, animal growth, feed allocation, silage-making, annual sales and purchases, and fertilization (uncalibrated). Herbage and total intake are estimated daily from sward characteristics, supplements (if any) and animal characteristics, and animal performance is estimated for each individual animal based on metabolisable energy and crude protein intake.

Commercial pastoral farms with similar biophysical and economic characteristics frequently are different in their outputs, as a consequence of differences in the management skill of graziers (Cros & Duru 1997). These authors developed an

explicit and rigorous modelling of alternative management strategies for their dairy model (SEPATOU), in the format of a decision module associated with a module of biophysical parameters (herbage growth, herbage consumption, animal performance). A similar approach has been followed in cow-calf systems (Romera et al. 2004) and a simplified option has been adopted for this model, in the shape of a "manager" block, constituting the decision module. The "manager" is in charge of applying the grazing strategy and adjusting components (contingency actions) in agreement to prior researcher-defined criteria. An economic module was added to the biophysical and decision modules for a more complete assessment of grain feeding strategies. A general outline of how the three modules interact is shown in Figure 1. The three modules are subsequently described separately.

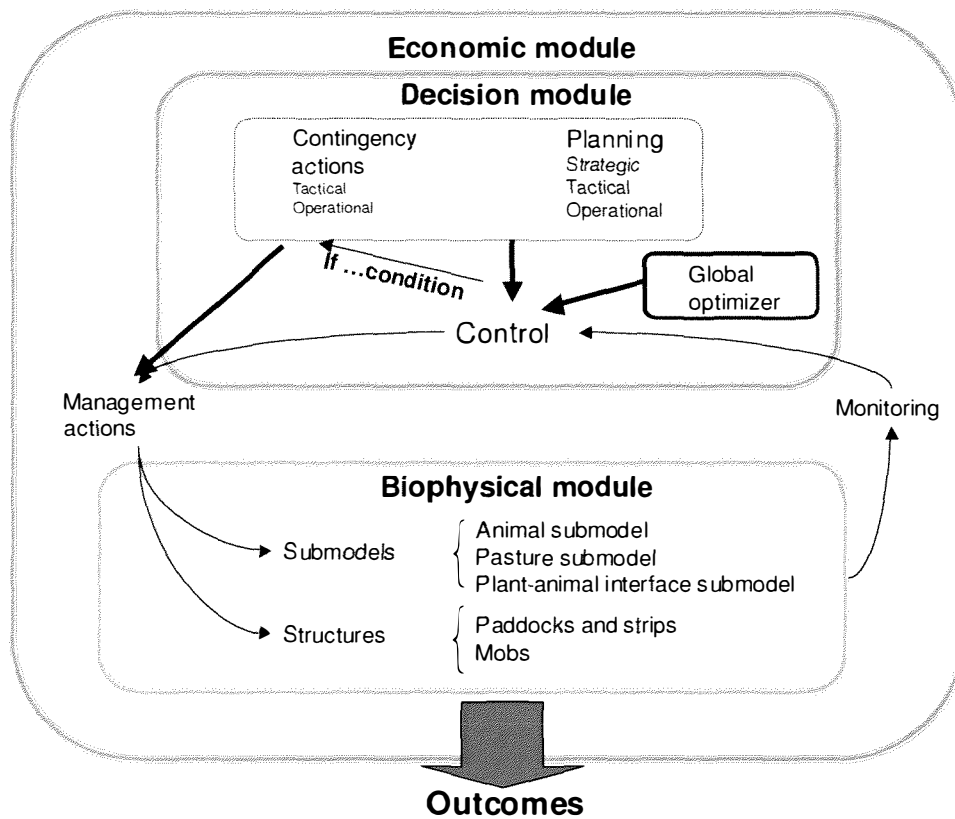


Figure 1. Cybernetic representation of the biophysical, decision and economic modules in BeefSim.

The model is deterministic, however when standard deviations of the imputed herbage accumulation rates are provided, different stochastic simulations can be generated. In the way time is treated, the model is dynamic, and in terms of the description for the understanding of the system, the model is mechanistic (France

& Thornley 1984). However, specific components and relationships are empirical. The model uses the modular-based simulation shell provided by 5.0 Extend™ (Imagine That, Inc) using its compiled language (ModL). The main advantages of this software are its interactivity (model parameters and logic can be changed in real time), reusability of developments, visual transparency (structure and behaviour can be conveyed at a glance), interapplication communication (i.e. easily connected with spreadsheets, etc.) and a built-in evolutionary optimiser (Krahl 2002).

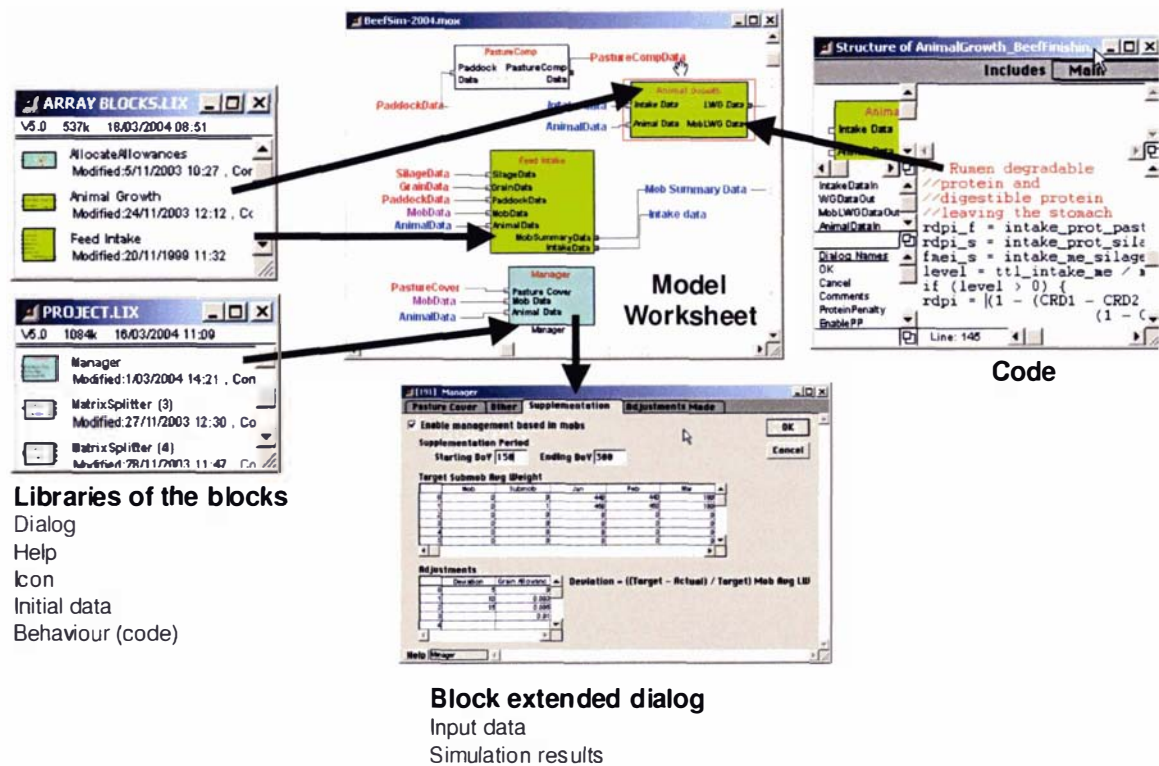


Figure 2. Extend modelling structure in the BeefSim model.

The model has 178 blocks communicated using resizable dynamic arrays. The customized blocks (main blocks ordered by functionality and simulation orders are presented in Appendix 6.A.) present a code (set of equations written in ModL), that provides their behaviour, and some present dialogs to enter input data to observe the simulation results (Figure 2). Blocks are stored in libraries, from where they are copied to the model worksheet when needed, and connected with other blocks to develop the whole model. The potential of using Extend™ to develop whole-farm models has been described elsewhere (Brennan & Gooday 1998; Barioni et al. 1999). Model abbreviations and their descriptions are alphabetically presented in

Table 1 (pp 172), and constants are presented in Tables 2 (p. 176), and 3 (p. 177).

2.2. Biophysical module

This module represents the main biological components of a pastoral-based beef finishing system. This module is divided into submodels, structures and management actions.

2.2.1. Submodels

2.2.1.2. Pasture submodel

The objective of this sub-model was to devise a tool that allows pasture production and utilization to be integrated within a whole-farm model, allowing short- and long-term evaluation of maize grain supplementation strategies. The processes that govern primary production are relatively well documented, and there are in the literature climate-driven models of herbage growth with varying grades of realism, accuracy and purpose (Doyle et al. 1989; Herrero et al. 1998; Moir et al. 2000; Thornley 2001; McCall & Bishop-Hurley 2003). The construction of a detailed mechanistic description of herbage growth including weather and soil components was beyond the scope of this study. Soil models are highly demanding in appropriate data for parameterisation and validation (Herrero et al 2000) and Argentinean beef cattle systems consist of heterogeneous pastures and soils (Rearte 1998). However, a climate and soil component could be added where specific soil, plant and climatic parameters are available.

The model uses user-defined monthly herbage accumulation rates (HAR), as done by Woodward et al. (1993) and Garcia et al. (2000). However, average herbage accumulation rate is converted to herbage gross growth rates (GGR) through the procedure described below. Although this procedure requires additional assumptions to be made, it does allow the division of herbage mass into leaf (L), sheath and stem (St) and dead (D) proportions (Doyle et al. 1989; Cacho et al. 1995). This division is important for an explicit representation of sward conditions (eg. quality losses during the carry-over of herbage between grazings). Additional advantages of this alternative are described in the herbage intake and diet composition sections (2.2.1.2. and 2.2.1.3., respectively). Some authors have

suggested incorporation of the spatial structure of the sward (Herrero et al. 1998), but the lack of information about L, St and D proportions within the sward strata in the current project limited its incorporation. Therefore:

$$HM = L + St + D \quad \text{Eqn. 1}$$

Where **HM** is herbage mass above ground level (kg DM ha⁻¹) and **L**, **St** and **D** represent kg DM ha⁻¹ of leaf, sheath plus stem and dead herbage masses above ground level, respectively.

Under grazing, herbage accumulation rate is a function of simultaneous and interacting processes of herbage gross growth, senescence and consumption (Lemaire & Agnusdei 2000). These factors make it unfeasible to convert realistically between HAR and GGR under grazing conditions. However, most of the available HAR (and those used in the model) are estimated by cutting techniques (Corrall & Fenlon 1978). Hence, HAR recorded under cutting conditions is:

$$HAR = GGR - S \quad \text{Eqn. 2}$$

Where **HAR** is the herbage accumulation rate (kg DM ha⁻¹ d⁻¹), **GGR** is herbage gross growth rate (kg DM ha⁻¹ d⁻¹) and **S** is the senescence rate (kg DM ha⁻¹ d⁻¹). **GGR** was modelled as a function of leaf mass, in a Mitscherlich-type function (Thornley & Johnson 1990) as:

$$GGR = HAR_{input} f_{adj} (1 - e^{-(\beta_1 L)}) \quad \text{Eqn. 3}$$

Barioni (1997) used **HAR_{input}** estimated by cutting techniques to calculate **GGR** including a dimensionless factor (**f_{adj}**) calibrated through a regression analysis from a constructed dataset. Here **f_{adj}** is included but in a different approach, estimating **f_{adj}** mathematically from leaf ceiling mass and β_1^4 (Eqn. 4). A description of assumptions and procedure used to estimate Eqn. 4 are shown in

⁴ Constant descriptions are presented in Table 1 and 2 and not mentioned in the text, except when needed for explanation.

appendix 6.B. Therefore, $HAR_{Input} f_{adj}$ converts HAR_{Input} (input of the model, assumed as the maximum achievable HAR) backwards into GGR expressed in (kg DM ha⁻¹ d⁻¹), L is leaf mass (kg DM ha⁻¹) and β_1 is a seasonal parameter (Table 2) that represents the partition of the aerial biomass production among leaf and stem parts (Doyle et al. 1989; Cacho et al. 1995). Therefore:

$$f_{adj} = \frac{\beta_1 L_{Ceil}}{\beta_1 L_{Ceil} + \left(1 - \ln\left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}}\right)\right) (1 - e^{\beta_1 L_{Ceil}})} \quad \text{Eqn. 4}$$

Where L_{Ceil} is leaf ceiling mass (kg DM ha⁻¹) described as:

$$L_{Ceil} = \frac{MaxL_{Ceil} + MinL_{Ceil}}{2} + (MaxL_{Ceil} - MinL_{Ceil}) \cos\left(2\pi \frac{t - \beta_2}{365}\right) \quad \text{Eqn. 5}$$

Where $MaxL_{Ceil}$ and $MinL_{Ceil}$ are defined limits for the seasonal variation of ceiling mass (Cacho et al. 1995), with values of 4500 and 2000 kg DM leaf ha⁻¹ and t is the simulation time (day of the year, 0=1 March by default). Leaf senescence (S_L , kg DM leaf ha⁻¹ d⁻¹) is described as a linear function of L as:

$$S_L = L\beta_3 \quad \text{Eqn. 6}$$

And

$$\beta_3 = \frac{HAR_{Input} f_{adj} (1 - e^{\beta_1 L_{Ceil}})}{L_{Ceil}} \quad \text{Eqn. 7}$$

Where β_3 is the slope of the linear function of leaf senescence versus leaf mass expressed in kg DM ha⁻¹ (Appendix 6.B.), $HAR_{Input} f_{adj}$ converts HAR_{Input} (input of the model) backwards into GGR (kg DM ha⁻¹ d⁻¹) and L_{Ceil} is leaf mass (kg DM ha⁻¹). Senescence of St component (S_{St} , kg DM ha⁻¹ d⁻¹) is assumed to be similar to that estimated for the L fraction. The rate of decomposition of D components has been modelled as affected by temperature and humidity (McCall & Bishop-Hurley 2003). However, in the absence of soil and climate submodels, a simplified

approach has been followed (Cacho et al. 1995) as:

$$D_R = D\beta_4 \quad \text{Eqn. 8}$$

Where D_R is dead decay rate ($\text{kg DM ha}^{-1} \text{d}^{-1}$) and D is dead herbage mass (kg DM ha^{-1}). Finally, the dynamics of herbage accumulation rate in the absence of grazing for each existing strip of the farm (section 2.2.3.1. Feed allocation) is estimated from pre-grazing herbage conditions as⁵:

$$L \leftarrow L + \beta_5 GGR - S_L \quad \text{Eqn. 9}$$

$$St \leftarrow St + (1 - \beta_5) GGR - S_{St} \quad \text{Eqn. 10}$$

$$D \leftarrow D + S_L + S_{St} - D_R \quad \text{Eqn. 11}$$

Where L is leaf mass (kg DM ha^{-1}), GGR is herbage gross growth rate (kg DM ha^{-1}), S_L is leaf senescence rate (kg DM ha^{-1}), St is sheath & stem mass (kg DM ha^{-1}), S_{St} is the sheath & stem senescence rate ($\text{kg DM ha}^{-1} \text{d}^{-1}$), D is dead herbage mass (kg DM ha^{-1}) and D_R is dead herbage decay rate ($\text{kg DM ha}^{-1} \text{d}^{-1}$). A stylized view of the structure of the pasture submodel is shown in Figure 3.

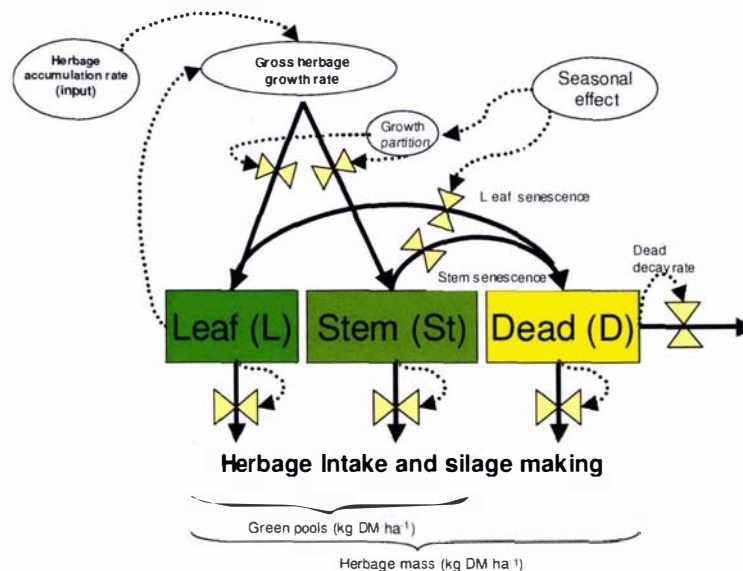


Figure 3. Structure of the pasture submodel used in the simulator.

⁵ The operator \leftarrow is used here to indicate that the value of the variable is updated at each simulation step, and its value on the previous step is part of the right hand of the equation.

2.2.1.2. Herbage intake

In grazing animals, feed intake constraints have been divided into nutritional and non-nutritional factors (Poppi & Hughes 1987). Nutritional factors may be related to metabolic demand (Illius & Jessop 1996) or to digestive capacity (Allen 1996). Non-nutritional factors are associated with herbage availability, and how it constrains the ability and behaviour of the animal in harvesting pasture (Hodgson 1990). There is some data available from Argentina (Cangiano & Gomez 1985; Cangiano et al. 2002) and elsewhere (Woodward 1997; Herrero et al. 1998; Hodgson & Brookes 1999) to calculate herbage intake from grazing behaviour measurements. However, because of limitations mentioned recently by Herrero et al. (2000) for integrating this approach in a higher time and space scale within a whole-farm model, a simpler alternative was preferred. Daily herbage intake without concentrate feeding was represented as:

$$I = \text{Min}(I_p, I_f) f_A \quad \text{Eqn. 12}$$

Where I (kg DM d⁻¹) is the herbage intake (silage intake is included if present), I_p is potential intake, I_f is fill capacity intake (both in kg DM d⁻¹) and f_A is a non-nutritional factor (0-1) associated with herbage availability (Section 2.2.1.2.3.).

2.2.1.2.1. Potential intake

Potential intake (I_p) is estimated following the approach of Freer et al. (1997) as:

$$\begin{cases} I_p = \kappa_1 SRWZ(\kappa_2 Z) & \text{if } W \leq SRW \\ I_p = \kappa_1 SRWBC(\kappa_2 BC) & \text{Otherwise} \end{cases} \quad \text{Eqn. 13}$$

And

$$Z = \frac{N}{SRW} \quad \text{Eqn. 14}$$

$$BC = \frac{LW_{Actual}}{N} \quad \text{Eqn. 15}$$

$$N = SRW - (SRW - W_{Birth}) \exp\left(\frac{\kappa_3 A}{SRW^{\kappa_4}}\right) \quad \text{Eqn. 16}$$

Where **SRW** is the standard reference weight as defined by (SCA 1990), **Z** is the relative animal size, **BC** is the animal body condition, **N** is the normal animal weight for the current animal age, **LW_{Actual}** is animal live weight (kg), **W_{Birth}** is animal birth weight (kg) and **A** is animal age (days).

2.2.1.2.2. Rumen fill intake

The digestive capacity intake is estimated following Finlayson et al. (1995) as:

$$I_F = \frac{\kappa_5 RC}{1 - Dig_{Herbage}} \quad \text{Eqn. 17}$$

And

$$RC = \kappa_6 LW_{Actual} - FS_{Factor} \quad \text{Eqn. 18}$$

Where I_F intake is constrained by digestive capacity (kg DM d⁻¹), **RC** represents the rumen capacity (kg DM d⁻¹), **LW_{Actual}** is animal live weight (kg), **Dig_{Herbage}** is the herbage digestibility (as fraction of DM) incorporating a term **FS_{Factor}** to represent hay or silage effect (fibrous supplements, FS) on fill intake (as fraction) added by Barioni (1997) to yield:

$$FS_{Factor} = \frac{FS \kappa_6 (1 - Dig_{FS})}{\kappa_7} \quad \text{Eqn. 19}$$

Where **FS** is fibrous supplement eaten (kg DM d⁻¹) assuming the offered FS is eaten (constrained arbitrarily to a maximum of 5 kg d⁻¹ less a feeding loss, as in this kind of system this feed is not the main part of the diet as stated by Rearte (1998), and **Dig_{FS}** represents the digestibility of the **FS**.

2.2.1.2.3. Intake constraints associated to herbage allowance

In a quantitative dairy cattle study about the sward characteristics that affect herbage intake under rotational grazing, pre-grazing mass, herbage allowance and post-grazing mass were the relevant factors identified (Stockdale 1985). An asymptotic relationship between herbage intake and herbage allowance is generally accepted (Hodgson 1984; Redmon et al. 1995). Herbage mass has also been shown to affect intake positively (Penning et al. 1994; Wales et al. 1999) however there is a negative effect when herbage mass and maturity are confounded (Reardon 1977; Stakelum 1986; Ferrer Cazcarra & Petit 1995). For this reason the effectiveness of sward characteristics as animal performance predictors can be improved when they are expressed in terms of green rather than total herbage dry matter (Baker et al. 1981). McCall (1984) included green herbage mass and green herbage allowance as the major driver variables in a rotational grazing intake model for sheep. This model has been applied to other whole-farm models, but building the green component from leaf and stem that were modelled independently (Finlayson et al. 1995; Barioni et al. 1999). In the case of models for rotational grazing systems, green herbage allowance (leaf+sheath+stem) has been used in a bull beef model (Doyle et al. 1989) and herbage dry matter mass in a dairy cattle model (Cros et al. 2003).

There is further evidence that sward characteristics expressed in leaf mass rather than green herbage mass can improve the understanding of what drives herbage intake (Butler & Hoogendoorn 1987; Penning et al. 1994; Okajima et al. 1996; Wade & Carvalho 2000). Thus was recognized by Herrero et al. (2000), who included in their model herbage intake as a function of defoliation of leaf area index (LAI) based on Johnson & Parsons (1985). Additionally, Herrero et al. (2000) included explicitly the effect of the animal live weight, as it is known that large ruminants are less able to exploit low herbage availability than small ones (Illius & Gordon 1987; Ferrer Cazcarra et al. 1995). In the present model, this component of intake was assumed to be driven by leaf mass and leaf allowance, and included the effect of animal size. The relationship to LW (direct or allometric) was found to be important in facilitating the derivation of functions for animals of different size, as the animals in a beef cattle finishing system can increase their live weight by two to

four times during the finishing process. Therefore:

$$f_A = f_L f_{LA} \quad \text{Eqn. 20}$$

Where

$$f_L = \frac{\left(\frac{\frac{L}{\kappa_8}}{\kappa_9 LW_{Actual}^{\kappa_{10}}} \right)^{\kappa_{11}}}{1 + \left(\frac{\frac{L}{\kappa_8}}{\kappa_9 LW_{Actual}^{\kappa_{10}}} \right)^{\kappa_{11}}} \quad \text{Eqn. 21}$$

Where f_L is a dimensionless factor depending on leaf mass ($0 < f_L < 1$) adapted from Herrero et al. (2000) by converting empirically L to LAI assuming a linear relationship (Doyle et al. 1989), L is leaf mass (kg DM ha⁻¹) and LW_{Actual} is animal live weight (kg).

Herrero et al. (2000) did not include a reference to herbage allowance, which is known to affect herbage intake in rotational grazing systems (Hodgson 1984; Stockdale 1985). Information relating leaf allowance and herbage intake is scarce, and most is from dairy cattle systems (Chapter 1, Table 2). Although some authors have reported a linear function of herbage intake as leaf allowance increases (Butler & Hoogendoorn 1987), there is evidence of an asymptotic relationship (Kim et al. 1995; Peyraud et al. 1999; Delagarde 2000), and intuitively that seems a more likely relationship. Here, f_{LA} is a dimensionless asymptotic value ($0 < f_{LA} < 1$) associated with the effect of leaf allowance on herbage intake. From the observation of Kim et al. (1995), assuming a zero intercept and asymptotic situation of intake at the maximum leaf allowance of 184 g leaf (kg LW^{0.75})⁻¹, the following equation was fitted ($R^2=0.99$, residual SS = 1.3^{-0.4}, $P < 0.05$).

$$\begin{cases} f_{LA} = 1 - \exp(\kappa_{12} LA) & \text{if } LA < 184 \text{ g (kg LW}^{0.75})^{-1} \\ f_{LA} = 1 & \text{Otherwise} \end{cases} \quad \text{Eqn. 22}$$

Where LA is leaf allowance expressed in $\text{g kg LW}^{0.75}$, and is estimated from the herbage allowance (% LW) allocated to the animal and leaf percentage of the sward in the corresponding strip that animals are currently grazing. In Figure 4 and Figure 5 the response surface of the relative intake as affected by LW, leaf allowance and mass for two different animal sizes are shown. The data suggest that a heavier animal (450 kg, Figure 5) is more demanding in the sward conditions to achieve a similar relative intake than a lighter one (100 kg, Figure 4). In Figure 6 a general outline of the different constraints to intake is presented.

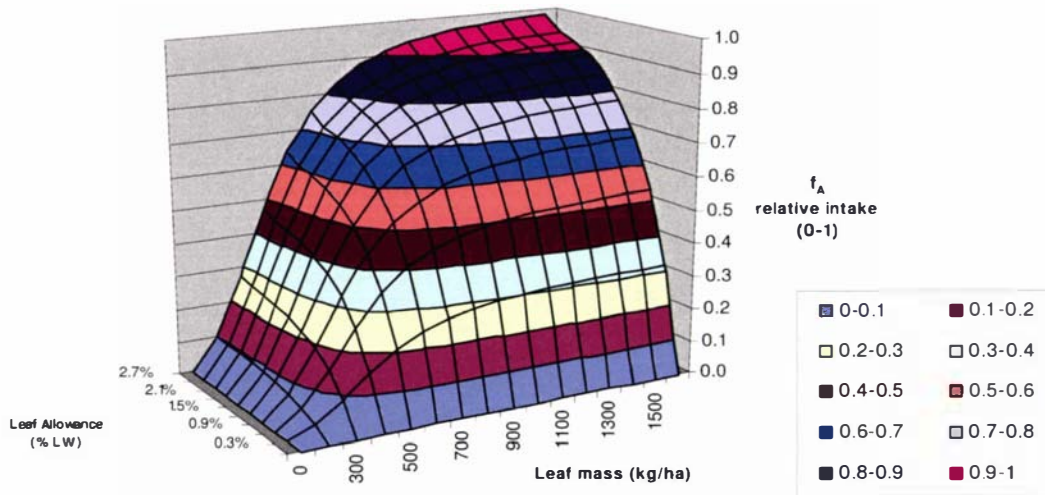


Figure 4. Response surface of relative intake (0-1) of a 100 kg LW animal to increasing levels of leaf herbage masses and leaf herbage allowances as predicted by Eqn.20. Leaf allowance is expressed here as % LW.

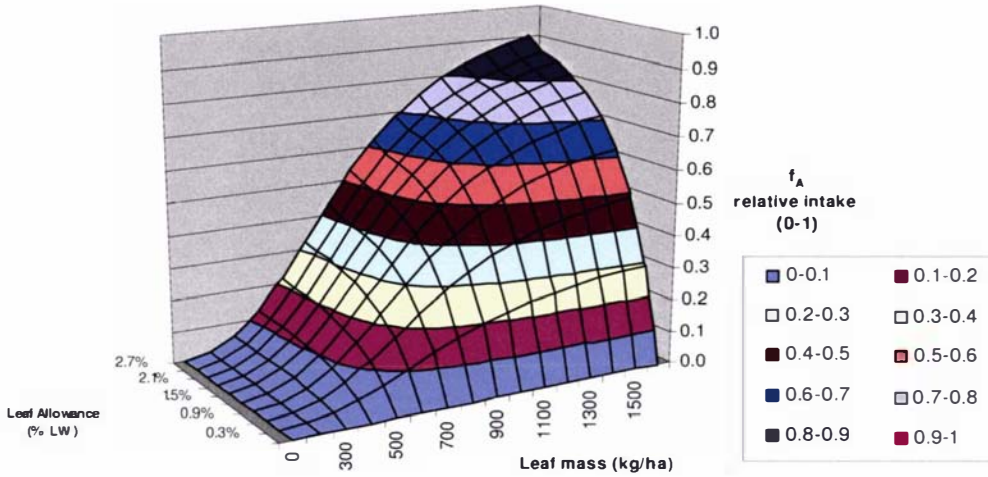


Figure 5. Response surface of relative intake (0-1) of a 450 kg LW animal to increasing levels of leaf herbage masses and leaf herbage allowances as predicted by Eqn.20. Leaf allowance is expressed here as % LW.

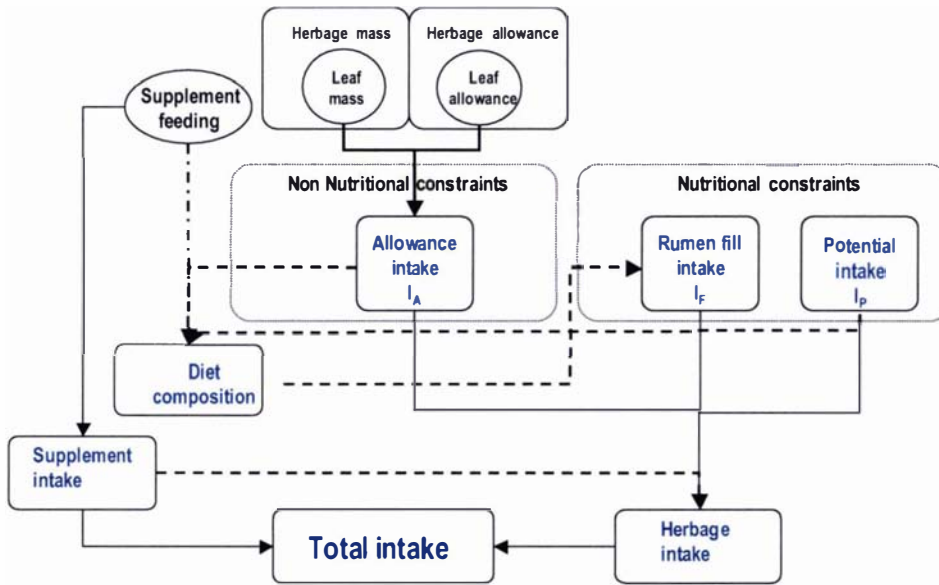


Figure 6. A general outline of how different constraints to intake are estimated and integrated in the “beef cattle finishing unit” simulator (continuous lines indicate mass fluxes, dashed lines indicate influence).

2.2.1.3. Diet composition

A sward is not uniform and the heterogeneous distribution of its components provides ruminants with the opportunity to graze selectively (Gordon & Lascano 1993; Hodgson & Brookes 1999). Species composition and grazing management play a major role in determining the diet selected by the animal, which is dependent on stocking rate, environmental conditions or other disturbances

(Herrero et al. 1998). Sward heterogeneity can affect the relationship between herbage intake and herbage allowance: leaf versus stem, green versus dead and species differences (Milne 1991). Animals first consume leaf and then stems, and once material other than leaves is eaten, there is a marked decline in digestibility of the diet selected (Penning et al. 1994). However, marked dietary enhancement with respect to the proportions of leaf over stem and dead material present in the sward does not necessarily reflect an act of conscious selectivity, it may be simply a consequence of canopy structure (Dougherty et al. 1988).

As described previously for the pasture model, herbage mass was divided into L, St and D, and these sward components were assumed to be selected as the diet according to the sequence Leaf>Stem>Dead (Ellis 1978; Dougherty et al. 1992; Nielsen et al. 2003). Adapting from the approach of Johnston and Parsons (1985) for the three sward components (L, St and D), the component proportions under continuous grazing are described as:

$$Sel_L = \frac{L\kappa_{13}}{L\kappa_{13} + St\kappa_{14} + D\kappa_{15}} \quad \text{Eqn. 23}$$

$$Sel_{St} = \frac{St\kappa_{14}}{L\kappa_{13} + St\kappa_{14} + D\kappa_{15}} \quad \text{Eqn. 24}$$

$$Sel_D = \frac{D\kappa_{15}}{L\kappa_{13} + St\kappa_{14} + D\kappa_{15}} \quad \text{Eqn. 25}$$

Where Sel_L , Sel_{St} and Sel_D are the proportions of leaf, stem and dead components contributing to the diet under continuous conditions, L , St and D represent kg DM ha⁻¹ of leaf, sheath & stem and dead herbage masses above ground level, respectively and κ_{13} , κ_{14} and κ_{15} represent the degree of preference (active, caused by sward structure or both) for each component. These equations imply that the grazing animals eat different proportions of leaf, stem and dead components than those available in the sward (L%, St% and D% respectively), and the degree of selectivity is controlled by the herbage mass and the preference parameters of each sward component.

The ability of the animal to harvest through grazing a nutritionally enhanced mix of

sward components declines as herbage allowance decreases (Geenty & Sykes 1982; Dougherty et al. 1989; Dougherty et al. 1990). Therefore, under rotational grazing conditions, the diet component proportions adapted from Barioni (1997) are described as:

$$\mathbf{Diet}_L = L\% + (\mathbf{Sel}_L - L\%)f_{LA} \quad \text{Eqn. 26}$$

$$\mathbf{Diet}_{St} = St\% + (\mathbf{Sel}_{St} - St\%)f_{LA} \quad \text{Eqn. 27}$$

$$\mathbf{Diet}_D = 1 - (\mathbf{Diet}_L + \mathbf{Diet}_{St}) \quad \text{Eqn. 28}$$

Where \mathbf{Diet}_L , \mathbf{Diet}_{St} and \mathbf{Diet}_D represent the proportion of leaf, stem and dead material in the diet. $L\%$, $St\%$ and $D\%$ are the proportion of leaf, stem and dead material in the sward. \mathbf{Sel}_L , \mathbf{Sel}_{St} and \mathbf{Sel}_D are the proportions of leaf, stem and dead components contributing to the diet under continuous grazing, respectively. f_{LA} is a factor associated to leaf allowance as defined in Eqn. 22.

Figure 7 shows an example of how the composition of the diet changes when the animal is allocated a highly restrictive leaf allowance ($f_{LA}=0.1$), where the component proportions are similar to those of the sward (0.41, 0.29 and 0.29 proportions of leaf, stem and dead respectively in this example). In contrast, when animals are allocated to unrestrictive conditions ($f_{LA}=1$), the component proportions are similar to those estimated by Eqns. 23-25. This situation is highly dynamic and is affected by the leaf content of the sward.

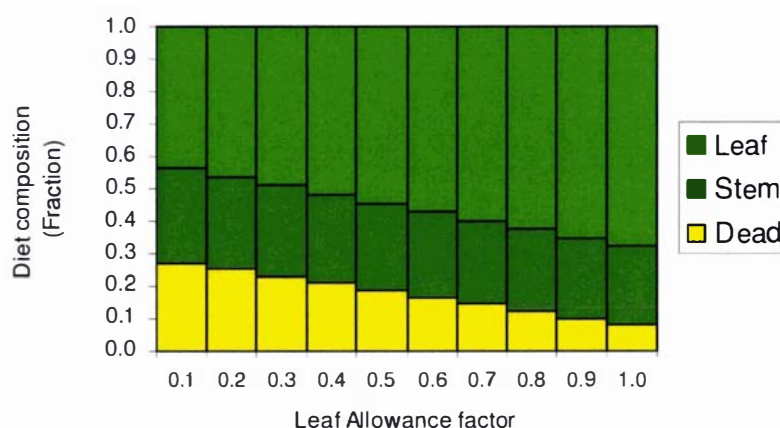


Figure 7. Diet composition at increasing level of leaf allowance with a sward composition in fractions of 0.41, 0.29 and 0.29 of leaf, stem and dead respectively (as estimated by Eqns. 26-28).

Figure 8 shows the influence of leaf allowance on leaf selection across the full range of possible sward leaf content, i.e. when the leaf % of the sward increases, only those animals allocated a higher leaf allowance are able to obtain a higher leaf proportion than available in the sward. With a very restrictive leaf allowance ($f_{LA}=0.1$), proportions of sward and diet components are similar.

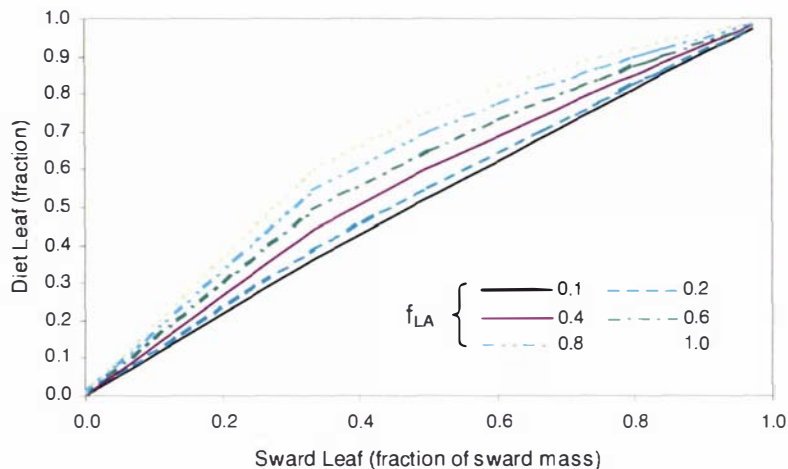


Figure 8. Effect of leaf fraction in the herbage DM (Eqn.26) and leaf allowances ($0 < f_{LA} < 1$, 1=unrestricted) on the fraction of leaf in diet DM.

2.2.1.4. High starch grain feeding and substitution rate

Grain feeding under grazing conditions adds complexity and incorporates further interactions to the already complex pasture-animal interface (Dixon & Stockdale 1999). Frequently herbage intake declines when grain is fed (Horn & McCollum 1987) and substitution rate is defined as the change in forage intake per unit increase in concentrate intake (SCA 1990). The substitution rate can be influenced by many factors including herbage availability and quality, nature of the supplement used and potential animal performance (Mayne 1988). There is strong evidence for sheep and beef cattle (Dixon & Stockdale 1999) and dairy cattle (Grainger & Matthews 1989; Robaina et al. 1998; Wales et al. 1999) of a linear relationship between unsupplemented herbage intake and substitution rate. This response seems to justify representing grain feeding to grazing animals as a two-step procedure, computing first the unsupplemented herbage intake, then the

substitution rate and finally the actual herbage and total daily intake, as done by other authors (Neaves et al. 1996; Woodward et al. 2000), therefore:

$$SR = K_{16} + K_{17} \frac{I1000}{LW_{Actual}^{0.75}} \quad \text{Eqn. 29}$$

Where **SR** is the substitution rate (kg DM herbage kg⁻¹ DM grain) when grain is fed, **I** is the herbage intake prior to grain feeding (Eqn. 13) but expressed in g DM d⁻¹, and **LW_{Actual}^{0.75}** is the animal metabolic liveweight.

2.2.1.5. Quality of herbage on offer and quality of herbage eaten

Herbage quality is a concept that include multiple factors in addition to herbage composition, such as nutrient digestion and diet selection (Bush & Burton 1994). The term herbage quality is restricted here to the percentage of crude protein and metabolisable energy content. A range of alternatives for modelling herbage quality has been used in the literature. Some authors have incorporated it as a user-defined variable (Woodward et al. 2000; Garcia et al. 2000) estimated from the contribution of green and dead herbage material (McCall 1984), built from leaf, stem and dead mass (Doyle et al. 1989; Cacho et al. 1995) or from sward structure and maturity (Woodward 2001). In this model herbage quality is adapted from the method used by Doyle et al. (1989), and is given by:

$$ME_{Herbage} = L\%ME_L + (St\%ME_{St})f_{Season} + D\%ME_D \quad \text{Eqn. 30}$$

$$Dig_{Herbage} = ME_{Herbage} K_{18} \quad \text{Eqn. 31}$$

$$CP_{Herbage} = L\%CP_L + (St\%CP_{St})f_{Season} + L\%CP_D \quad \text{Eqn. 32}$$

$$ME_{HerbageEaten} = Diet_L ME_L + (Diet_{St} ME_{St})f_{Season} + Diet_D ME_D \quad \text{Eqn. 33}$$

$$CP_{HerbageEaten} = Diet_L CP_L + (Diet_{St} CP_{St})f_{Season} + Diet_D CP_D \quad \text{Eqn. 34}$$

Where **ME_{Herbage}**, **Dig_{Herbage}** and **CP_{Herbage}** are the metabolisable energy (MJ kg DM⁻¹), *in vitro* DM digestibility of the herbage and crude protein (% DM), respectively; **ME_{HerbageEaten}** and **CP_{HerbageEaten}** represent the metabolisable energy (MJ kg DM⁻¹) and crude protein (% DM) of the herbage eaten, **L%**, **St%** and **D%** are the

fraction of leaf, stem and dead material in the herbage, $Diet_L$, $Diet_{St}$ and $Diet_D$ represent the fraction of leaf, stem and dead material in the diet, ME_L , ME_{St} , ME_D and CP_L , CP_{St} , CP_D are the annual average of metabolisable energy (MJ kg DM⁻¹) and crude protein (fraction of the DM) of the leaf, sheath & stem and dead component of the sward and f_{Season} is a seasonal factor affecting stem quality, to take account of plant maturation during late spring and summer, i.e. decrease in the leaf to stem ratio and a decline in the quality of the sheath and stems (Nelson & Moser 1994).

In this model leaf, stem and dead masses and their qualities are treated separately, therefore green to dead ratio or leaf to stem ratio implicitly affect herbage quality. The seasonal change of herbage quality is present (although more moderate) when an intensive grazing system is followed (Hodgson & Brookes 1999). Therefore:

$$f_{Season} = 1 + \kappa_{19} \sin\left(\frac{2\pi(t-150)}{365}\right) \quad \text{Eqn. 35}$$

Where t is the simulation time (day of the year, 0=1st March) and 150 adjusts the seasonality to yield the lower value of f_{Season} at the end of January, and κ_{19} regulates the magnitude of the seasonal change.

Herbage quality and herbage intake are linked to the sward components. In Figure 9 is shown an example of a 30-d grazing period, describing the sward composition of a series of daily strips, before and after grazing. In this particular example, animals were allocated to a herbage allowance of 5 % of LW d⁻¹.

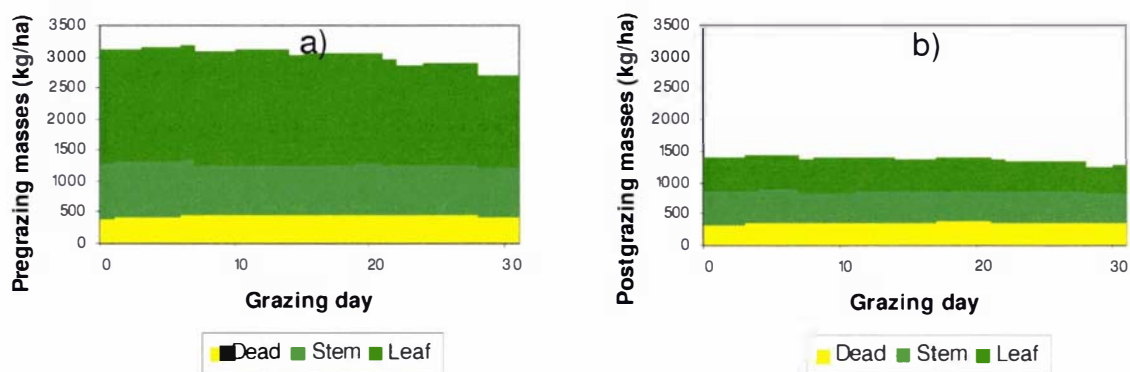


Figure 9. Simulation of Herbage mass composition a) pre-grazing and b) post-grazing in a series of strips of herbage grazed daily.

Herbage allowance was of 5 % LW d⁻¹ in a period of 30 days by animals weighing 310 kg LW at day 0.

2.2.1.6. Total daily nutrient intake

In the following equation the herbage intake and supplemented feeds (if any) are integrated to calculate the metabolisable energy and crude protein eaten daily as:

$$TI = I_H + I_{FS} + I_{Maize} \quad \text{Eqn. 36}$$

$$I_H = I - (I_{Maize} SR) \quad \text{Eqn. 37}$$

$$I_{Maize} = Maize_{Fed} (1 - \kappa_{20}) \quad \text{Eqn. 38}$$

$$Diet_{ME} = ME_{HerbageEaten} I_H + ME_{FS} I_{FS} + ME_{Maize} I_{Maize} \quad \text{Eqn. 39}$$

$$Diet_{CP} = CP_{HerbageEaten} I_H + CP_{FS} I_{FS} + CP_{Maize} I_{Maize} \quad \text{Eqn. 40}$$

Where TI is total dry matter intake (kg DM d⁻¹), I_H is herbage intake (kg DM d⁻¹), I_{FS} is fibrous supplement intake (kg DM d⁻¹), if any. I_{Maize} is maize grain intake (kg DM d⁻¹), SR is the substitution rate (kg DM herbage kg⁻¹ DM grain) when grain is fed. $Maize_{Fed}$ is the amount of grain fed (kg DM grain kg LW⁻¹ d⁻¹) which is arbitrarily restricted to a maximum of 2 % of LW per day, $Diet_{ME}$ is the total metabolisable energy eaten daily (MJ ME d⁻¹). $ME_{HerbageEaten}$, ME_{FS} and ME_{Maize} are the metabolisable energy density (MJ ME kg⁻¹ DM) of herbage eaten,

fibrous supplement and maize grain, respectively, $Diet_{CP}$ is the total protein eaten daily (kg CP d⁻¹), $CP_{HerbageEaten}$, CP_{FS} and CP_{Maize} are the crude protein density (g CP kg⁻¹ DM) of herbage eaten, fibrous supplement and maize grain, respectively.

2.2.1.7. Animal performance

Animal growth rates and consequently the updated animal liveweights are estimated daily i.e. simulated animals gain or lose weight, depending on their nutritional balance associated with animal characteristics and the corresponding individual ME and CP eaten daily (Eqns. 39 and 40 respectively). Partition of dietary metabolisable energy and crude protein to maintenance and production are calculated from Freer et al. (1997) and based on published requirements for maintenance and growth (SCA 1990), hence a full detailed description is not presented here.

2.2.2. Structures

Paddocks, grazing strips and animals within mob constitute the structures of the model. By default, the model specifies twelve paddocks, but this feature can be easily modified. For each paddock, width and length (in meters), L St and D mass and monthly herbage accumulation rates must be provided by the user. The size of the grazing strips are internally estimated by the model (section 2.2.3.1.).

The mob is constituted as groups of individuals, and may be of different liveweight, breed or sex. This information is provided to the model by different parameters required for nutritional requirement estimation (Freer et al. 1997), that internally in the model are organized as a look up table (24 breeds and with the corresponding **SRW** for female, castrates and males). Although the animal performance model takes individual animals as units, feed allocation routines use the mob as the unit (section 2.2.3.1.). For the sake of simplicity in the grazing plan, the present version of the model uses a single mob, but this feature can be easily expanded when needed. In this case, when animals enter the farm they need to be "tagged" individually to a mob for identification.

2.2.3. Management actions

2.2.3.1. Feed allocation

It is important to emphasise that although herbage intake is partly controlled by leaf mass and allowance (Section 2.2.1.2.3.), daily herbage allocation is based simply on DM herbage allowance ($\% \text{ LW d}^{-1}$, cut above ground level). This means that any given herbage allowance can produce different values of herbage intake, diet composition and animal performance, depending on sward characteristics.

Herbage allowance can provide a more sensible control of the plant-animal interface than stocking rate alone. A grazing management based on herbage residuals may be more robust (Hodgson 1984), but this latter approach was not used given the difficulty to control residuals in a daily rotational model (one new strip day^{-1}) when the simulation step is of 1 day, which creates difficulties in constraining the herbage intake function. Additionally, herbage allowance was the variable of control in the field experiments, and these two sward characteristics are normally highly correlated (Stockdale 1985).

The mob is the unit for feed allocations, and to run the model, herbage allowances ($\% \text{ live weight in herbage DM above ground level}$) must be assigned to the mob on a monthly basis. When grazing starts, the paddock with the highest herbage mass is allocated for grazing (Woodward et al. 1993). Once a paddock is allocated to a mob, the model checks for the assigned herbage allowance, calculates the LW of the mob, available herbage mass and size of the paddock, and creates a grazing strip⁶. In practical terms, each strip could be defined by temporary electric fences. This is repeated daily until the whole paddock is grazed. Most of the time the size of the paddock does not yield an entire number of strips (i.e. exact grazing days). To avoid herbage wastage when the paddock is almost finished, if the ungrazed area left is less than 60 % of the present strip it is added to the current day and the paddock is completely grazed. Conversely, if the ungrazed area left is higher than 60 % of present strip, this area is allocated as a new strip next day with a lower allowance than programmed this day. In this way the complete paddock is utilised.

⁶ Fraction of the paddock allocated daily.

In Figure 10.a) an example shows how the model selects the paddock with the highest mass (starting at paddock 11) and then allocates daily the planned herbage allowance in different strips (5 strips for paddock 11). Although on the second day, paddock 11 does not have the highest herbage mass (Figure 10.b), the animals remain in paddock 11 until the whole paddock is utilised (Figure 10.a), and then move to paddock four.

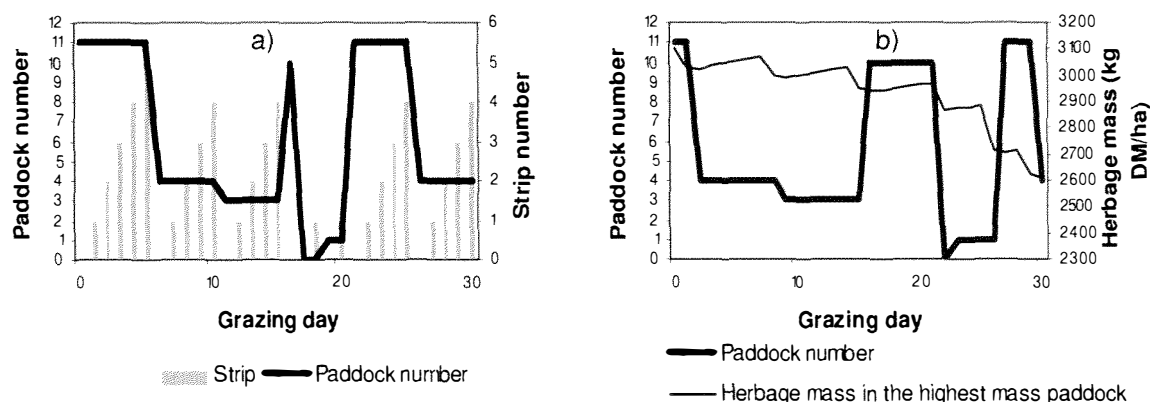


Figure 10. a) Paddock currently under grazing and number of allocated strips and b) herbage mass and number of the paddock with the highest herbage mass in a regrazing sequence of 30 days with 12 paddocks.

All the strip information is stored in a resizable dynamic array (paddockdata, Appendix 6.A.) that keeps in memory the leaf, stem and dead masses, start and end points of the strips within the paddocks. The herbage accumulation rate (model input) is the same for the whole paddock, but the gross growth rate (Eqn. 3) is estimated daily for each strip of the farm (the model keeps a memory of dimensions, position and post-grazing sward conditions, which are updated daily). In the same way as herbage is allocated, silage and grain allowance may be defined for the mob.

"BeefSim" is essentially a pasture-based simulator, which allows the inclusion of grain and silage supplementation. Integration of a small feedlot into the pastoral system can be simulated by assigning the mob to a paddock with zero herbage mass and $HAR_{input,=0}$, so animal performance will be estimated from the allocated silage and grain feeds, and the intake in this case will be determined by nutritional constraints only (Eqn. 20= 0).

2.2.3.2. Pasture fertilization

Argentinean beef finishing systems commonly only use pasture fertilization at seeding time, with application of phosphorus and nitrogen at levels below 70 and 100 kg ha⁻¹ respectively (Rearte 1998). This situation is incorporated implicitly to the model through the magnitude of the herbage accumulation rates that are inputted (HAR_{Input}) into the pasture model.

The strategic role of fertilizer in other countries (e.g. New Zealand) enhancing the growth of perennial pastures to cope with herbage deficits is not used widely in Argentina, where strategic grain supplementation is generally preferred (Santini & Elizalde 1993; Rearte & Pieroni 2001). Nevertheless, the increasing recognition of the potential importance of strategic fertilization for dairy and beef cattle finishing systems is reflected in research efforts in the use of nitrogen fertilisers (Guaita et al. 1996; Lattanzi & Mazzanti 1997; De Battista & Costa 1998; Martin & Refi 2002) and phosphorous fertilisers (Berardo & Marino 2000; Marino & Berardo 2000; Picone et al. 2003). However, most of the information is presented as extra kg DM produced per annum, so the calibration of dynamic equations associated with dose rate and time of application to add this functionality of the model was not feasible at this stage. However, the undoubted high potential strategic value of fertilization is recognized in the model by presenting an uncalibrated alternative, that will be explored beyond this initial study.

Typical fertilizer response equations are in the quadratic form $Y = a_0 + a_1X + a_2X^2$ or the inverse polynomial $y = \frac{aX}{X+b}$ (Thompson et al. 2000), where Y is the described pasture yield as a function of fertilizer X ; a_0 , a_1 , a_2 , a and b are empirical constants. An alternative approach is the quadratic fertiliser response function, using the square root of fertiliser rate (Colwell 1994). Good and poor features for each of these approaches are quoted in the literature, but one important issue is to select statistically the model which fits the data best (Ratkowsky et al. 1997; Belanger et al. 2000). In the absence of adequate data, the static (no time involved) fertiliser response here uses the quadratic approach

i.e:

$$FR = \kappa_{21} + \kappa_{22}FD + \kappa_{23}FD^2 \quad \text{Eqn. 41}$$

Where **FR** is the fertiliser response (kg DM ha⁻¹) and **FD** is the quantity of fertiliser applied (kg ha⁻¹). The use of this equation is limited to the period of time represented by original experimental data used for fitting the parameters.

Following the approach of Barioni (1997), the dynamics of the fertiliser response in the absence of climate and soil models can be simplified into two parameters, the total duration of the fertiliser response (**Spell**, expressed in d) and the initial fertiliser response (kg DM ha⁻¹), defined by:

$$Spell = \kappa_{24} - \kappa_{25}GGR \quad \text{Eqn. 42}$$

Where **Spell** is the total duration of the fertiliser response (d), **GGR** is the herbage gross growth rate (kg DM ha⁻¹ d⁻¹) as defined by Eqn 3. The inclusion of GGR in the response to fertiliser defines in a simplified way how the current environmental and structural conditions of the sward constrain the fertiliser response (Kemp et al. 1999). It is worth noting that in the model GGR depends on the HAR_{input}, but also to the leaf mass in that particular paddock (i.e. two paddocks with the same inputted HAR and equivalent fertiliser dose but with different leaf mass, will respond to the application differently).

For the sake of simplicity, the response to fertiliser is assumed to be at maximum immediately after application date, described linearly as:

$$IFR = \frac{2FD}{Spell} \quad \text{Eqn. 43}$$

Where **IFR** is the initial fertiliser response (kg extra DM ha⁻¹ d⁻¹), **FD** is the quantity of fertiliser applied (kg ha⁻¹) and **Spell** is the total duration of the fertiliser response (d). Finally, the daily fertiliser response is represented with a hyperlogistic equation (Haefner 1997) as:

$$\Delta HAR_F = IFR \left(1 - \left(\frac{t_{AfterF}}{Spell} \right) \right) \quad \text{Eqn. 44}$$

Where ΔHAR_F is the extra herbage accumulation rate above unfertilised accumulation rate (kg DM ha⁻¹), IFR is the initial fertiliser response (kg extra DM ha⁻¹ d⁻¹), t_{AfterF} is the time (d) after fertiliser was applied. **Spell** is the total duration of the fertiliser response (d).

Eqns. 41-44 are dependent on the information provided by the researcher about the paddock/s to be fertilized, type of fertilizer and dose and timing of application. This information is used later for economic analysis of the particular fertilizer policy (Eqn. 58).

2.2.3.3. Silage making

Feed-budget deficits and surpluses normally occur in grazing systems, and silage making is incorporated here to make the pastoral system more flexible and sustainable (Parsons 1998; Holmes & Matthews 2001). In Argentinean beef cattle systems, hay is usually made at the end of the growing season when rainfall decreases, allowing rapid drying under field conditions, however at this time of the year grasses have a low nutritive value (Viviani Rossi & Gutierrez 1995). Silage is a preferred conservation process to ensure quality, but it is not widely used in Argentina for beef cattle systems (Rearte 1998). For conservation purposes, the paddock is the minimum unit, so when a paddock is cut, all the information about its individual strips is deleted (i.e. paddock= 1 strip).

The user must provide information about the time interval where conservation is allowed, and the farm pasture cover that triggers conservation. If conditions for pasture conservation are achieved, a currently ungrazed paddock with the highest herbage mass is selected, information about grazing strips (if grazed previously) is deleted, and the paddock is harvested. By default, herbage mass after cutting of 1000 kg DM ha⁻¹ is assumed. This procedure is repeated until pasture cover conditions are met. The post-harvesting leaf, stem and dead material mass are related to their values in pre-harvesting conditions (Barioni 1997), and described

as:

$$L_{AH} = L_{BH} \left(1 - \frac{HM_{preH}}{HM_{PostH}} \right) \quad \text{Eqn. 45}$$

$$St_{AH} = St_{BH} \left(1 - \frac{HM_{preH}}{HM_{PostH}} \right) \quad \text{Eqn. 46}$$

$$D_{AH} = D_{BH} \left(1 - \frac{HM_{preH}}{HM_{PostH}} \right) \quad \text{Eqn. 47}$$

Where L_{AH} , St_{AH} and D_{AH} are the leaf, sheath & stem and dead masses in the paddock after harvesting (kg DM ha⁻¹), L_{BH} , St_{BH} and D_{BH} are the leaf, sheath & stem and dead masses in the paddock before harvesting (kg DM ha⁻¹) and HM_{preH} and HM_{PostH} are the herbage mass pre- and post-harvesting in the paddock (kg DM ha⁻¹). The type of storage affects harvest rates, forage losses and nutritive value of feeds produced (Buckmaster et al. 1989). For simplicity, harvested mass is converted here to silage mass assuming 15 % of DM losses in the whole process (Viviani Rossi & Gutierrez 1995), and for the nutritional value of pasture silage regional information is used (Guaita & Fernandez 2002).

2.2.3.4. Animal sale and purchases

By default animals are bought as 6-month-old weaners (1 March), but animals can enter at any time of the year. Animal information can be incorporated individually, including age (d), LW (kg) and breed and sex. Alternatively if desired, animals can be generated randomly providing mean, maximum and minimum values of these parameters. This information is used to estimate their nutritional requirements (section 2.2.7.).

Animals can be sold unfinished or incorporated into a feedlot within the farm, but the default procedure is to identify them as a "finished animal" when a target liveweight is reached. By default (this can be changed in the block dialog), heifers are finished at 280 kg LW and steers at 380 kg LW (British bred animals). Selling procedure is activated only when the minimum number for trading is reached. By default and for practical reasons, this is defined as a truck unit (30 steers of 380 kg

liveweight), so although some animals can be finished, they are kept in the mob (eating and growing) until the minimum animal number for trading is achieved. Animals are ‘lost’ randomly in agreement to the defined mortality rate within each animal type on the farm. Internally, stocking density expressed as animals ha⁻¹ and kg LW ha⁻¹ are estimated daily.

2.3. Decision module

Grain feeding may be incorporated, within other technologies, into the farm plan. However, typically the use of this technology is not simply decided at the beginning of year, and its implementation is part of a more structured process, linked to the dynamic conditions of the components within the farm system. The same is valid for the herbage allowance allocated to animals. Garcia et al. (2000) introduced the interactivity between model and user to incorporate human management. Similarly, the software used here allows interactivity, as the model parameters and logic can be changed in real time (Krahl 2002). Additionally, for more independent runs, this module incorporates the concept of ‘‘grazing strategy’’ simplified from Cros & Duru (1997). Within this module, the general strategy and contingency procedures are designed as a sequential set of management rules, which are applied for a ‘‘manager’’ block. Parker (1999) mentioned that translating strategy effectively into an action requires a clear link with the monitoring processes. In practice, good graziers design a strategy, initiate it and then monitor it in cyclical procedures (micro-budgets) to manage ‘‘deviations’’ from the plan due to variation in the environment, combining formal and informal procedures (Gray et al. 2003). In this model, ‘‘deviations’’ are simplified into two aspects: a) pasture cover deviation, and b) target live weight deviation, defined as:

$$PCover_{Dev} = \left(\frac{(Pcover_{Target} - Pcover_{Actual})}{Pcover_{Target}} \right) \quad \text{Eqn. 48}$$

Where $PCover_{Dev}$ is the (positive or negative) deviation of the current pasture cover ($PCover_{Actual}$) from pre-defined target pasture cover for different times of the year ($PCover_{Target}$), both expressed in kg DM ha⁻¹ and $PCover_{Actual}$ represents the weighted average of herbage mass (Eqn. 1) over all strips of the farm.

$$LW_{Dev} = \left(\frac{(LW_{Target} - LW_{Actual})}{LW_{Target}} \right) \quad \text{Eqn. 49}$$

Where LW_{Dev} is the (positive or negative) deviation of the current average of animal liveweights (LW_{Actual}) from pre-defined targets for animal liveweight for different times of the year (LW_{Target}), both expressed in kg LW.

$PCover_{Dev}$ and LW_{Dev} are checked by default on a weekly and monthly basis, respectively. This means that although pasture cover, individual intakes or animal liveweights can be obtained daily from the model, monitoring is constrained to measurable variables on a real farm. On this point, Wright and Dent (1969) suggested that there is little point in insisting that the model should predict to a given degree of accuracy, if this accuracy cannot be incorporated into the management decisions of real systems.

The "manager" block, together with the information obtained from this simple monitoring routine, has the chance to adjust the different variables according to pre-defined grazing strategies containing contingency actions (Figure 11). Management tasks have a temporal and hierarchical organisation (Cros et al. 2004), hence the grazing strategy used here ensures the important issues are addressed and allows a clear course of action to proceed. Associated with the initial objective, the adjustment of grazing strategy in the current version of the model is restricted to: herbage allowance adjustment and silage making associated with $PCover_{Dev}$, and grain feeding associated with LW_{Dev} . Information on the threshold deviation and levels of adjustment of the variables are provided as tables in the dialog of the "manager" block (Figure 12). Once a grain supplementation is initiated, it is maintained for a minimum period of 30 days, after which the decision is evaluated again based in the updated deviation of the target liveweight and the defined conditions in the "manager" block. This complete feature may be turned on/off, in order to run particular short-term trials without any adjustment.

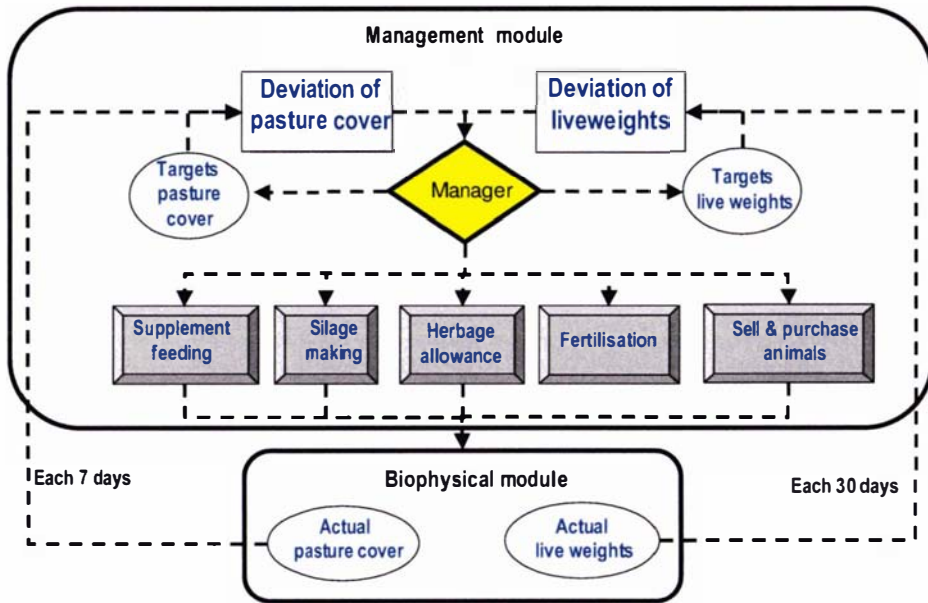


Figure 11. Main view of the relationship between the decision and the biophysical module.

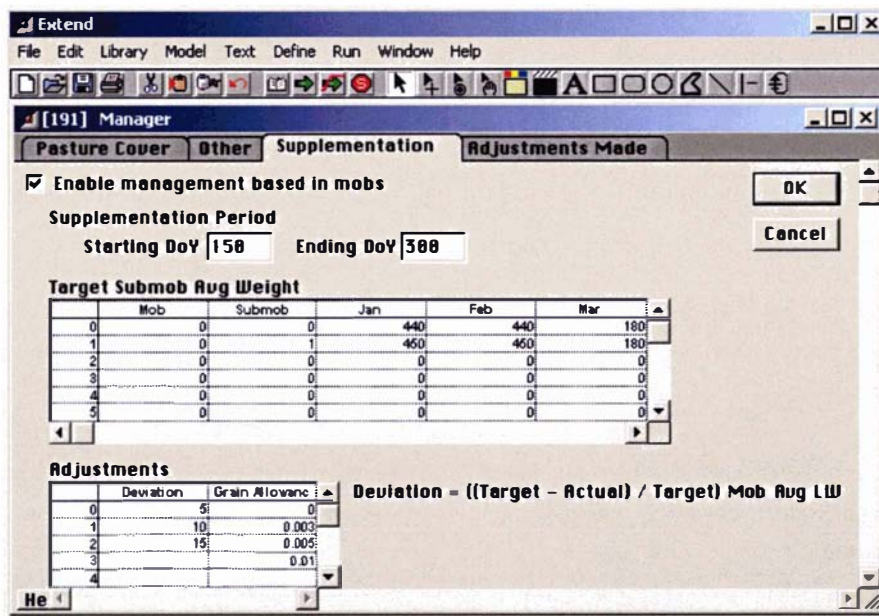


Figure 12. Extended dialog of the manager block.

2.4. Economic module

This module gives an indication of the economic response of the systems, acting as a constraint when high levels of technical efficiency (LWG, herbage utilisation, LW ha⁻¹) are pursued including off-farm inputs, such as maize grain.

Grazed herbage is usually less expensive than concentrate, and feeding supplement and silage making are additional expenses to the system. Supplementary feeding to grazing animals is a "process technology" that interacts with different components of the system, with direct and indirect effects on the animal and to the system (Chapter 1). In grazing systems, economic impacts are rarely related linearly to biological impacts, therefore in the case of grain feeding, whole-farm models have been used for economic appraisal in beef (Ruiz et al. 2000; Perillat et al. 2004) and dairy cattle systems (Soder & Rotz 2001).

There are different approaches and methodologies to evaluate a livestock business. In this study, a simple methodology widely used in Argentina (AACREA 1990) for assessing bio-economic farming performance of a complete year (expressed as gross margin) is incorporated as:

$$AP_{Costs} = \sum (LW_{In} P_{In} K_{26} (1 + P_{Costs} + T_{Costs})) \quad \text{Eqn. 50}$$

Where AP_{Costs} are the animal purchase costs (\$US yr⁻¹), LW_{In} is the individual animal liveweight at purchasing (kg), P_{In} is the purchase price (\$US kg LW⁻¹), P_{Costs} are the purchase costs (proportion of animal cost) and T_{Costs} are the transportation costs (proportion of animal cost).

$$AS_{Returns} = \sum (LW_{Out} P_{Out} K_{26} (1 - S_{Costs} + T_{Costs})) \quad \text{Eqn. 51}$$

Where $AS_{Returns}$ are the animal sale returns (\$US yr⁻¹), LW_{Out} is the individual animal liveweight at sale (kg), P_{Out} is the sale price (\$US kg LW⁻¹), S_{Costs} are the sale costs (proportion of animal cost) and T_{Costs} are the transportation costs (proportion of animal cost).

$$NI = AS_{Returns} - AP_{Costs} \quad \text{Eqn. 52}$$

NI is the net income (\$US), $AS_{Returns}$ are the animal sale returns (\$US yr⁻¹) and AP_{Costs} are the animal purchase costs (\$US yr⁻¹).

$$DC = Labour_{Costs} + TAH_{Costs} + TFC_{Costs} + Tsup p_{Costs} + Tfert_{Costs} \quad \text{Eqn. 53}$$

DC are the direct expenses of production (\$US yr⁻¹) and $Labour_{Costs}$ are the labour expenses (\$US yr⁻¹).

$$TAH_{Costs} = AH_{Costs} An_{Tot} \quad \text{Eqn. 54}$$

TAH_{Costs} are total animal health expenses expressed in \$US yr⁻¹, AH_{Costs} are animal health expenses (\$US hd yr⁻¹), An_{Tot} is the number of animals in the farm at starting of simulation (input) plus those purchased during the run.

$$TFC_{Costs} = FC_{Costs} A_{Conserved} \quad \text{Eqn. 55}$$

TFC_{Costs} are total expenses of forage conservation, FC_{Costs} are the expenses for conserving forage (\$US ha⁻¹) and $A_{Conserved}$ is the pasture area conserved (ha yr⁻¹).

$$TSupp_{Costs} = Grain_{Fed} (P_{Grain} + D_{Grain}) \quad \text{Eqn. 56}$$

$TSupp_{Costs}$ are the total supplementation expenses (\$US yr⁻¹), $Maize_{Fed}$ is the amount of maize grain fed (ton yr⁻¹), P_{Maize} is the grain price (\$US ton⁻¹) and D_{Maize} are the maize grain processing and distribution expenses (\$US ton⁻¹).

In multi-year simulations, the negative difference of silage inventory (if any) between starting conditions and the end of the productive cycle expressed in ton DM multiplied by the price of the silage (\$US ton⁻¹), is added to the total supplementation expenses of that year. Additionally, in multiyear simulation, finished and unfinished animal prices need to be provided to estimate the economic results when the productive cycle is closed.

$$Tfert_{Costs} = \sum (Fert_{Paddock} A_{Paddock} (P_{Fert} + App_{Costs})) \quad \text{Eqn. 57}$$

$Tfert_{Costs}$ are the total fertilisation expenses (\$US yr⁻¹) at any moment different than seeding time (included in pasture seeding costs), $Fert_{Paddock}$ is amount of fertiliser applied in each paddock (kg ha⁻¹), $A_{Paddock}$ is the area of each fertilised paddock (ha), P_{Fert} is the price of the fertiliser (\$US ton⁻¹) and App_{Costs} is the cost of fertilisation (\$US ha⁻¹).

$$GM = \frac{(NI - DC - P_{Amort})}{A_{Tot}} \quad \text{Eqn. 58}$$

GM is the gross margin of the farm (\$US yr⁻¹ ha⁻¹), NI is the net income (\$US), DC are the direct costs of production (\$US yr⁻¹), P_{Amort} is the amortisation cost of the pasture (\$US yr⁻¹ ha⁻¹) assuming four years as the duration of the pasture and A_{Tot} is the total area of the farm (ha) and:

$$P_{Amort} = PR_{Cost} PR_{Pr op} A_{Tot} \quad \text{Eqn. 59}$$

P_{Amort} are the costs of pasture renovation (\$US yr⁻¹) including fertilisation at seeding time, PR_{Cost} are the cost of seeding a pasture (\$US ha⁻¹), $PR_{Pr op}$ is the proportion of pasture renovation (% farm area yr⁻¹) and A_{Tot} is the total area of the farm (ha). In Figure 13 some of the inputs and outputs of the economics block are shown.

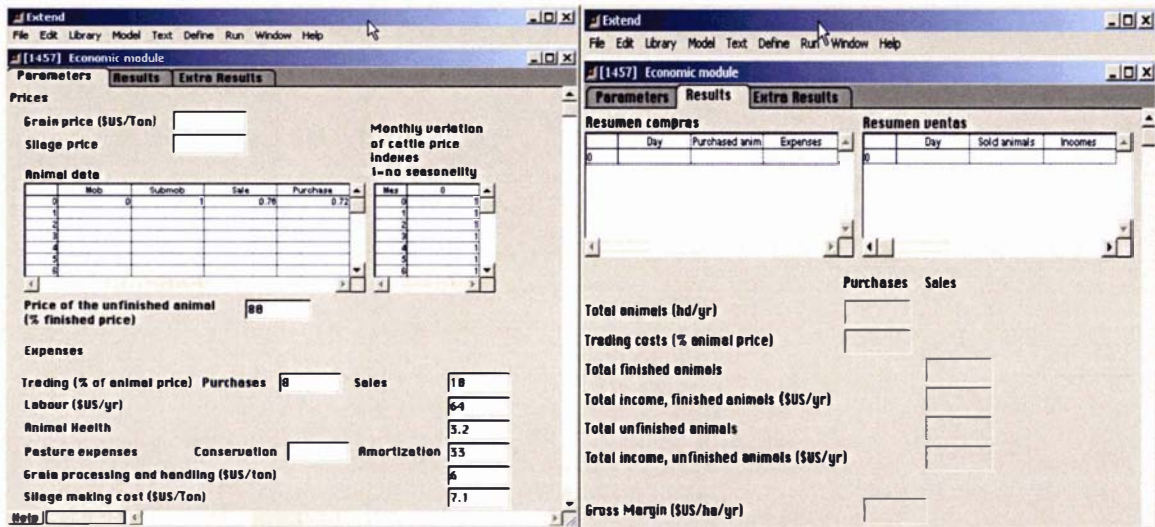


Figure 13. Extended dialog of economics block. White rectangles indicate required inputs and grey rectangles are estimated within the block.

3. Running mode

The model can be run in three different modes, “full interactive”, “automatic” and “automatic associated with optimization”. For the full interactive option, minimum information is required of the features of the simulated farm, and then the model stops when a user’s decision is needed. Extend allows efficient interactions with the user, so parameters and logic can be changed in real time following the approach of Garcia et al. (2000). The automatic alternative involves application by the manager of a grazing strategy defined by the researcher in the form of simple rules associated with $PCover_{Dev}$ and to LW_{Dev} (section 2.3.). Most of the rule-based models enunciate the rules that control the run (eg. SEPATOU, Cros et al. 2003), whereas BeefSim allows one to track the magnitude of the adjustment and when they occur (Figure 14). This offers the possibility of understanding the behaviour of the system through required adjustment (within the allowed range), and not only through its outputs (i.e. the behaviour of the rule is followed).

The third option is associated with a built-in global optimiser that can manipulate different variables (eg. initial stocking rate, herbage allowances, grain allowances, etc) to maximise others individually or in combination (eg. harvesting efficiency, animal production per ha, gross margin etc) or minimize them (herbage wastage, grain fed etc). Figure 15 shows the dialog of the global optimiser.

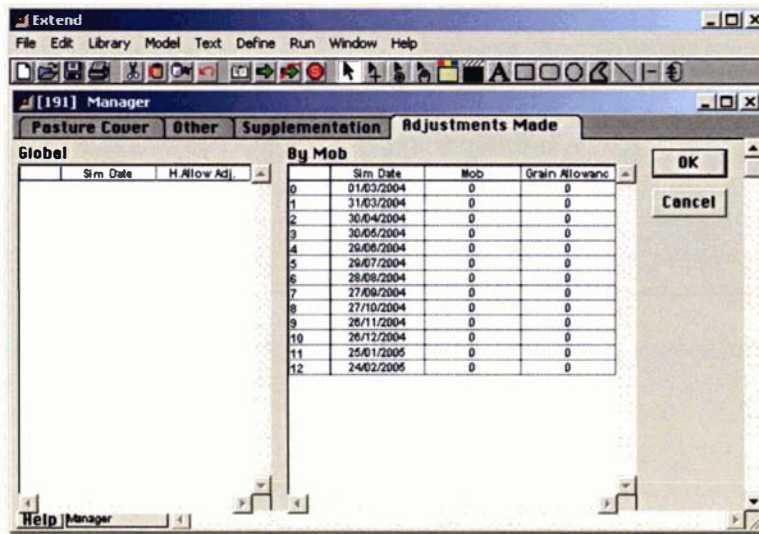


Figure 14. Tracking of adjustments made to grain supplementation by the manager block in association with deviation between actual liveweight and targets liveweight (Eqn. 50).

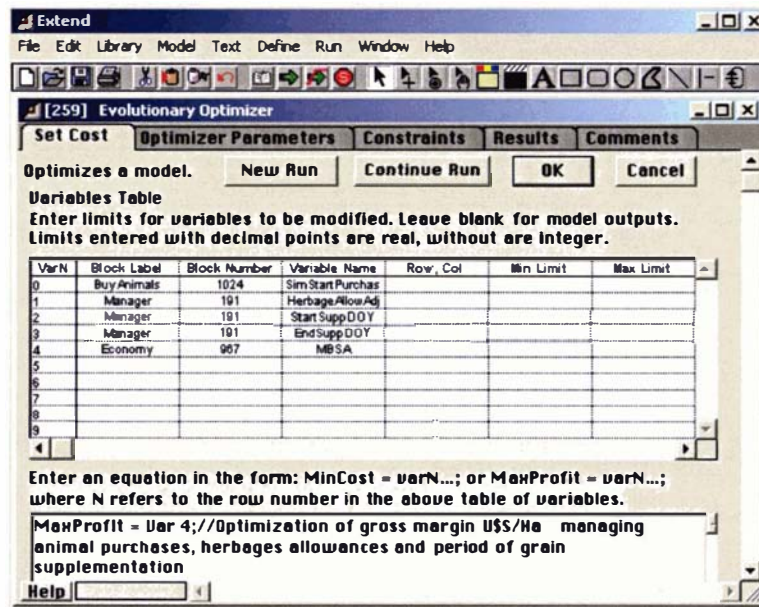


Figure 15. Dialog of the evolutionary optimizer block (front tab).

4. Conclusions

A beef cattle finishing unit simulator (BeefSim) has been developed, representing the main biological processes of the system, together with some indication of economics. This research tool can simulate different levels of grain supplementation, stocking rates, and herbage allowances, from one day to multi-year runs. In the next chapter, the model will be tested for its capability to reproduce grazing trials developed within this thesis and also from the literature.

Table 1. Alphabetical order of model definitions.

Abbreviations	Description	unit
A	Animal age	d
$A_{\text{Conserved}}$	Surface of forage conserved	ha yr ⁻¹
AH_{Costs}	Health expenses per animal	\$US hd ⁻¹ yr ⁻¹
A_{Tot}	Total surface of farm	ha
An_{Tot}	Animals in the farm when simulation starts	hd
A_{Paddock}	Area of each paddock	ha
AP_{Costs}	Total expenses of buying animals	\$US yr ⁻¹
App_{Costs}	Expense of applying fertiliser	\$US ha ⁻¹
AS_{Return}	Animal sale returns	\$US
		Ratio of normal
BC	Relative animal body condition	weight (N)
CP_{D}	Crude protein in the dead component	Fraction of DM
CP_{Diet}	Crude protein eaten	kg d ⁻¹
CP_{Diet}	Animal diet crude protein content	% DM
CP_{FS}	Fibrous supplement crude protein content	% DM
CP_{Maize}	Maize grain crude protein content	Fraction of DM
CP_{Herbage}	Herbage crude protein content	Fraction of DM
$CP_{\text{HerbageEaten}}$	Crude Protein of the herbage eaten	% DM
CP_{L}	Crude protein in the leaf component	Fraction of DM
CP_{St}	Crude protein in the sheath & stem component	Fraction of DM
D	Dead mass	kg DM ha ⁻¹
D%	Fraction of dead in the herbage	Fraction of DM
D_{AH}	Dead masses after harvesting	kg DM ha ⁻¹
D_{BH}	Dead masses before harvesting	kg DM ha ⁻¹
DC	Direct costs	
	Total expense of processing and feeding	
D_{Maize}	supplement	\$US ton ⁻¹
$Diet_{\text{ME}}$	Metabolisable energy eaten	MJ ME d ⁻¹
$Diet_{\text{CP}}$	Crude protein eaten	g CP d ⁻¹
	Fraction of dead components in the diet under	
$Diet_{\text{D}}$	rotational conditions	Fraction
	Fraction of leaf component in the diet under	
$Diet_{\text{L}}$	rotational conditions	Fraction
	Fraction of sheath & stem in the diet under	
$Diet_{\text{St}}$	rotational conditions	Fraction

Table 1. Alphabetical order of model definitions (Cont.)

Abbreviations	Description	Unit
Dig _{Herbage}	<i>In vitro</i> herbage DM digestibility	Fraction of DM
Dig _{FS}	<i>In vitro</i> DM digestibility of fibrous supplement	Fraction of DM
D _R	Dead decay rate	Fraction d ⁻¹
f _A	Intake restriction factor associated to herbage availability	Fraction
f _{Adj}	Intake restriction factor associated to herbage conversion factor from herbage accumulation rate to herbage growth rate	Ratio of HAR _{Input}
FC _{Costs}	Expenses of conserving an hectare	\$US ha ⁻¹
FD	Fertilizer rate	kg ha ⁻¹
Fert _{Paddock}	Total fertilizer per paddock	kg yr ⁻¹
f _L	Intake restriction factor associated to leaf mass	Fraction
f _{LA}	Intake restriction factor associated to leaf allowance	Fraction
FR	Fertilizer response	kg DM ha ⁻¹
FS	Fibrous supplement eaten	kg DM d ⁻¹
f _{Season}	Seasonal factor associated with the decline of stem component	Fraction
FS _{Factor}	Reduction of rumen capacity by feeding fibrous supplement	kg DM d ⁻¹
GGR	Herbage gross growth rate	kg DM ha ⁻¹ d ⁻¹
GM	Gross margin	\$US ha ⁻¹ yr ⁻¹
HAR	Herbage accumulation rate	kg DM ha ⁻¹ d ⁻¹
HAR _{Input}	Herbage accumulation rate (input)	kg DM ha ⁻¹ d ⁻¹
HAR _{Actual}	Herbage accumulation rate actual	kg DM ha ⁻¹ d ⁻¹
HM	Herbage mass	kg DM ha ⁻¹
HM _{PostH}	Post-harvesting herbage mass	kg DM ha ⁻¹
HM _{PreH}	Pre-harvesting herbage mass	kg DM ha ⁻¹
I	Individual herbage intake and silage intake (if any) when grain is not fed	kg DM ha ⁻¹
I _F	Individual Intake estimated from rumen fill constraints	kg DM ha ⁻¹
IFR	Initial fertiliser response	kg DM ha ⁻¹
I _{FS}	Fibrous supplement intake	kg DM d ⁻¹
I _H	Herbage intake	kg DM d ⁻¹

Table 1. Alphabetical order of model definitions (Cont.)

Abbreviations	Description	Unit
I_{Maize}	Maize grain intake	kg DM d ⁻¹
	Individual Intake estimated from potential and	
I_{P}	rumen fill constraints	kg DM d ⁻¹
L	Leaf mass	kg DM ha ⁻¹
$L\%$	Fraction of sheath & stem in the herbage	Fraction of DM
LA	Leaf allowance	g (kg LW ^{0.75}) ⁻¹ d ⁻¹
$\text{Labour}_{\text{Costs}}$	Labour expenses	\$US yr ⁻¹
L_{AH}	Leaf mass after harvesting	kg DM ha ⁻¹
L_{BH}	Leaf mass before harvesting	kg DM ha ⁻¹
L_{Ceil}	Leaf ceiling mass	kg DM ha ⁻¹
L_{Ceil}	Leaf ceiling mass	kg DM ha ⁻¹
LW	Animal liveweight	kg
LW_{Birth}	Animal birth liveweight	kg
LW_{Actual}	Actual animal liveweight	kg hd ⁻¹
LW_{Dev}	Deviation of animal liveweight on a given date	%
LW_{In}	Liveweight of each animal at purchase	kg
LW_{Out}	Liveweight of each animal at sale	kg
	Target average animal liveweight of the farm for	
LW_{Target}	specific date	kg hd ⁻¹
$\text{Maize}_{\text{Fed}}$	Maize grain fed	% LW d ⁻¹
$\text{Max}_{\text{LCeil}}$	Seasonal maximum leaf ceiling mass	kg DM ha ⁻¹
ME_{D}	Metabolisable energy in the dead component	MJ ME kg DM ⁻¹
ME_{Diet}	Metabolisable energy in the animal diet	MJ ME kg DM ⁻¹
ME_{FS}	Metabolisable energy in fibrous supplement	MJ ME kg DM ⁻¹
ME_{Maize}	Metabolisable energy in maize grain	MJ ME kg DM ⁻¹
$\text{ME}_{\text{Herbage}}$	Metabolisable energy	MJ ME kg DM ⁻¹
$\text{ME}_{\text{HerbageEaten}}$	Metabolisable energy of the herbage eaten	MJ ME kg DM ⁻¹
	Metabolisable energy in the sheath & stem	
ME_{L}	component	MJ ME kg DM ⁻¹

Table 1. Alphabetical order of model definitions (Cont.).

Abbreviations	Description	Unit
ME _{St}	Metabolisable energy in the leaf component	MJ ME kg DM ⁻¹
Min _{LCeill}	Seasonal minimum leaf ceiling mass	kg DM ha ⁻¹
N	Normal liveweight as defined in SCA (1990)	fraction
NI	Net income	\$US
P _{Amort}	Pasture amortisation cost	\$US yr ⁻¹ ha ⁻¹
P _{Costs}	Purchase costs	Fraction of animal cost
P _{coverCurrent}	Current average pasture cover on the farm	kg DM ha ⁻¹
P _{coverDev}	Deviation of target pasture covers on a given date	%
P _{coverTarget}	Target average pasture cover on the farm for specific date	kg DM ha ⁻¹
P _{Fert}	Price of fertiliser	\$US ton ⁻¹
P _{In}	Price of animals at purchase	\$US kg LW ⁻¹
P _{Out}	Price of animals at sale	\$US kg LW ⁻¹
P _{Maize}	Price of maize grain	\$US ton ⁻¹
PR _{Cost}	Expense of seeding a pasture	\$US ha ⁻¹
PR _{Prop}	Proportion of total farm pasture renovated	proportion yr ⁻¹
RC	Rumen capacity	kg
S	Total senescence rate	kg DM ha ⁻¹ d ⁻¹
S _{Costs}	Sale costs	Fraction of animal cost
Sel _D	Fraction of leaf, sheath & stem and dead components under continuous grazing management	Fraction
Sel _L	Fraction of leaf component under continuous grazing management	Fraction
Sel _{St}	Fraction of sheath & stem component under continuous grazing management	Fraction
S _L	Leaf senescence rate	kg DM ha ⁻¹ d ⁻¹
Spell	Total duration of the fertilizer response	d
SR	Substitution rate	kg DM herbage kg DM grain ⁻¹
SRW	Standard reference animal weight as defined in SCA (1990)	kg

Table 1. Alphabetical order of model definitions (Cont.).

Abbreviations	Description	Unit
S _{St}	Sheath & Stem senescence rate	kg DM ha ⁻¹ d ⁻¹
St	Sheath & stem mass	kg DM ha ⁻¹
St%	Fraction of leaf in the herbage	Fraction of DM
St _{AH}	Sheath & stem mass after harvesting	kg DM ha ⁻¹
St _{BH}	Sheath & stem mass after harvesting	kg DM ha ⁻¹
Supp _{Fed}	Total supplement fed	Ton yr ⁻¹
t	Current simulation time	d
t _{AfterF}	Time after fertilisation	d
TAH _{Costs}	Total costs of animal health	\$US yr ⁻¹
T _{Costs}	Transportation costs	% animal cost
TFC _{Costs}	Total costs of forage conservation	\$US yr ⁻¹
TFert _{Costs}	Total costs of fertilisation	\$US yr ⁻¹
TI	Total dry matter intake	kg DM d ⁻¹
TotMaizeEaten	Total amount of maize grain eaten in the farm	ton. DM yr ⁻¹
TSupp _{Costs}	Total costs of supplementation	\$US yr ⁻¹
Z	Relative animal size as defined in SCA (1990)	Fraction
ΔHAR _F	Extra herbage accumulation rate above herbage accumulation rate of the unfertilised pasture	kg DM ha ⁻¹ d ⁻¹

Table 2. Constants used in the pasture sub-model.

Constant	Description	Value	Source
β ₁	Slope of herbage gross growth rate	Vegetative = - 0.0014 Reproductive = - 0.0023	Barioni (1997)
β ₂	Day when minimum L _{Ceil} occurs	355	Cacho et al. (1995)
β ₃	Slope of the linear leaf senescence	Estimated by Eqn.7	
β ₄	Maximum and minimum proportion of dead decomposition	15 February = 0.02 1 July=0.05, interpolated the rest of the year	Cacho et al. (1995)
β ₅	Seasonal partitioning fraction of gross herbage growth rate to leaf component	Vegetative = 0.70 Reproductive = 0.65	Cacho et al. (1995)

Table 3. Model constants.

Constant	Definition	Units	value	Reference
K ₁	Relative size	kg kg ⁻¹	0.025	(SCA 1990)
K ₂	--		1.7	(SCA 1990)
K ₃	Growth rate constant	Kg LW ^{0.27} d ⁻¹	0.0157	(SCA 1990)
K ₄	Allometric scalar for animal growth rate		0.27	(SCA 1990)
K ₅	Intake parameter		0.063	(Finlayson et al. 1995)
K ₆	DM Losses when fibrous supplement is fed		0.1	Assumed
K ₇	Intake parameter		0.17	(Finlayson et al. 1995)
K ₈	Conversion L to LAI	kg	290	(Doyle et al. 1989)
K ₉	Intake parameter	-	0.229	(Herrero et al. 2000)
K ₁₀	Allometric parameter	-	0.36	(Herrero et al. 2000)
K ₁₁	Intake parameter	-	3	(Johnson & Parsons 1985)
K ₁₂	Slope for Leaf allowance effect	-	-0.0344±0.8 ⁻³	Fitted from King et al. (1995)
K ₁₃	Leaf preference	Proportion	0.6	Barioni (1997)
K ₁₄	Stem preference	Proportion	0.3	Barioni (1997)
K ₁₅	Dead preference	Proportion	0.1	Barioni (1997)
K ₁₆	Regression intercept	-	-0.12	Dixon and Stockdale (1999)
K ₁₇	Regression slope	-	0.0079	Dixon and Stockdale (1999)
K ₁₈	Conversion factor of ME to Dig DM		0.157	AFRC (1993)
K ₁₉	Seasonal variation of Stem quality	% Proportion of average value	Default=0.1	User-defined
K ₂₀	Losses in grain feeding	Proportion of DM grain fed	0.05	User-defined
K ₂₁	Fertiliser parameter	-	Uncalibrated	
K ₂₂	Fertiliser parameter	-	Uncalibrated	
K ₂₃	Fertiliser parameter			
K ₂₄	Fertiliser parameter		80	Barioni (1997)
K ₂₅	Fertiliser parameter		0.6	Barioni (1997)
K ₂₆	Shrunk LW loss	Proportion of LW	0.04	Assumed

References

- AACREA. 1990: Normas para Medir los Resultados Económicos en las Empresas Agropecuarias. *Convenio AACREA - BANCO RIO. Buenos Aires. Argentina* :80 p.
- AFRC. 1993: Energy and protein requirements of ruminants. *Published by the AFRC Technical Committee on Response to Nutrients* :176 p.
- Allen S. A. 1996: Physical constraints on voluntary intake of forages by ruminants. *Journal of Animal Science* 74:3063-3075.
- Arosteguy J. 1984: Invernada en la Pampa deprimida de la Provincia de Buenos Aires. *Revista Argentina De Producción Animal* 4:843-853.
- Baker R. D.; Alvarez F.; Le Du L. P. 1981: The effect of herbage allowance upon the herbage intake and performance of suckler cows and calves. *Grass and Forage Science* 36:189-199.
- Barioni L. 1997: A dynamic simulation model for planning and controlling grazing systems. Thesis Master, Agricultural Systems and Management at Massey University.168 p.
- Barioni L. G.; Dake C. K. G.; Parker W. J. 1999: Optimizing rotational grazing in sheep management systems. *Environment International* 25:819-825.
- Belanger G.; Walsh J. R.; Richards J. E.; Milburn P.; Ziadi N. 2000: Comparison of three statistical models describing potato yield response to nitrogen fertilizer. *Agronomy Journal* 92:902-908.
- Berardo A.; Marino M. A. 2000: Fertilización fosfatada de pasturas en el sudeste bonaerense. 1. Residualidad del P aplicado y efecto de las refertilizaciones anuales. *Revista Argentina De Producción Animal* 20:103-111.
- Brennan D.; Gooday J. 1998. *Australian Bureau of Agricultural and Resource Economics (ABARE)*:65-75.
- Buckmaster D. R.; Rotz C. A.; Muck R. E. 1989: comprehensive model of forage

changes in the silo. *Transactions of the ASAE* 32:1143-1152.

- Bush L.; Burton H. 1994: Intrinsic chemical factors in forage quality. In: Fahey, J.R. ed. *Forage Quality, Evaluation and Utilization*. American Society of Agronomy, Inc.:367-405.
- Butler B. M.; Hoogendoorn C. J. 1987: Pasture quality and animal performance over late spring and summer. *Proceedings of the New Zealand Grassland Association* 47:31-33.
- Cacho O. J.; Finlayson J. D.; Bywater A. C. 1995: A simulation model of grazing sheep: II. Whole-farm model. *Agricultural Systems* 48:25-37.
- Cangiano C. A.; Galli J. R.; Pece M. A.; Dichio L.; Rozsypalek S. H. 2002: Effect of liveweight and pasture height on cattle bite dimensions during progressive defoliation. *Australian Journal of Agricultural Research* 53:541-549.
- Cangiano C. A.; Gomez P. 1985: Estimación del consumo de forraje mediante componentes del comportamiento ingestivo de novillos en pastoreo. *Revista Argentina De Producción Animal* 5:573-579.
- Cohen R. D. H.; Stevens J. P.; Moore A. D.; Donnelly J. R. 2003: Validating and using the GrassGro decision support tool for a mixed grass/alfalfa pasture in western Canada. *Canadian Journal of Animal Science* 82:171-182.
- Colwell J. D. 1994: *Estimating fertiliser requirement. A quantitative approach*. Oxford, CAB International, Wallingford. U.K. 262 p.
- Corrall A. J.; Fenlon J. S. 1978: A comparative method for describing the seasonal distribution of production from grasses. *Journal of Agricultural Science, Cambridge* 91 :61-67.
- Cros M. J.; Duru M.; Garcia F.; Martin-Clouaire R. 2003: A biophysical dairy farm model to evaluate rotational grazing management strategies. *Agronomie* 23:105-122.
- Cros M. J.; Duru M.; Garcia F.; Martin-Clouaire R. 2004: Simulating management strategies: the rotational grazing example. *Agricultural Systems* 80:23-42.

- Cros M. J.; Duru M. G. F. M.-C. R. 1997: Characterising and simulating a rotational grazing strategy. *First European Conference for Information Technology in Agriculture. Copenhagen. 15-18 June. 1-4.*
- De Battista J. P.; Costa M. C. 1998: Efecto de la fertilización nitrogenada y la frecuencia de defoliación sobre la producción y calidad del trebol rojo. *Revista Argentina De Producción Animal. 21 Congreso Argentino De Prod. Animal. 18:192-193.*
- Delagarde R.; Peyraud J.; Delaby L. 2000: Influence of herbage allowance on intake and behaviour of dairy cows grazing perennial ryegrass swards in autumn. *In: Rook, A.J. & Penning, P. D. Eds. The Principles and Practice of Grazing, for Profit and Environmental Gain, Within Temperate Grasslands Systems. Occasional Symposium No 34, British Grassland Society 34:101-102.*
- Demment M. W.; Peyraud J. L.; Laca E. A. 1995: Herbage intake at grazing: a modelling approach. *In: Journet, M.; Grenet, E.; Farce, M.H.; Theriez, M.; Demarquilly, C. Eds. Recent development in Nutrition of Ruminants.:121-141.*
- Dixon R. M.; Stockdale R. C. 1999: Associative effects between forages and grains: consequences for feed utilisation. *Australian Journal of Agricultural Research 50:757-753.*
- Dougherty C.; Smith E.; Bradley N.; Forbes T.; Cornelius P.; Lauriault L.; Arnold C. 1988: Ingestive behaviour of beef cattle grazing alfalfa (*Medicago sativa L.*). *Grass and Forage Science 43: 121-130.*
- Dougherty C. T.; Bradley N. W.; Cornelius P. L.; Lauriault L. M. 1989: Accessibility of herbage allowance and ingestive behavior of beef cattle. *Applied Animal Behavior Science 23:87-97.*
- Dougherty C. T.; Bradley N. W.; Lauriault L. M.; Arias J. E.; Cornelius P. L. 1992: Allowance-intake relations of cattle grazing vegetative tall fescue. *Grass and Forage Science 47:211-219.*

- Dougherty C. T.; Collins M. B. N. W.; Cornelius P. L.; Lauriault L. M. 1990: Moderation of ingestive behaviour of beef cattle by grazing induced changes in lucerne swards. *Grass and Forage Science* 45:135-142.
- Dove H. 1996: Constraints to the modelling of diet selection and intake in the grazing ruminant. *Australian Journal of Agricultural Research* 47:257-275.
- Doyle C. J.; Baars J. A.; Bywater A. C. 1989: A simulation model of bull beef production under rotational grazing in the Waikato region of New Zealand. *Agricultural Systems* 31:247-278.
- Ellis W. C. 1978: Determinants of grazed forage intake and digestibility. *Journal of Dairy Science* 61:1828-1840.
- Ferrer Cazcarra R.; Petit M. 1995: The influence of animal age and sward height on the herbage intake and grazing behavior of Charolais cattle. *Animal Science* 61:497-506.
- Ferrer Cazcarra R.; Petit M.; D'hour P. 1995: The effect of sward height on grazing behaviour and herbage intake of three sized of Charolais cattle grazing cocksfoot (*Dactylis glomerata*) swards. *Animal Science* 61:511-518.
- Finlayson J. D.; Cacho O. J.; Bywater A. C. 1995: A simulation model of grazing sheep: animal growth and intake. *Agricultural Systems* 48:1-25.
- France J.; Thornley J. H. M. 1984: *Mathematical Models in Agriculture: A Quantitative Approach to Problems in Agriculture and Related Sciences*. Butterworths & Co (Publishers):335 p.
- Freer M.; Moore A. D.; Donnely J. R. 1997: GRAZPLAN: Decision Support System for Australian grazing enterprises - II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* 54:77-126.
- Garcia S. C.; Holmes C. W.; MacDonald A. 2000: IDFS: a dynamic Interactive dairy farm simulator. *Asian-Australasian Journal of Animal Sciences* 13.A:112.
- Garcia S. C.; Santini F.; Castaño G. 1998: Producción de carne bajo pastoreo:

- Alternativas de intensificación. Material didáctico Nro 14. INTA, Cerbas.:52 p.
- Geenty K.; Sykes A. R. 1982: Influence of herbage allowance on diet quality in lactating ewes. *Proceedings of the New Zealand Society of Animal Production* 42:161-163.
- Gordon I. J.; Lascano C. 1993: Foraging strategies of ruminant livestock on intensively managed grasslands: potential and constraints. *Proceedings of the XVII International Grassland Congress* :681-690.
- Grainger C.; Matthews G. L. 1989: Positive relation between substitution rate and pasture allowance for cows receiving concentrates. *Australian Journal of Experimental Agriculture* 29:355-360.
- Gray D. J.; Parker W. J.; Kemp E. A.; Kemp P. D.; Brookes I. M.; Horne D.; Kenyon P. R.; Matthew C.; Morris S. T.; Reid J. I.; Valentine I. 2003: Feed planning - alternative approaches used by farmers. *Proceedings of the New Zealand Grassland Association* 65:205-209.
- Guaita M. S.; Echeverria H. E.; Escuder C. J. 1996: Fertilización de una pastura de raigrás perenne y trébol rojo: Recuperación de nitrógeno en el sistema suelo-planta. *Revista Argentina De Producción Animal* 17:97-104.
- Guaita M. S.; Fernandez H. H. 2002: Composición química y variabilidad de alimentos analizados en el laboratorio de nutrición animal y evaluación de calidad de forrajes de la unidad integrada Balcarce. *Revista Argentina De Producción Animal. 25 Congreso Argentino De Prod. Animal.* 22:57-58.
- Haefner J. W. 1997: *Modeling Biological System: Principles and Applications*. Utah State University. Chapman&Hall: 473 p.
- Herrero M.; Dent J. B.; Fawcett R. H. 1998: The plant/animal interface in models of grazing systems. *In: Peart, R.M. & Curry, R.B. Eds. Agricultural System Modeling and Simulation*. New York. Marcel Dekker, Inc. 495-542.
- Herrero M.; Fawcett R. H.; Silveira V.; Busque J.; Bernues A.; Dent J. B. 2000: Modelling the growth and utilisation of kikuyu grass (*pennisetum*

- clandestinum*) under grazing. 1. Model definition and parameterisation. *Agricultural Systems* 65:73-97.
- Hodgson J. 1984: Sward conditions, herbage allowance and animal production. *Proceedings of the New Zealand Society of Animal Production* 44: 99-104.
- Hodgson J. 1990: *Grazing Management: Science into Practice*. Longman Handbooks in agriculture, Longman Scientific and Technical co-published with John Wiley. New York: 203 p.
- Hodgson J.; Brookes I. M. 1999: Nutrition of grazing animals. *In: White, J.& Hodgson, J. Eds. New Zealand Pasture and Crop Science*. Oxford University press. 117-132.
- Holmes C. W.; Matthews P. N. P. 2001: Feeding of conserved forage implications to grassland management and production. *Proceedings of the XV International Grassland Congress* :671-679.
- Horn G. W.; McCollum F. T. 1987: Energy supplementation of grazing ruminants, July 23-24. *Proceedings of the Grazing Livestock Nutrition Conference* :125-136.
- Illius A. W.; Gordon I. J. 1987: The allometry of food intake in grazing ruminants. *Journal of Animal Ecology* 56:989-999.
- Illius A. W.; Jessop N. S. 1996: Metabolic constraints on voluntary intake in ruminants. *Journal of Animal Science* 74:3052-3062.
- Johnson I. R.; Parsons A. J. 1985: A theoretical analysis of grass growth under grazing. *Journal of Theoretical Biology* 112:345-368.
- Kemp P. D.; Condon I. M.; Matthew C. 1999: Pastures and soil fertility. *In: White, J.& Hodgson, J. Eds. New Zealand Pasture and Crop Science*. Oxford University press. 67-82.
- Kim T. H.; An K. W.; Jung W. J. 1995: Effects of daily herbage allowance on sward structure, herbage intake and milk production by dairy cows grazing a pure perennial ryegrass sward. *Asian-Australasian Journal of Animal Sciences*

14:1383-1388.

- Kloster A. M.; Latimori N. J.; Amigone M. A. 2003: Comparación de sistemas de pastoreo rotativo (convencional vs. líderes y seguidores) sobre una pastura base alfalfa. *Revista Argentina De Producción Animal* 23:25-32.
- Krahl D. 2002: The Extend simulation environment. *Proceedings of the 2002 Winter Simulation Conference* :205-213.
- Lattanzi F.; Mazzanti A. E. 1997: Fertilización nitrogenada de pasturas en Festuca arundinacea de tiempo templado y mediterráneo. *Revista Argentina De Producción Animal* 17:166-167 (resumen).
- Lemaire G.; Agnusdei M. 2000: Leaf tissue turnover and efficiency of herbage utilization. *In: Hodgson, J.; Lemaire, G.; Moraes, A.; Carvalho, P.C.F.; Nabinger, C. Eds. Grassland Ecophysiology and Grazing Ecology.* CAB International. 265-288.
- Loewer O. J. 1998: GRAZE: A beef-forage model of selective grazing. *In: R.M. Peart, R.M. & Curry, R.B. Eds. Agricultural Systems Modeling and Simulation.* Marcel Dekker, New York. 301-417.
- Machado C.; Striebeck G.; Vasolo V.; Di Croce F.; Gonzalez F.; Duhalde J.; Parente M.; Auza N. 2001: Suplementación de grano de maíz en pastoreo y a corral como alternativas de terminación de novillos en el verano. *Avances En Producción Animal* 26:139-146.
- Marino M. A.; Berardo A. 2000: Fertilización fosfatada de pasturas en el sudeste bonaerense. *Revista Argentina De Producción Animal* 20:113-121.
- Marshall P. R.; McCall D. G.; Johns K. L. 1991: Stockpol: A decision support model for livestock farms. *Proceedings of the New Zealand Grassland Association* 53:137-140.
- Martin B.; Refi R. 2002: Efectos de la intensidad de pastoreo y la fertilización nitrogenada en el crecimiento y la estabilidad de una pastura con alfalfa. *Revista Argentina De Producción Animal* 22:123-124 (resumen).

- Mayne C. S. 1988: Effects of supplementation on the performance of both growing and lactating cattle at pasture. *In: Frame, J. Ed. Efficient Beef Production from Grass*. Occasional Symposium. No.25, British Grassland Society, Berkshire, UK. 55-71.
- McCall D. G. 1984: A systems approach to research planning for North Island Hill Country. PhD Thesis. Massey University. 261 p.
- McCall D. G.; Bishop-Hurley G. J. 2003: A pasture growth model for use in a whole-farm dairy production model. *Agricultural Systems* 76:1183-1205.
- McKinion J. M. 1980: Dynamic simulation: a positive feedback mechanism for experimental research in the biological sciences. *Agricultural Systems* 5:239-250.
- Milne J. A. 1991: Diet selection by grazing animals. *Proceedings of the Nutrition Society* 50:77-85.
- Moir J. L.; Scotter D. R.; Hedley M. J.; Mackay A. D. 2000: A climate-driven, soil fertility dependent, pasture production model. *New Zealand Journal of Agricultural Research* 43:491-500.
- Neaves P. J.; Parker W. J.; Holmes C. W. 1996: A farm level model to aid decisions regarding the feeding of concentrates to dairy cattle. *Proceedings of the New Zealand Society of Animal Production* 56:280-284.
- Nelson C. J.; Moser L. E. 1994: Plant factors affecting forage quality. *In: Fahey, G. C. Jr.; Collins, M.; Mertens, D.R.; Moser, L.E. Eds. Forage Quality, Evaluation, and Utilization*. American Society of Agronomy:115-154.
- Nielsen B.; Thamsborg S. M.; Andersen H. R.; Kristensen T. 2003: Effect of winter feeding level and season on herbage intake in dairy breed steers on perennial ryegrass/white clover pasture. *Animal Science* 76:341-352.
- Okajima T.; Kamijoh T.; Yokota H.; Ohshima M. 1996: Relationships between daily herbage intake of grazing cattle with daily herbage allowance and leafiness. *Asian-Australasian Journal of Animal Sciences* 9:577-582.

- Pannell D. J. 1999: On the estimation of on-farm benefits of agricultural research. *Agricultural Systems* 61:123-134.
- Parker W. J. 1999: Farm performance measurement - linking monitoring to business strategy. *Proceedings of the New Zealand Society of Animal Production* 59:6-13.
- Parsons D. J. 1998: Optimising silage harvesting plans in a grass and grazing simulation using the revised simplex method and a genetic algorithm. *Agricultural Systems* 56:29-44.
- Penning P. D.; Parsons A. J.; Orr R. J.; Hooper G. E. 1994: Intake and behavior responses by sheep to changes in sward characteristics under rotational grazing. *Grass and Forage Science* 49:476-486.
- Perillat B. J.; Brown W. J.; Cohen R. D. H. 2004: A risk efficiency analysis of backgrounding and finishing steers on pasture in Saskatchewan, Canada. *Agricultural Systems* 80:213-233.
- Peyraud J. L.; Delaby L.; Delagarde R.; Parga J. 1999: Effect of grazing management, sward state and supplementation strategies on intake, digestion and performances of grazing dairy cows. In: *Anais Da Reuniao Da Sociedade Brasileira De Zootenia*, 36, Porto Alegre. RS 26-28 Julho.
- Picone L. I.; Zamuder E. C. B. A.; Marino M. A. 2003: Phosphorous transformation as affected by sampling date, fertiliser and phosphorous uptake in a soil under pasture. *Nutrient Cycling in Agroecosystems* 67:225-232.
- Poppi D. P.; Hughes T. P. y. L. P. J. 1987: Intake of pasture by grazing ruminants. In: Nicol, A.M. Ed. *Feeding livestock on pasture*. New Zealand Society of Animal Production, Occasional Publication Nr 10. 55-63.
- Ratkowsky D. A.; Sale P. W. G.; Tennakoon S. B.; Johnson D.; Simpson P. G. 1997: Models for pasture yield in response to phosphate applications. *Australian Journal of Experimental Agriculture* 37:905-912.
- Reardon T. F. 1977: Effect of herbage per unit area and herbage allowance on dry matter intake by steers. *Proceedings of the New Zealand Society of Animal*

Production 37: 58-61.

- Rearte D. 1998: Beef cattle production and meat quality on grazing system in temperate regions. *Revista Argentina De Producción Animal 18*:129-142.
- Rearte D. 1999: Sistemas pastoriles intensivos de producción de carne de la región templada. In: *Anais Da Reuniao Da Sociedade Brasileira De Zootenia, 36, Porto Alegre. RS 26-28 Julho*:213-223.
- Rearte D.; Pieroni G. A. 2001: Supplementation of temperate pastures. *Proceedings of the XV International Grassland Congress* :679-691.
- Redmon L.; McCollum T.; Horn G.; Matthew D.; Cravey S.; Gunter P.; Beck J.; Mieres M. ; San Julian R. 1995: Forage intake by beef steers grazing winter wheat with varied herbage allowances. *Journal of Range Management 48*:198-201.
- Robaina A. C.; Grainger C.; Moate P.; Taylor J.; Steward J. 1998: Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture 38*:541-549.
- Romera A. J.; Morris S. T.; Hodgson J.; Stirling W. D.; Woodward S. J. R. 2004: A model for simulating rule-based management of cow-calf systems. *Computers and Electronics in Agriculture 42*:67-86.
- Ruiz D. E. M.; Pardo Sampere L.; Garcia Martinez A.; Rodriguez Alcaide J.; Pamio J. O.; Pena Blanco F.; Domenech Garcia V. 2000: Technical and allocative efficiency analysis for cattle fattening on Argentina Pampas. *Agricultural Systems 65*:179-199.
- Santini F. J.; Elizalde J. C. 1993: Utilización de granos en la alimentación de rumiantes. *Revista Argentina De Producción Animal 13*:39-60.
- SCA. 1990: Feeding Standards for Australian livestock. *Standing Committee on Agriculture, Ruminants Subcommittee. CSIRO Publications. 266 p.*
- Soder K. J.; Rotz C. A. 2001: Economic and environmental impact of four levels of concentrate supplementation in grazing dairy herds. *Journal of Dairy*

- Science* 84:2560-2572.
- Stakelum G. 1986: Herbage intake of grazing dairy cows. II. Effects of herbage allowance, herbage mass and concentrate feeding on the intake of cows grazing primary spring grass. *Irish Journal of Agricultural Research* 25:41-51.
- Stockdale R. C. 1985: Influence of some sward characteristics on the consumption of irrigated pastures grazed by lactating dairy cows. *Grass and Forage Science* 40:31-39.
- Thompson D. J.; Brooke B. M.; Garland G. J.; Hall J. W.; Majak W. 2000: Effect of stage of growth of alfalfa on the incidence of bloat in cattle. *Canadian Journal of Animal Science* 80:725-727.
- Thornley J. H. M. 2001: Modelling grassland ecosystems. *Proceedings of the XIX International Grassland Congress. Brazil.* 1029-1035.
- Thornley J. H. M.; Johnson I. R. E. 1990: *Plant and Crop Modelling: a Mathematical Approach to Plant and Crop Physiology*. Oxford, England; New York: Clarendon Press. 669 p.
- Viviani Rossi E.; Gutierrez L. M. 1995: Factores que condicionan la calidad de los forrajes conservados en el sudeste bonaerense. *1 Jornadas De Actualización Para Veterinarios Egresados Del Sistema De Residencia Interna En Salud Animal. INTA, Balcarce, Argentina.*
- Wade M.; Carvalho P. C. F. 2000: Defoliation patterns and herbage intake on pastures. *In: Hodgson, J.; Lemaire, G.; Moraes, A.; Carvalho, P.C.F.; Nabinger, C. Eds. Grassland Ecophysiology and Grazing Ecology.* CAB International. 233-248.
- Wales W. J.; Doyle P. T.; Stockdale R. C.; Dellow D. W. 1999: Effects of variation in herbage mass, allowance, and level of supplement on nutrient intake and milk production of dairy cows in spring and summer. *Australian Journal of Experimental Agriculture* 39:119-130.
- Walker J. W.; Stuth J. W.; Heitschmidt R. K. 1989: A simulation approach for

evaluating field data from grazing trials. *Agricultural Systems* 30:301-316.

Woodward S. J. R. 1997: Formulae for predicting animals' daily intake of pasture and grazing time from bite weight and composition. *Livestock Production Science* 52:1-10.

Woodward S. J. R. 2001: Validating a model that predicts daily growth and feed quality of New Zealand dairy pastures. *Environment International* 27:133-137.

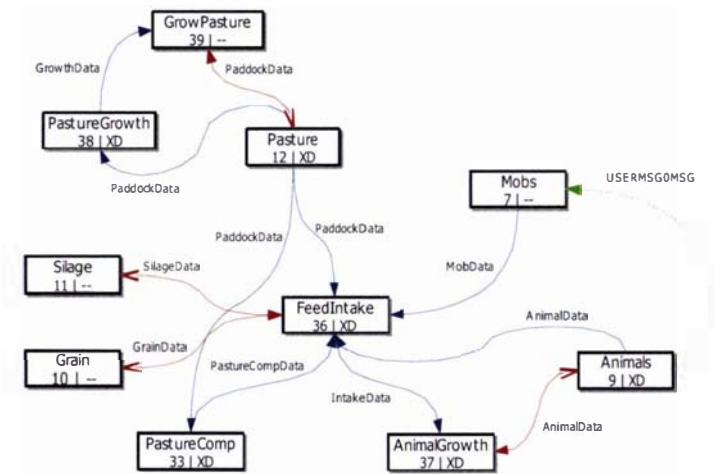
Woodward S. J. R.; Wake G.; Pleasant A. B.; McCall D. 1993: A simple model for optimizing rotational grazing. *Agricultural Systems* 41:123-155.

Woodward S. J. R.; Webby R. W.; Johnstone L. J. C. 2000: A decision tool for calculating herbage mass and metabolizable energy requirements of growing cattle and sheep. *Proceedings of the New Zealand Grassland Association* 62:13-18.

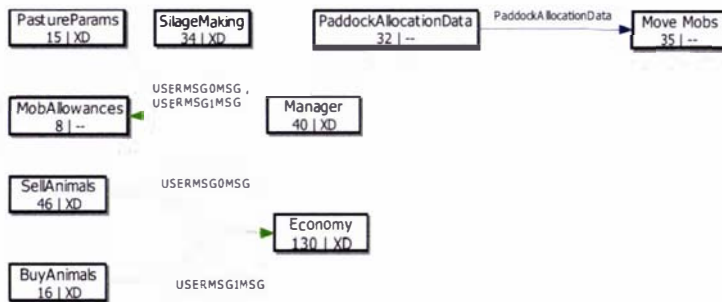
Wright A.; Dent J. B. 1969: The application of simulating techniques to the study of grazing systems. *Australian Journal of Agricultural Economics* 13:144-153.

Appendix 6.A. Main structure of the model and simulation order.

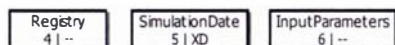
Biological blocks



Decision & Management blocks



Support blocks



References

- Block**
N: name; *n*: simulation order; *XD*: XD if block has an extended dialog, -- if not
- Data use link**
 Block *User* requires data *D* from block *Data Source*
- Data modification link**
 Block *User* modifies data *D* from block *Data Source*
- Data use and modification link**
 Block *User* requires data *D* from block *Data Source* and modifies part of it
- Message link**
 Block *Sender* sends message *Msg* to block *Receiver*

Appendix 6.B. Derivation of Eqns. 4 and 7

Assumptions:

- a) $GGR(L) = HAR_{Input} f_{adj} (1 - e^{\beta_1 L})$ (Gross growth rate)
- b) $HAR_{Actual}(L) = HAR_{Input} f_{adj} (1 - e^{\beta_1 L}) - \beta_3 L$ (Herbage accumulation rate)
- c) $S(L) = \beta_3 L$ (Senescence rate)

- 1) $GGR(L_{Ceil}) = S(L_{Ceil})$ or $HAR_{Actual}(L_{Ceil}) = 0$
- 2) $\max_L \{HAR_{Actual}(L)\} = HAR_{Input}$

Working:

from 1)

$$HAR_{Actual}(L_{Ceil}) = HAR_{Input} f_{adj} (1 - e^{\beta_1 L_{Ceil}}) - \beta_3 L_{Ceil} = 0$$

$$3) \Rightarrow \beta_3 = \frac{HAR_{Input} f_{adj} (1 - e^{\beta_1 L_{Ceil}})}{L_{Ceil}}$$

from 2)

$$\max_L \{HAR_{Actual}(L)\} \text{ occurs when } \frac{\partial HAR_{Actual}(L)}{\partial L} = 0$$

Differentiating from b)

$$\Rightarrow \frac{\partial HAR_{Actual}(L)}{\partial L} = -HAR_{Input} f_{adj} \beta_1 e^{\beta_1 L} - \beta_3 = 0$$

Substituting with 3) and solving for L, therefore $\max_L \{HAR_{Actual}(L)\}$ occurs when

$$4) \quad L = \frac{\ln\left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}}\right)}{\beta_1}$$

From 2) and substituting L from 4)

$$\max_L \{HAR_{Actual}(L)\} = HAR_{Input} \quad 2) \text{ above}$$

$$\Rightarrow HAR_{Actual} \left(\frac{\ln \left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}} \right)}{\beta_1} \right) = HAR_{Input}$$

from using b) to expand the left hand side to give the equation and replacing L from 4)

$$HAR_{Input} f_{adj} \left(1 - e^{-\beta_1 \frac{\ln \left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}} \right)}{\beta_1}} \right) - \beta_3 \frac{\ln \left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}} \right)}{\beta_1} = HAR_{Input}$$

Substituting β_3 with 3)

$$HAR_{Input} f_{adj} \left(1 - e^{-\beta_1 \frac{\ln \left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}} \right)}{\beta_1}} \right) - \frac{HAR_{Input} f_{adj} \left(1 - e^{-\beta_1 L_{Ceil}} \right) \ln \left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}} \right)}{L_{Ceil} \beta_1} = HAR_{Input}$$

An rearranging the equation and solved for f_{adj} gives

$$f_{adj} = \frac{\beta_1 L_{Ceil}}{\beta_1 L_{Ceil} + \left(1 - \ln \left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}} \right) \right) (1 - e^{-\beta_1 L_{Ceil}})}$$

When all is put together it ends up with:

$$GGR(L) = \frac{HAR_{Input} \beta_1 L_{Ceil} (1 - e^{-\beta_1 L})}{\beta_1 L_{Ceil} + \left(1 - \ln \left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}} \right) \right) (1 - e^{-\beta_1 L_{Ceil}})}$$

$$S(L) = \frac{HAR_{Input} \beta_1 L (1 - e^{-\beta_1 L_{Ceil}})}{\beta_1 L_{Ceil} + \left(1 - \ln \left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}} \right) \right) (1 - e^{-\beta_1 L_{Ceil}})}$$

$$HAR_{Actual}(L) = \frac{HAR_{Input} \beta_1 L_{Ceil} (1 - e^{-\beta_1 L}) - HAR_{Input} \beta_1 L (1 - e^{-\beta_1 L_{Ceil}})}{\beta_1 L_{Ceil} + \left(1 - \ln\left(\frac{-1 + e^{\beta_1 L_{Ceil}}}{\beta_1 L_{Ceil}}\right)\right)} (1 - e^{-\beta_1 L_{Ceil}})$$

Modelling studies of grain feeding in a grazing-based beef cattle finishing operation:

2. Model evaluation and system simulations

Abstract

The objective of this study was to evaluate the model developed in Chapter 6 in terms of its capability for predicting experimental data of herbage intake and animal performance, and to use the model to compare the impacts of the strategic use of maize grain in beef cattle finishing systems. The model predicted the experimental measurements of liveweight gain and herbage intake with accuracy ($P < 0.05$) and without bias. A “baseline system” with a stocking rate of 2.5 steers ha^{-1} was built from experimental data, and the model was used to evaluate additional stocking rates of 3.5, 4.5 and 5.5 hd ha^{-1} . These stocking rates were simulated without maize feeding and with a strategic maize feeding strategy in which maize grain was added when the modelled monthly LW fell below pre-defined LW targets. Liveweight production per ha on the grazing only treatments increased markedly to when stocking rates increased from 2.5 to 3.5 hd ha^{-1} (from 487 to 644 $\text{kg LW ha}^{-1} \text{yr}^{-1}$, respectively), with no improvement thereafter. Gross margins in the grazed only treatment decreased linearly as stocking rate increased, reflecting increasing numbers of unfinished animals. In the case of supplemented treatments, there was a linear increase in production per ha as stocking rate increased (from 487 to 1070 $\text{kg LW ha}^{-1} \text{yr}^{-1}$, respectively). Gross margin reached the highest value at 4.5 hd ha^{-1} . Other sward parameters are also presented. It is concluded that the model showed accuracy for predicting animal performance and herbage intake under a range of experimental circumstances, and provides an adequate tool for investigation of alternative grazing-based beef cattle finishing systems.

Keywords: system modelling; beef cattle production; intake; liveweight gain.

1. Introduction

In Chapter 6 a dynamic model representing the main biology and some economic indicators of a grazing-based beef cattle finishing unit was described. Model evaluation is a critical step to quantify the degree to which the objectives of model development are addressed (Carlson et al. 1993). However, this procedure is not straightforward, as the lack of or incomplete availability of independent field information for an adequate evaluation of agricultural simulation models is a

common problem (Herrero et al. 1998; Cohen et al. 2003).

In particular, information on the plant-animal interface is an important component in the understanding of the behaviour of grazing systems, but information on this topic is often the major constraint to model development (Dove 1996). For effective validation, a model was developed independently of the data collected from field experiments against which it was tested.

The objectives of this chapter were to: a) evaluate the model developed in Chapter 6 in terms of its capability for predicting herbage intake and animal performance from field experiments; and b) explore different system comparisons of the strategic use of maize grain in beef cattle finishing systems.

2. Model evaluation

The predictive capacity of the beef cattle finishing unit simulator (Chapter 6) was assessed against information from Chapters 3 and 4 i.e. LWG and herbage intake over a range of treatments and sward conditions, using the method suggested by Mayer & Butler (1993). In Table 1 the main initial parameters used in the simulations are detailed. Similar to the field experiments, the model was set up to graze in a single grazing cycle. To represent herbage quality associated with the herbage components, average values from Chapter 5, Table 3, were used to represent ME_L , ME_{St} , ME_D (11.7, 10.9, 7.0) and CP_L , CP_{St} , CP_D (25.0, 14.1 and 8.3) the annual average of metabolisable energy (MJ ME kg DM⁻¹) and crude protein (% DM) of the leaf, sheath & stem and dead components of the sward, respectively. Explanation of how herbage quality is handled is presented in Chapter 6, section 2.2.1.5.

Table 2 shows the fitted regressions using the two steps (i.e. with and without an intercept) suggested by Mayer and Butler (1993) for assessment of model prediction. A significant ($P < 0.05$) agreement was obtained between modelled values for LWG (Figure 1) and herbage intake (Figure 2) with values recorded under experimental conditions. In both cases the linear regressions fitted significantly, the R^2 value obtained for LWG being slightly higher than that

observed for herbage intake (Table 2), and for both variables, intercepts were not significantly ($P>0.05$) different from zero (Table 2). Similarly, both variables adjusted significantly to linear regressions without intercept ($P<0.01$) and the slopes were not different from 1.0. There were no indications that the relationships shown in Figure 1 and 2 were affected by supplementation or herbage allowance level. From this initial evaluation, it can be concluded that the model predicted the experimental information with acceptable accuracy and without bias.

Table 1. Initial parameters from Chapter 3 and 4 considered for the simulations.

	Chapter 3	Chapter 4
Animal class	heifers	steers
Initial liveweight (kg)	223	258
Duration (d)	49	57
▣ Treatments	4	6
Pre-grazing leaf mass (kg DM ha ⁻¹)	2452	682
Pre-grazing sheath & stem mass (kg DM ha ⁻¹)	1866	1011
Pre-grazing dead mass (kg DM ha ⁻¹)	1013	658
HAR _{input} (kg DM ha ⁻¹ d ⁻¹)	16	41

▣ = See details in Chapter 3-4 and HAR_{input} = herbage accumulation rate estimated from accumulated mass in first grazed strips in each treatments.

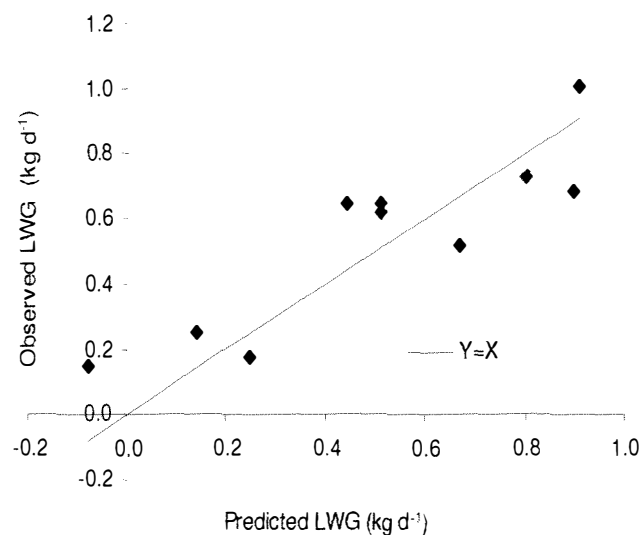
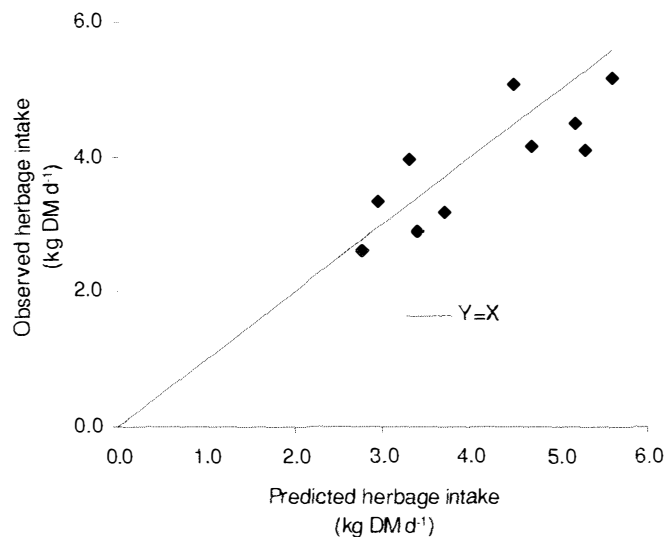


Figure 1. Regression of observed liveweight gain on predicted liveweight gain from the model (Chapter 6) of beef bred animals grazing at different herbage allowances and maize supplementation levels (Chapter 3 and 4).

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.

		LWG (kg d ⁻¹)	Sig.	Herbage intake (kg DM d ⁻¹)	Sig.
Y=a+bX	a	0.17±0.08	NS	1.01±0.63	NS
	b	0.73±0.13	**	0.69±0.17	**
	RMSE	0.13		0.54	
	R ²	0.78		0.66	
Y=bX	b	0.98±0.08	***	0.93±0.04	**
	R ²	0.93		0.98	
	P(b ≠ 1)		NS		NS

LWG= liveweight gain, Sig.= significance level, NS= non significant differences (P>0.05), **=P<0.01 and ***=P<0.001.

**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).

3. Model application

The development of the model in Chapter 6 was oriented towards intensive beef cattle grazing systems, particularly 12-month systems that finish steers before new weaners enter the farm in the autumn. In Chapter 1 it was emphasised that in such systems, adequate animal performance during the summer is important so as to avoid feed requirements of finishing animals overlapping with those of weaners entering in the autumn. Grain supplementation during summer may be used when there is risk of not being able to finish the animals within the productive cycle. Preliminary research suggests that a level of grain feeding above 1.4 % LW d⁻¹ (approximately half of the total DM intake) is needed to achieve the target date for finishing (Machado et al. 2001). However, it is well recognised that heavier cattle

are less efficient in terms of feed conversion efficiency (SCA 1990; NRC 2000), and that heavier animals in summer require a higher absolute investment than lighter animals (i.e. $1.4 \% \text{ LW d}^{-1}$ for an animal of 320 kg LW represents 4.5 kg DM grain d^{-1}). One option could be to feed grain (if necessary), earlier in the productive cycle as a more “proactive” alternative to preventing liveweight falling below targets, and together with the adjustment of stocking rate, this may allow a more efficient use of grain supplements (Hodgson & Tayler 1972; Rearte & Pieroni 2001). Therefore, “BeefSim” was used to investigate the effects of increasing stocking rate (including herbage allowance management) and maize grain supplementation associated with farm monitoring, on sward, animal and system variables.

3.1. Development of a “baseline” farm

Prior to establishing system comparisons, it is necessary to define a “baseline” system. This may be defined arbitrarily, but it was preferred to use available information from farmlets developed at INTA Balcarce Experimental Station – Argentina, in order to reduce the number of assumptions. Therefore, the model was set up to resemble some of the characteristics of the control (unsupplemented) farmlet described in Garcia et al. (1998).

Additionally, three variables were necessary to set up the model; monthly herbage accumulation rates ($\text{HAR}_{\text{Input}}$), monthly target pasture covers and pre-defined herbage allowances.

3.1.1. Herbage accumulation rates

Information on $\text{HAR}_{\text{Input}}$ for beef cattle finishing grass/legumes pastures in Argentina is scarce. Information is not available from the most relevant farmlet trials (Mezzadra et al. 1992; Romera et al. 1998; Garcia et al. 1998; Mezzadra et al. 2003), or the information is condensed into average figures between seasons (autumn-winter and spring-summer) as presented by Kloster et al. (2000). To establish the simulation to represent the observations of Garcia et al. (1998), information on HAR was used from an alfalfa-grass pasture in the southeast of

Buenos Aires province reported by Machado et al. (2003)⁷, plus 4 years of data for a pasture of similar characteristics using similar measurement procedures (Corrall & Fenlon 1978) recorded at the CHEI-Barrow- Experimental Station - Argentina. These values were condensed within months in Table 3.

Table 3. Mean and standard deviations of monthly herbage accumulation rate (kg DM ha⁻¹ d⁻¹) for an alfalfa-grass pasture in the southeast of Buenos Aires province (Tres arroyos, n=6), and pasture cover target assumed in the simulations.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Mean HAR	33.5	31.5	32.7	30.3	20.6	13.5	11.7	14.2	23.7	47.6	57.1	43.3
SD	12.3	8.8	9.3	9.8	5.7	4.5	9.1	14.3	13.8	19.1	22.3	17.0
Target PC	2400	2400	2000	2000	2000	1800	1800	2000	2300	2300	2300	2300

HAR= herbage accumulation rate, SD= standard deviation of the mean, PC= pasture cover.

3.1.2. Target pasture cover and its monitoring

Seasonal sward targets of pasture cover are well defined in New Zealand (Matthews et al. 1999). However, in Argentina no such targets were available. For the purpose of the model comparison, values presented in Table 3 were assumed as reference values in the simulations, based on information from New Zealand (Coutinho et al. 1998).

The (positive or negative) deviation from these targets ($PCover_{Dev}$, Chapter 6, Eqn. 48) are estimated weekly, representing what is a "farm walk" in a real system. When the herbage adjustment is "on" in the "manager" block, it can adjust the pre-defined herbage allowances downward or upwards in response to variation in pasture cover. The procedure is controlled by a set of rules available in tables in the "manager" block linked to $PCover_{Dev}$ (presented graphically in Figure 3). The formula that describes this part of the management control is given by:

$$HA_{Applied} = HA_{Input} \left(1 + Adj_{HA} \frac{PCover_{Dev}}{100} \right) \quad \text{Eqn. 60}$$

Where $HA_{Applied}$ is the DM herbage allowance (% LW d⁻¹) actually applied and estimated weekly when the herbage adjustment is "on" in the "manager" block, HA_{Input} is the pre-defined monthly DM herbage allowance (% LW d⁻¹) at the start of

⁷ Corresponding measurements made for the experimental site and time interval presented in Chapter 5.

the simulation, ADJ_{HA} is the factor adjustment (Figure 3) and $PCover_{Dev}$ is the positive or negative deviation from the target pasture covers (kg ha^{-1}).

The adjustment of herbage allowance is intended to manipulate herbage intake in response to herbage deficit and surplus, running the model in “automatic” mode and with herbage adjustment set to “on” (Chapter 6, section 3.). If the “full interactive” mode is chosen instead, desired adjustments at different times in the simulation are made directly by the user.

For example, if during the first week of September, a pasture cover of 2600 kg ha^{-1} is present, this means that $PCover_{Dev} = +300 \text{ kg ha}^{-1}$ (2300 kg ha^{-1} of target pasture cover in Table 3, subtracted from actual pasture cover). The ADJ_{HA} corresponding to this $PCover_{Dev}$ and month of the year is $+0.05$ (Figure 3). In this example, an HA_{Input} 6 \% LW d^{-1} (0.06 in model notation) was allocated to the animals. Substituting this information in Eqn. 1 leads to an $HA_{Applied} = 0.07$ (7 \% LW d^{-1}) as the final result. If the $PCover_{Dev} = +300 \text{ kg ha}^{-1}$ was in April at the same HA_{Input} as in the September example, ADJ_{HA} in this month would be 0.12 , and $HA_{Applied}$ would be in this month 0.082 (8.2 \% LW d^{-1}). $HA_{Applied}$ is arbitrarily constrained to 12 \% LW d^{-1} as done by McCall (1984), a level where maximum intake is reached (Hodgson 1984).

ADJ_{HA} (Figure 3) is divided into two periods, one with a tighter control of herbage allowance adjustment in the reproductive season (assumed here from September to February inclusive), where there is the risk of losing sward conditions at high herbage allowances (Chapter 1, section 4). If the sward is managed more tightly, this allows the excess to be harvested when the pasture cover threshold for conservation is achieved. Positive adjustments after $+600 \text{ kg DM}$ to $+1500 \text{ kg DM}$ are the same as shown for $+600 \text{ kg DM}$ (Figure 3). If $PCover_{Dev}$ is below -400 kg DM or above 1500 kg DM , the simulation is aborted as the outcome was considered not to be feasible, because of excessive or too low stocking rate for the system.

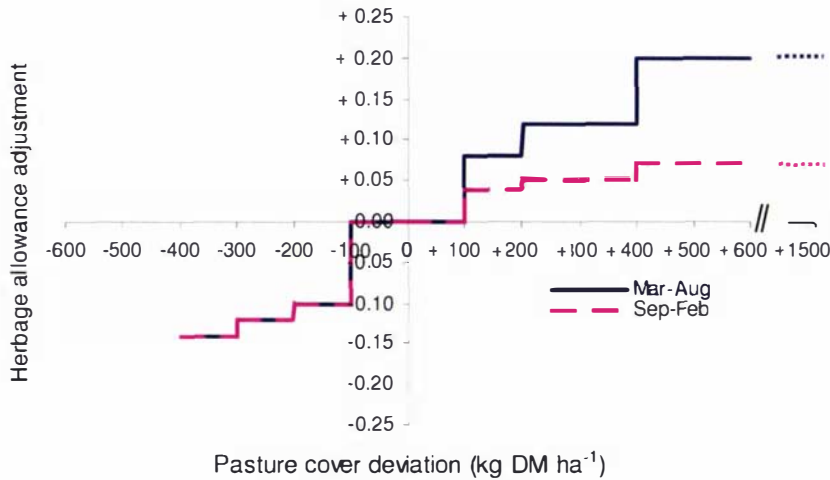


Figure 3. Herbage allowance adjustment as a function of indicated pasture cover deviation from target.

The basic assumption and results for the “baseline” simulation are presented in Table 4. At the start, the paddocks (12 as default number) were organised in a sequence of re-growth states with an averaged pasture cover of 2000 kg DM ha⁻¹ (pasture cover for March, Table 3). The model was allowed to sell the animals individually, when animals reached 370 kg LW achieved (specified by Garcia et. al. (1998)), and in practice animal sales were spread from 1 January to 26 February. To adjust the system and define the value for ADJ_{HA} , different combinations of HA_{input} and ADJ_{HA} were tested against the projected outcome for the baseline system. Finally, an HA_{input} of 3 % LW d⁻¹ (0.03 in model notation) during autumn-winter and 4 % LW d⁻¹ (0.04 in model notation) during Spring-Summer, were used. It must be noted that the “manager” was adjusting the herbage allowance weekly, to yield an overall mean of $HA_{Applied}$ of 5.2±2 % LW d⁻¹ (0.052 in model notation).

The projected pattern of animal liveweight (Figure 4) shows the expected seasonal pattern, associated with a set of conditions defined by the user (i.e. pre-defined herbage allowance, target pasture covers, values for ADJ_{HA} , changes in herbage quality).

The highest LWG was in Spring (0.86 kg ha⁻¹ d⁻¹) in agreement with the 0.84 kg ha⁻¹ d⁻¹ (average of two seasons) estimated from equations presented by Mezzadra et

al. (1992) for similar stocking rates and cattle types. The combination of the ADJ_{HA} being more restrictive in spring-summer together with the method used for herbage conservation, meant that although there was a clear herbage surplus which yielded $2700 \text{ kg DM ha}^{-1} \text{ yr}^{-1}$ of harvested herbage for conservation (Table 4), the animals were not fed the highest possible allowances.

Table 4. Results of setting the model as the referenced beef cattle finishing farmlet for development of a “baseline” system.

	(Garcia et al. 1998) Pasture only	Model
Animal class		steers
Stocking rate (hd ha^{-1})		2.5
Farmlet Area (ha)		10
Initial liveweight (kg)		175
Final liveweight (kg)		370
Duration (d)	361	353
Mean liveweight gain (kg d^{-1})	0.54	0.55
▣LW Production ($\text{kg LW ha}^{-1} \text{ yr}^{-1}$)	492	487
▣Stock efficiency (%)	72	68
#Herbage harvested for conservation ($\text{kg ha}^{-1} \text{ yr}^{-1}$)	N/A	2700
Herbage DM allowance ($\% \text{ LW d}^{-1}$)	N/A	5.2 ± 2

▣ = see text for definition, # = this value represents the total DM harvested, but not conserved reserves, where different losses are applied and N/A = not available.

Liveweight production and stocking efficiency are two production indicators used widely in Argentinean beef cattle systems. The former is given by:

$$\text{LW production} = (\text{Animal sales} - \text{animal purchases} \pm \text{inventory difference}) / \text{production area}$$

And

$$\text{Inventory difference} = \text{Farm final LW (kg)} - \text{farm start LW (kg)}^8$$

Where LW production is the total LW production ($\text{total LW ha}^{-1} \text{ yr}^{-1}$), animal sales and animal purchases are the sales and the purchases during the year (in total LW yr^{-1}), production area represents the grazing area (ha) effectively dedicated to beef cattle production (i.e. it could be used temporarily by other stock). Inventory difference (kg) is the difference between total LW on the farm at the end (kg) less the starting total farm LW (kg) and stock efficiency is given by:

⁸ In the simulated alternatives, stock inventory difference is zero

$$\text{Stock efficiency} = (\text{LW production} / \text{average animal LW on the farm})100$$

That is, stock efficiency (%) is of yearly LW production (total LW ha⁻¹ yr⁻¹) divided by the average yearly animal LW on the farm expressed in kg LW.

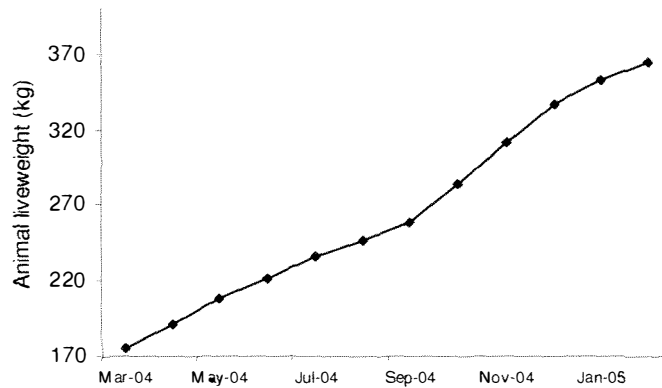


Figure 4. Monthly target animal liveweights in the “baseline” system. Liveweights at the start of the corresponding month.

The model fitted very well to field data, but this was not considered a model validation, as different parameters were adjusted iteratively to obtain these results. However, it was shown that the model had enough flexibility to represent acceptably the field information, which encourages the use of the “baseline” system for further comparisons to be made in the next section.

3.2. Simulation of intensive beef cattle finishing systems

With the herbage adjustment in “on” status in the “manager” block, the following stocking rates were simulated: 2.5 (“baseline” system), 3.5, 4.5 and 5.5 hd ha⁻¹. These stocking rates were simulated without maize feeding, and with strategic maize feeding (i.e. maize was fed when the defined monthly LW fell below the targets specified in Figure 4).

3.2.1. Basic management rules

- Maize supplementation starts if LW_{Dev} (negative) is greater than the minimum deviation defined in the management table (Chapter 6, Figure 12) and the current simulation time is within the supplementation period. In this

exercise, supplementation was allowed on any day of the year to increase the flexibility of the system (i.e. starting and ending days are 0 and 364, respectively). Once the conditions for maize supplementation were met, it was maintained for a minimum of 30 days, until the next animal weighing, where the decision to continue feeding was re-assessed.

- Herbage was conserved (Chapter 6, section 2.2.3.3.) if pasture cover was higher than 3000 kg DM ha⁻¹, there was a currently ungrazed paddock with herbage mass higher than 3800 kg DM ha⁻¹ and the simulation time was within the interval where harvesting was allowed (15 December to 15 February).
- Animals were individually simulated, and HAR_{Input} was set up as deterministic value.

3.2.2. Main results

At a stocking rate of 2.5 hd ha⁻¹ animal performance in both the grazed only and strategic maize grain treatments was exactly the same. This simply shows that there was no need to add supplement at this stocking rate, because there was no deviation of the LW_{Dev} from targets.

Increasing the stocking rate from 2.5 to 5.5 weaners ha⁻¹ decreased the herbage allowance allocated to the animals, pre- and post-grazing herbage mass, and the pasture cover on the farm. The herbage allowances shown in Table 5 represent averages of the weekly adjustments made by the “manager”, based on the information presented in Table 3 and Figure 3, and the pasture cover estimated at each weekly farm walk.

The duration of the process was 353 d in the “baseline” system (Table 4), and between 343 and 362 days in the supplemented animals. In the case of unsupplemented animals grazed at stocking rates of 3.5, 4.5 and 5.5 hd ha⁻¹, the proportion of unfinished animals at the end of the cycle increased substantially (Table 5) to 1.0 at 5.5 hd ha⁻¹.

Table 5. Effect of stocking rate and use of strategic feeding of maize grain in a simulated farmlet (10 ha) with steers starting on the 1 March at 175 kg LW.

Stocking rates (hd ha ⁻¹)	Grazed only				Strategic feeding of maize grain			
	2.5	3.5	4.5	5.5	2.5	3.5	4.5	5.5
Sward parameters								
• Herbage allowance (% LW d ⁻¹)	5.0	4.8	4.7	3.5	5.0	5.0	4.6	3.2
• Pre-grazing herbage mass (kg ha ⁻¹)	3750	3460	3160	2920	3750	3480	3067	2910
*Post-grazing herbage mass (kg ha ⁻¹)	2160	1790	1590	1395	2160	1900	1670	1563
*Pasture cover (kg ha ⁻¹)	2490	2220	2140	2010	2490	2322	2150	2080
ΣHAR _{Actual} (kg ha ⁻¹ yr ⁻¹)	8500	8700	9000	9100	8500	8600	8900	9000
ΣHAR _{Actual} / ΣHAR _{Input}	0.77	0.79	0.82	0.83	0.77	0.78	0.81	0.81
Total herbage eaten (kg ha ⁻¹ yr ⁻¹)	5800	7400	8500	8500	5800	6400	7700	8000
Total grain eaten (kg ha ⁻¹ yr ⁻¹)	--	--	--	--	--	800	1600	2800
Animal performance								
Average LWG (kg d ⁻¹)	0.55	0.50	0.41	0.35	0.54	0.57	0.55	0.55
MJ ME-LWG / MJ ME-maintenance	0.52	0.49	0.41	0.36	0.52	0.54	0.51	0.52
System performance								
#Herbage conservation (kg ha ⁻¹ yr ⁻¹)	2700	1300	500	600	2700	2200	1200	1000
▫LW Production (kg LW ha ⁻¹ yr ⁻¹)	487	644	673	711	487	766	875	1070
▫Stock efficiency (%)	68	66	59	54	68	71	70	71
Unfinished animals at 28 February (Proportion of the mob)	0.00	0.71	0.88	1.00	0.00	0.00	0.00	0.00

*= Means of daily observations, ΣHAR_{Actual} = is the yearly accumulated HAR_{Actual},
 ΣHAR_{Input}= is the yearly accumulated HAR_{Input}
 MJ ME-LWG = energy used for LWG, / MJ ME-maintenance= energy used for maintenance,
 #= this value represent the total DM harvested, but not present herbage reserves, where different losses are applied (Chapter 6, section 2.2.3.3.) and ▫ = see text for definition.

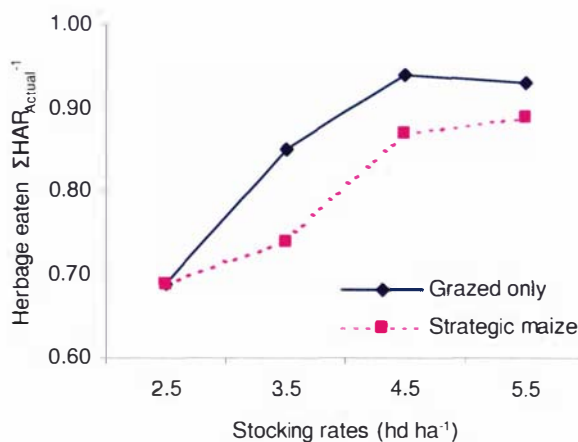


Figure 5. Effect of stocking rate and use of strategic feeding of maize grain on the ratio between herbage eaten (kg ha⁻¹ yr⁻¹) and Σherbage accumulation (kg ha⁻¹ yr⁻¹) as an indicator of grazing efficiency in the simulated alternatives.

Increasing the stocking rate increased substantially the total herbage eaten on the farm (Table 5). HAR_{Actual} also increased slightly with increased stocking rate, but there was a much more substantial increase in the proportion of HAR_{Actual} that was eaten (Figure 3). Maize grain feeding decreased total herbage eaten (Table 5), which led to a lower proportion of the herbage produced being grazed (total herbage eaten / ΣHAR_{Actual}) than in grazing only alternatives (Figure 5). Herbage conservation was lower in grazed only treatments, and declined with stocking rate. For each additional animal per ha, herbage eaten increased by 920 and 790 kg ha⁻¹ yr⁻¹, for grazing only and maize grain supplemented treatments, respectively.

Increasing the stocking rate in the grazed only treatments decreased LWG substantially, and increased the proportion of the total ME that was used for maintenance by the animals. This level of LWG agreed with the results of Mezzadra et al. (1992) but was slightly higher than that observed by Romera et al. (1998), both experiments using Angus steers of small-sized biotype (Figure 6). Romera et al. (1998) suggested that their relative lowest animal performance was likely to be caused by accumulated effects of continuous use of the pasture at the allocated stocking rate on pasture composition.

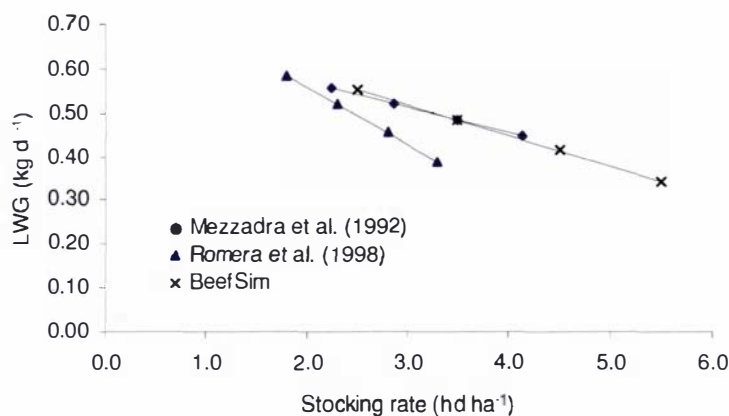


Figure 6. Effect of the stocking rate (X) on total liveweight gain (Y) of Angus steers obtained from the model and from the literature. For the fitted linear functions: Mezzadra et al. (1992), $Y=0.69-0.06X$, $R^2=0.41$. Romera et al. (1998) $Y=0.82-0.13X$, $R^2=0.41$, and predicted with the model $Y=0.73-0.07X$, $R^2=0.98$.

Supplementation maintained LWG at a level similar to the “baseline” system (no supplement, 2.5 hd ha⁻¹). This is explained by the fact that the objective of the rules

for maize grain feeding was to maintain target LW, not exceed the targets. One important advantage of the use of grain in this way is that the speed of the production cycle does not increase, so there were animals available to use the herbage produced during summer. Reducing the stocking rate too far during summer, or excessive use of grain supplement (i.e. finishing animals early), could lead to the need for a substantial increase in herbage conservation to control pastures. Additionally, as LW_{Dev} was monitored from the beginning of the cycle, most of the grain was fed early in the cycle (in winter). Supplementation level and duration depended on the degree of monthly LW_{Dev} observed in each treatment (results not shown). Unsupplemented LWG was low (this is the reason why LW targets were not achieved), and in this situation, the highest response to grain is expected (Chapter 1, Figure 1) and protein makes a higher contribution to the LWG of younger animals with more accretion of water than fat tissue (SCA 1990; NRC 2000).

3.2.3. Gross Margin and LW production

Gross Margins for the simulated farm were estimated as described in Chapter 6, section 2.4, using assigned values for the economic parameters presented in Table 6. Animals are sold when the target LW is reached, but it is assumed that all animals are sold at the end of the production cycle, either finished or unfinished (at a lower price, as indicated in Table 6).

Table 6. Assigned values for the economic parameters of the model.

Description	Unit	Value
Price of animals at purchase	\$US kg LW ⁻¹	0.76
Price of animals at sale	\$US kg LW ⁻¹	0.72
Animal purchase costs	Proportion of animal value	0.08
Value of the unfinished animal	Proportion of the value of a finished animal	0.8
Animal sale costs	Proportion of animal value	0.10
Labour costs	\$US ha ⁻¹ yr ⁻¹	64
Animal health costs	\$US hd ⁻¹ yr ⁻¹	3.2
Herbage conservation	\$US ha ⁻¹	7.1
Silage costs	\$US ton ⁻¹	7.1
Costs of pasture renovation (25 % annually)	\$US ha ⁻¹	33
Maize grain cost	\$US ton ⁻¹	88
Costs of maize cracking and cost of distributing the maize grain	\$US ton ⁻¹	6

Liveweight production on the grazed only treatments increased markedly when stocking rates increased from 2.5 to 3.5 hd ha⁻¹, with no improvement thereafter (Figure 7). Gross margin in grazed only treatments decreased linearly as stocking rate increased (most of the animals were sold in an unfinished state). As was mentioned in Chapter 6, section 2.4., the use of production per ha could be misleading when off-farm inputs such as grains are incorporated into the system. In the case of supplemented treatments (Figure 7), there was a linear increase in LW production as the stocking rate increased, but gross margin reached the highest value at 4.5 hd ha⁻¹.

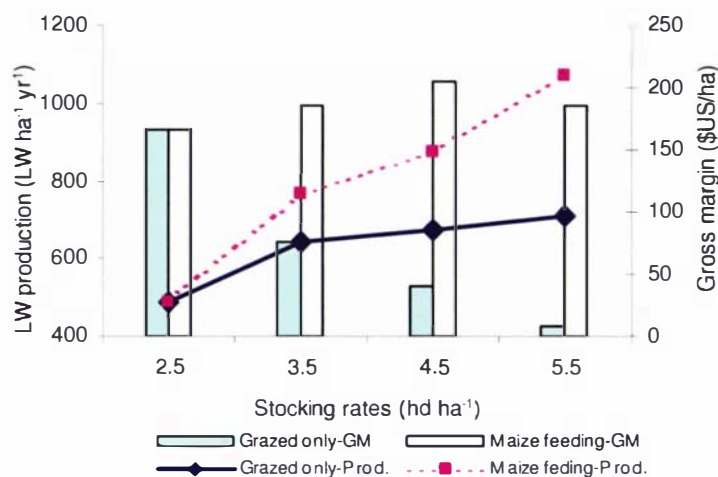


Figure 7. Effect of stocking rate and use of strategic feeding of maize grain on gross margin (GM) and LW production (Prod.) in the simulated alternatives.

Gross margin was included here to establish comparisons between groups, and to constrain the situation where a large amount of grain is used. The values presented are not adequate for benchmarking with other systems, for reasons associated with the design of the farmlet used to set up the baseline system (Garcia et al. 1998): No crops were included (i.e. oat) in the system comparison, a common source of feeds that represents roughly between 19 % and 33 % of the net income (NI, Chapter 6 Eqn. 53) (AACREA 2004); herbage is conserved but in this exercise is not fed back; and in the simulation, no value is assigned to the conserved herbage and for closing the production-economic cycle, animals unfinished are sold at a lower price.

2.2. Variation of herbage accumulation rates

The previous exercise was done with average values for HAR_{Input} (Table 3). A final exercise was run to test the chances that the “manager” block in a “baseline” system can cope with variation of HAR_{Input} and effectively still achieve the target LW for a pre-defined day of the cycle (day 270). This is important for the system performance and, in this simulation 1 December was used as the cut off date. One hundred yearly HAR_{Input} profiles were generated by random sampling, using the standard deviation of the HAR_{Input} (Table 3), for each of the twelve months in sequence. Each of the profiles was used to run a productive cycle with the herbage adjustment turned “on” in the “manager” block and with no grain feeding allowed,

and estimating the probability of exceeding the target LW (1 December) used in the definition of the “baseline” system (Figure 4). It was observed that in this example, the manager had a 0.62 chance of exceeding the 345 kg LW target at the 1 December, without feeding grain (Figure 8). This exercise was developed only to show the kind of factors to be taken into account when the degree of physical “riskiness” of alternatives is evaluated. Stochastic components can be added relatively easily to the model (stochastic HAR_{Input} , grain and animal prices, random level of individual grain intake from the average grain allowance to the mob, etc). In this case systems comparison was done with a deterministic HAR_{Input} , a limitation imposed by the fact that the basic data set to define the “baseline” system (Table 3) covered only 6 years at the CHEI-Barrow experimental station. Examples in the literature show how different the modelled response of a grazing system may be when stochastic functions are added from reliable sources of information (Cacho & Bywater 1994; Cacho et al. 1999). Although understandably more limited, a deterministic option was preferred for the system comparison, as a low benefit was expected in terms of insights of model behaviour, when reliable data were not available.

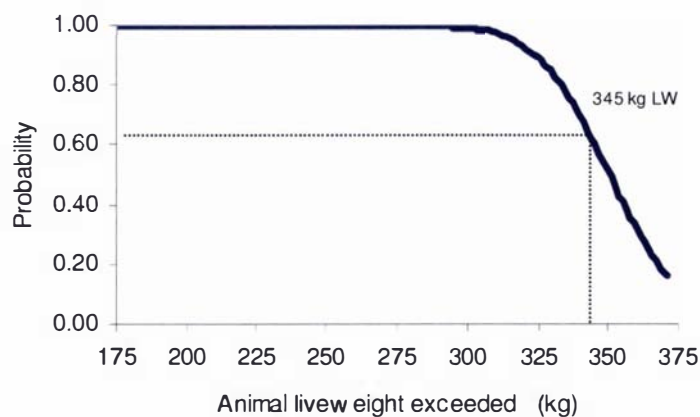


Figure 8. Accumulated probability that animals exceed a given liveweight on 1 December. Constructed from the simulation of 100 production cycles using stochastic herbage accumulation years (Table 3). 345 kg LW represents the target LW for the “baseline” system.

3. Implications and conclusions

At the present state of development, the model can reproduce accurately the initial set of information about liveweight gain and herbage intake used for validation.

Additionally, it has been shown that BeefSim has adequate flexibility in terms of the target system where it is to be used. System comparisons developed to investigate the effect of stocking rate and strategic use of maize grain, show that unsupplemented options were in agreement with the literature. In the case when maize grain was fed, it was demonstrated that a simple monitoring procedure can help to use the grain more sensibly, and gain insight into the system. Although the inclusion of "random" functions to the model may be tempting, use of a deterministic simulation is preferred until reliable data is available. The model is research oriented, but condenses practical information with potential use for education and decision-making.

References

- AACREA. 2004: Margen Bruto Invernada 282:25.
- Cacho O. J.; Bywater A. C. 1994: Use of a grazing model to study management and risk. *Proceeding of the New Zealand Society of Animal Production* 54:377-381.
- Cacho O. J.; Bywater A. C.; Dillon J. L. 1999: Assessment of production risk in grazing models. *Agricultural Systems* 60:87-98.
- Carlson D. H.; Thurow T. L.; Jones C. A. 1993: Biophysical simulation models as a foundation of decision support systems. *In: J.W. Stuth and B.G. Lyons. Eds. Decision Support Systems for the Management of Grazed Ecosystems. UNESCO-MAB Book Series. Parthenon Press. New York.:38-68.*
- Cohen R. D. H.; Stevens J. P.; Moore A. D.; Donnelly J. R. 2003: Validating and using the GrassGro decision support tool for a mixed grass/alfalfa pasture in western Canada. *Canadian Journal of Animal Science* 82:171-182.
- Corrall A. J.; Fenlon J. S. 1978: A comparative method for describing the seasonal distribution of production from grasses. *Journal of Agricultural Science, Cambridge* 91 :61-67.
- Coutinho B. H.; Matthews P. N. P.; Morris S. T. 1998: The effect of grazing

- management on pasture and animal production in late autumn to early spring in a one year bull beef grazing system. *Proceedings of the New Zealand Society of Animal Production* 58:236-238.
- Dove H. 1996: Constraints to the modelling of diet selection and intake in the grazing ruminant. *Australian Journal of Agricultural Research* 47:257-275.
- Garcia S. C.; Santini F.; Castaño G. 1998: Producción de carne bajo pastoreo: Alternativas de intensificación. Material didáctico Nro 14. INTA, Cerbas.:52 p.
- Herrero M.; Dent J. B.; Fawcett R. H. 1998: The plant/animal interface in models of grazing systems. In: Peart, R.M. & Curry, R.B. Eds. *Agricultural System Modeling and Simulation*. New York. Marcel Dekker, Inc. 495-542.
- Hodgson J. 1984: Sward conditions, herbage allowance and animal production. *Proceedings of the New Zealand Society of Animal Production* 44: 99-104.
- Hodgson J.; Tayler J. C. 1972: The effect of supplementary barley upon growth and efficiency of food conversion in calves kept at high grazing intensity. *Journal of the British Grassland Society* 27:7-11.
- Kloster A. M.; Latimori N. J.; Amigone M. A. 2000: Evaluación de dos sistemas de pastoreo rotativo a dos niveles de asignación de forraje en una pastura de alfalfa y gramíneas. *Revista Argentina De Producción Animal* 20:187-198.
- Machado C. F.; Berger H.; Morris S. T.; Hodgson J.; Copes M.; y Duhalde J. 2003: Calibración estacional de mediciones de altura del canopeo con plato y con bastón de altura para estimar la biomasa de forrajera de una pastura base alfalfa. *Revista Argentina De Producción Animal* 23:73-74 (resumen).
- Machado C.; Striebeck G.; Vasolo V.; Di Croce F.; Gonzalez F.; Duhalde J.; Parente M.; Auza N. 2001: Suplementación de grano de maíz en pastoreo y a corral como alternativas de terminación de novillos en el verano. *Avances En Producción Animal* 26:139-146.
- Matthews P. N. P.; Harrington K. C.; Hampton J. G. 1999: Management of grazing

- systems. In: White, J.& Hodgson, J. Eds. *New Zealand pasture and crop science*. Oxford University press. 153-174.
- Mayer D. G.; Butler D. G. 1993: Statistical validation. *Ecological Modelling* 68:21-32.
- McCall D. G. 1984: A systems approach to research planning for North Island Hill Country. PhD Thesis. Massey University. 261 p.
- Mezzadra C.; Escuder J.; Miquel M. C. 1992: Effects of genotype and stocking density on post-weaning daily gain and meat production per ha in cattle. *Animal Production* 55:65-72.
- Mezzadra C. A.; Melucci L. M.; Villarreal E. L.; Faverdin C. 2003: Comparación del desempeño productivo de novillos puros y cruza británicos bajo sistemas de engorde semi-intensivos e intensivos. *Revista Argentina De Producción Animal* 23:45-52.
- NRC. 2000: Nutrient requirements of beef cattle. *National Research Council. National Academy Press. Washington, D.C.*
- Rearte D.; Pieroni G. A. 2001: Supplementation of temperate pastures. *Proceedings of the XV International Grassland Congress* :679-691.
- Romera A. J.; Mezzadra C. A.; Villarreal E. L.; Brizuela M. A.; Corva P. M. 1998: Productivity of grazing Angus steers of different structural size. *Animal Science* 67:455-460.
- SCA. 1990: Feeding Standards for Australian livestock. *Standing Committee on Agriculture, Ruminants Subcommittee. CSIRO Publications.* 266 p.

Overview

1. Introduction

The objectives of this thesis were specified as follows, with particular reference to their importance to grazing-based beef cattle finishing in the context of Argentina:

To provide information on herbage allowance-intake functions and the effects on animal performance when maize grain is supplemented, in beef cattle finishing systems.

To investigate the seasonal change of herbage quality in a beef cattle finishing pasture.

To develop a “finishing beef cattle unit” simulator driven by stocking rate and herbage allowance, as a tool for information synthesis and research on the biological and economic implications of grazing management and grain feeding in intensive beef cattle systems.

The field research reported in this thesis was concerned with two key aspects of intensive beef cattle finishing under rotational grazing systems: herbage allowance-intake functions and the effects on animal performance when maize grain is supplemented, and seasonal changes in herbage quality. These factors are highly interrelated in grazing systems, but evidence on them is limited for Argentinean conditions. Taken into account together with the dynamic changes and interactions occurring naturally in the herbage and animal, modelling was used as a research tool to integrate the information about herbage allowance, maize grain supplementation and herbage quality in a systems context.

The main conclusions of the field research programme were considered in Chapters 4 and 5 and the outcomes of the modelling exercise were discussed in Chapter 7. The field objectives were achieved, and the effectiveness of the model was demonstrated in some preliminary investigations of alternative management strategies. This overview will integrate the main outcomes of the different parts of the thesis, highlighting the benefits of the combined approach for the advancement of the topic and identifying needs of further research.

2. Main conclusions of the grazing studies

The n-alkane & ^{13}C method proved to be accurate for quantitative estimates of herbage and maize grain intakes, and allowed the estimates of a substantial variation in individual maize grain intakes (between 31 to 41 % CV) when animals are supplemented in groups. This variation is of potential importance in terms of both system management and system modelling, because it contributes directly to variation in liveweight gain, but there is little published information about it. This method also allowed the establishment of significant relationships between herbage dry matter allowance, herbage intake and animal performance, which were dynamic in nature, but were also robust within about a range of experimental conditions including season, sward composition and animal use.

The n-alkane & ^{13}C method was the preferred basis for quantifying the substitution rate of grazed pasture for maize grain. Substitution rate is by definition a compound variable (i.e. a reference of unsupplemented herbage intake is required for its estimation), therefore the term “individual substitution rate” used in Chapter 4, should be applied with caution. Also it was recognized that bias can be introduced by the fact that unsupplemented animals tend to become progressively lighter than supplemented animals. However, from this analysis it was possible to show a consistent pattern of substitution rate over a range of herbage allowances and levels of grain feeding.

The n-alkane method was effective in providing estimates of diet digestibility, but it was not successful in predicting the botanical and morphological characteristics of the diet selected. Other methods, such as micro-histological evaluation of faeces and differences in nutrient and component selection indexes, were tested early in the programme (Chapter 2), but they were not considered to be reliable and they were too laborious for continued use under field conditions.

3. Seasonal variation of pasture quality

The outcome of the studies on seasonal variation in herbage quality initially were 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. The study reported in Annex B for New Zealand conditions covered a longer period (40 months) than that reported for an Argentinean pasture in Chapter 5 (28 months). Comparison of herbage quality variables from different pastures and weather conditions is limited. However, a clear and consistent seasonal pattern in herbage nutritive value was observed in both studies. The lowest values for crude protein occurring in summer in both cases, and the lowest values of metabolisable energy content were in summer and autumn for the New Zealand pasture (Annex B), and during autumn in Argentina (Chapter 5). These fluctuations need to be compared with the relative nutritional requirement of the animals. In this case, both studies gave levels of crude protein and metabolisable energy content sufficient to meet or exceed those specified for growing beef animals (Hodgson & Brookes 1999). In agreement with the literature, intensive pasture management is likely to be a key factor in achieving these results (Clark 1995), and care is needed in extrapolating to other management conditions. More research is needed into feed protein fractions to evaluate the implications of “excess” levels of crude protein on animal performance, rumen metabolism and animal nutritional requirements of free grazing animals.

Prediction of the nutrient content of herbage from observations on sward morphology (Chapter 5) was based on the approach suggested by Fick et al. (1994), but used a different combination of morphological and maturity descriptors as predictors of herbage quality. The significant relationships established between morphological and maturity estimates and herbage nutritional variables in a pasture under grazing conditions (Chapter 5) are promising in terms of potential inferences to the seasonal changes of herbage quality, but could not be taken further in the field studies. There is a need for further work on the evaluation of these preliminary equations.

4. Modelling for information synthesis in a whole-system context

An objective of this thesis was to develop a “finishing beef cattle unit” simulator, as a tool for information synthesis (Chapter 6) and research on the biological and economic implications of grazing management and grain feeding in intensive beef cattle systems (Chapter 7). The model integrated in a simplified way (as does any

model) current knowledge of different disciplines, in a form in which the system can be interrogated in terms of its response to different management conditions, scenarios and timeframes.

The advantage of field experimentation linked with modelling is widely recognised in the literature. There are also frequent claims from modellers about limited data availability, or inadequate description of information (Herrero et al. 1998; Cohen et al. 2003). In this thesis, there was a “conceptual complementarity” between field experimentation and model development, activities that were developed simultaneously. The selection of grazing management techniques was influenced by the modelling process and also by the fact that the experiments were mostly developed on commercial farms. Conversely, choices between alternative approaches for model components were affected by the feasibility of field information procedures.

The term model “evaluation” implies a more conservative expression than “validation” (Oreskes 1998), and it was preferred here. Two key outcomes of the model, liveweight gain and herbage intake, were formally evaluated against experimental information under different levels of herbage allowance and maize feeding, and were accurately predicted. However, it is important to emphasise that model development was completely independent from field experiments in terms of the use of data.

Overall outcomes of the model such as total liveweight gain at different stocking rates were also informally compared with the literature (Chapter 7, Figure 6), with an acceptable agreement. The field studies on herbage intake and animal performance were relatively short-term (Chapter 2, 3 and 4), but provided evidence of responses to variation in herbage allowance and grain use which can effectively be incorporated into a dynamic model of animal responses to management decisions. Evaluation of other components of the model was not attempted. Herbage accumulation rate is an input for the model, and the system for animal requirements has been widely tested previously in grazing conditions (Donnelly et al. 2002). Diet composition was predicted arbitrarily from sward composition as done in other models (Doyle et al. 1989; Cacho et al. 1995). Limitations of

information on diet composition made its evaluation unfeasible. However, the fact that the model was effective in predicting liveweight gain adequately indicates that herbage intake was the main driver of this response, in agreement with observations in the field experiments (Chapter 4).

Herbage dry matter allowances and grain feeding were the main experimental variables used in the grazing studies. Studies have been reported where fixed herbage allowances have been applied continuously over complete production cycles (Bartholomew et al. 1981; Kloster et al. 2000). However, herbage allowance applied in this way seriously limits management flexibility. One of the goals in the modelling study was to integrate the flexibility of management decisions about the allocation of herbage dry matter allowance, with stocking rate, grain feeding and herbage conservation, all available as management decisions. When the model is simulated under a “fully interactive” mode (Chapter 6, section 3.), the user directly enters all the information in real time. Alternatively, Chapter 7 describes a simple but original procedure intended to manipulate herbage intake (and animal performance) in real time, in response to herbage deficit and surplus, identified by a “manager” in a routine of pasture monitoring and budgeting. The functionality of this “automatic” feature was demonstrated in a system comparison (Chapter 7, Table 5) where grain feeding was managed under simple rules driven by deviation from pre-defined targets of animal liveweight and pasture cover for different months of the year.

5. Further research and development

The variation of grain intake detected in the field experiments had important practical implications, because highest individual grain intakes were associated with highest liveweight gain (Chapter 3 and 4). This function can be easily incorporated in the model, by developing random intakes around an allocated average level of maize grain feeding. However, as the technique used to measure grain intake represents a 5-day period, it is not known if this variability represents a daily random variation between individuals, or is indicative of consistent animal differences. These alternatives may have different implications for animal and system response to grain feeding. As liveweight gain records cover 14 days, the

association with maize grain intake may indicate consistent animal differences. However, until more detailed information becomes available including individual recording of animal behaviour with automated recorders, this question cannot be resolved.

Information on herbage accumulation rates in Argentinean pastures is scarce. As mentioned in Chapter 6, the development of a soil-weather model to predict herbage accumulation is a complex task (Woodward & Rollo 2002), which was beyond the objectives of this study. However, the structure of the model representing explicitly leaf mass (clearly linked to leaf area index), and working with a mathematically estimated gross growth rate (easily replaced by a climate-driven module that predicts the gross growth rate directly) from inputted herbage accumulation rate, provides the basis for a further development in this area. Climate data is more readily available in Argentina than databases of herbage accumulation rate, and these empirical databases take years to develop. This limits the model for use in other sites. However, it is important to emphasise that this does not mean that pasture research efforts are not needed. On the contrary, they should be reinforced, but require adequate description of composition, structure and dynamics of the sward, observations which will provide a comprehensive means to calibrate and evaluate the best options from the literature. There is also a need for more detailed information on pasture response to fertilizer application.

The way that herbage quality is handled in the model (Chapter 6, section 2.2.1.5.), allows the dynamic modelling of different aspects of sward morphology and herbage nutritive values. At this stage of model development the herbage gross growth rate is back-calculated from herbage accumulation rate, so caution is required in the analyses. However, it also provides opportunity for investigation of the effects of management on pasture changes in metabolisable energy and crude protein content of the sward, testing different levels of seasonal change in stem quality, eventually adding a penalty factor associated with stem mass on stem quality when data becomes available.

6. Conclusions

The results from this series of short-term studies showed consistency in the comparison of the effects of herbage allowance and level of maize supplementation on herbage intake and animal liveweight gain. Although these effects require further confirmation and a wider scope of experimental conditions, they constitute a good basis for model development. The n-alkane & ¹³C method proved to be reliable for estimation of herbage and maize grain consumption, with an important contribution in the identification of variability of grain intake between animals fed in groups.

Although there was a clear seasonal pattern in herbage nutritive value, under an intensive pasture management this did not seem to be a limiting factor for growing beef cattle, at least in terms of the content of metabolisable energy or crude protein.

When tested against field observations, the model showed acceptable accuracy in predicting liveweight gain and herbage intake of beef cattle under a wide range of herbage dry matter allowances and maize grain intakes. The model has been shown to be flexible when challenged with different grazing management conditions, providing a good biological basis for a more holistic appraisal of the effects of "process technologies" such as grain feeding in beef cattle finishing systems. This provides confidence in its future use as a research aid or an educational tool for agricultural students and professionals.

References

- Bartholomew P.; McLauchlan W.; Chestnutt D. 1981: An assessment of the influence on net herbage accumulation, herbage consumption and individual animal performance of two lengths of grazing rotation and three herbage allowances for grazing beef cattle. *Journal of Agricultural Science, Cambridge* 96:363-373.
- Cacho O. J.; Finlayson J. D.; Bywater A. C. 1995: A simulation model of grazing sheep: II. Whole-farm model. *Agricultural Systems* 48:25-37.

- Clark E. A. 1995: Maintaining forage quality by intensive management. *Proceedings of the Western Canadian Dairy Seminar* 7:135-146.
- Cohen R. D. H.; Stevens J. P.; Moore A. D.; Donnelly J. R. 2003: Validating and using the GrassGro decision support tool for a mixed grass/alfalfa pasture in western Canada. *Canadian Journal of Animal Science* 82:171-182.
- Donnelly J. R.; Freer M.; Salmon L.; Moore A. D.; Simpson R. J.; Dove H.; Bolger T. P. 2002: Evolution of the GRAZPLAN decision support tools and adoption by the grazing industry in temperate Australia. *Agricultural Systems* 74:115-139.
- Doyle C. J.; Baars J. A.; Bywater A. C. 1989: A simulation model of bull beef production under rotational grazing in the Waikato region of New Zealand. *Agricultural Systems* 31:247-278.
- Fick G. W.; Wilkens P. W.; Cherney J. H. 1994: Modeling forage quality changes in the growing crop. In: Fahey, J.R. ed. *Forage Quality, Evaluation and Utilization*. American Society of Agronomy, Inc.:757-795.
- Herrero M.; Dent J. B.; Fawcett R. H. 1998: The plant/animal interface in models of grazing systems. In: Peart, R.M. & Curry, R.B. Eds. *Agricultural System Modeling and Simulation*. New York. Marcel Dekker, Inc. 495-542.
- Hodgson J.; Brookes I. M. 1999: Nutrition of grazing animals. In: White, J.& Hodgson, J. Eds. *New Zealand Pasture and Crop Science*. Oxford University press. 117-132.
- Kloster A. M.; Latimori N. J.; Amigone M. A. 2000: Evaluación de dos sistemas de pastoreo rotativo a dos niveles de asignación de forraje en una pastura de alfalfa y gramíneas. *Revista Argentina De Producción Animal* 20:187-198.
- Oreskes N. 1998: Evaluation (not validations) of quantitative models. *Environmental Health Perspectives* 106:1453-1460.
- Woodward S. J. R.; Rollo M. D. 2002: Why pasture growth prediction is difficult? *Agronomy* 32:17-26.

Annexes

**Maize supplementation and feedlot as an
alternative for summer steer finishing systems⁹**

⁹ Machado, C.; Striebeck, G.; Vasolo, V. ;Di Croce, F.; Gonzalez, F. ; Duhalde, J.; Parente, M. ; Auza, 2001. *Avances en Producción animal* 26: 139-146 [in spanish]

Abstract

The aim of this trial was to investigate tactical alternatives of maize grain supplementation and feedlot in finishing systems of beef cattle during summer. Ninety one Angus steers (310 ± 2.7 Kg LW) were randomly allocated by liveweight to the following feeding treatments on 5 January: grazing pasture only (P), grazing pasture plus concentrate at 1 % of live weight (S1), grazing pasture plus concentrate at 2 % of live weight (S2) and concentrate at 2 % of live weight plus alfalfa hay in feedlot (F). An alfalfa-based pasture was used. Animals were strip-grazed with a 4-day average break. On days 0, 15, 33, 55, 82, 98, 114, 127, 142 and 156, animals were weighed unfasted and after a 15-h fasted period, and liveweight gain (LWG) estimated. Supplement levels were adjusted at each weighing time. When steers in a treatment group reached an average of 400 kg (15-h fasted), they were slaughtered. Before slaughter, animals were weighed full and after a 15-h fast to estimate shrunk live weight losses. Dry matter intake (DMI) was estimated from pre- and post-grazing estimations of herbage mass. Feed-intake of F was estimated from the difference between the offered and rejected feeds (for grain and hay) on a daily basis, and a similar procedure was used to estimate supplement intake in treatments S1 and S2. The animals in S2 and F treatments were fed twice daily (8 am and 5 pm), while S1 were fed only once a day (8 am). In S1, 100 % of cracked maize (DM basis) was used, but S2 and F supplements were protein-corrected with brewer's grain (10 %) plus the addition of urea. DMI plus concentrate (when present) were 2.9, 2.7, 2.9 and 3.1 % LW for P, S1, S2 and F, respectively. Dry matter intakes during the trial were more variable when less concentrate was fed. Actual concentrate feeding levels were 0.75, 1.46 and 1.46 % of LW for S1, S2 and F respectively. LWG's were higher ($P < 0.05$) in S2 (0.90 kg d^{-1}) and F (0.90 kg d^{-1}) than P (0.62 kg d^{-1}) and S1 (0.72 kg d^{-1}). Target LW was reached at 154, 119, 98 and 93 days for P, S1, S2 and F respectively. Significant differences were detected for the percentage of shrunk liveweight losses, where P (5.1 %) and S1 (4.7 %) were higher than S2 (2.6%) and F (3.3%). Feeding supplements and feedlotting improved LWG and the percentage of shrunk liveweight losses, although only S2 and F achieved finish in time to avoid the requirement overlapping with new weaners entering the system in the autumn.

Key-words: Supplement; summer; grazing; beef cattle; system; maize.

1. Introduction

The success of any grazing system depends on the management skills to produce herbage of high quantity and quality, to use it adequately by grazing and to convert it efficiently into animal products (Hodgson 1990). The Buenos Aires Province, Argentina, is an agricultural area where beef production is based on perennial pastures, which are part of the rotational system of soil use for cash crops. During summer and autumn-winter it is difficult to achieve a satisfactory and predictable animal liveweight gain (LWG), so grain supplementation is frequently used in this season, with variable results.

In these beef cattle production systems where animals are finished at 15-20 months of age, animal performance during the final summer finishing period is extremely important to avoid feed requirement overlap of finishing animals with that of weaners entering the system in the autumn. Grain supplementation has been used to overcome this problem, with variable responses in animal production (Lake et al. 1974; Reardon 1975; Boom & Sheath 1998; Boom & Sheath 1999), and also large fluctuations in herbage substitution rates (Mayne 1988; Dixon & Stockdale 1999).

Supplementation may increase animal performance or increase the carrying capacity (Perry et al. 1972; Mayne 1988; Stockdale & Trigg 1989; Prache et al. 1990) therefore allowing pastures to be used intensively, improving forage utilisation and ultimately providing a better match of animal feed requirements (Stockdale et al. 1987). Although supplements increase feed costs, they may provide more physical certainty to the system, accelerate the finishing process, meet market specification and release pasture for other animals (Taylor & Gulbransen 1990). Particularly in mixed cash crop and livestock systems, a predictable release of land use is important to optimize the use of available resources.

With intensification of pasture-based beef cattle systems occurring in Argentina,

these seasonal constraints have become more evident (Rearte 1998). Strategic use of fertilisers, supplementation and irrigation has been researched in beef steer farmlets (Garcia et al. 1998), however local information about summer responses to supplementation is scarce and variable. The aim of this research was therefore to investigate the level of grain supplementation and the method of feeding (grazing vs. feedlot) on animal performance as a tool to overcome summer constraints for a pasture-based beefcattle finishing system.

2. Materials and methods

A trial was developed on a commercial farm ("Cacho-Rita", CREA San Cayetano) situated 38° 20' S, 60°13' W. Ninety one Angus steers (310±2.71 kg LW) were randomly allocated by liveweight, to the following feeding treatments in 5 January (i.e 22-23 animals per treatment): grazing pasture only (P), grazing pasture plus supplements at 1 % of LW (S1), grazing pasture plus supplements at 2 % of LW (S2), and supplementation at 2 % of LW plus hay in a feedlot (F).

A 2-year alfalfa-based pasture (*Medicago sativa*, *Trifolium pratense*, *Trifolium repens*, *Bromus unioloides* and *Dactylis glomerata*) was used. The previous September, the paddock had been cut for haymaking. In order to achieve a similar herbage condition amongst treatments, the available pasture area was categorized into different sectors and then proportionally allocated to the three grazing treatments. Animals were strip-grazed with a 4-d break using electric fences with no back-grazing, and treatments were balanced to achieve a similar herbage utilisation by adjusting the grazed area. Cutting or grazing with other animals removed the surplus of herbage from the paddock. Feedlot animals were assigned to a pen of 30 x 40 m, with shade available. All supplements were fed in a trough with 0.5 m hd⁻¹ provided. Water was supplied *ad libitum* in all the treatments.

On days 0, 15, 33, 55, 82, 98, 114, 127, 142 and 156, animals were fasted for 15 h before weighing. Supplement levels were readjusted at each weighing. Steers were slaughtered when a treatment group reached an average of 400 kg LW (15 h fasted LW). Prior to slaughter, animals were weighed straight off pasture and then again after a 15-h fasted period, to estimate fasted losses.

Dry matter intake was estimated by using the pre- and post-grazing difference method (Frame 1981), by cutting 10 quadrats before and after grazing a strip within each treatment at ground level and dry matter content estimated by oven-drying the samples for 48 h at 60 °C until constant weight. Soil contamination of samples was avoided. Estimated dry matter intakes were corrected for net herbage accumulation rate recorded simultaneously on the same pasture from the rate of change in herbage mass (by cutting 10 quadrats per time) between two times (Hodgson et al. 1999).

Dry matter intake for the feedlot group was estimated daily from the difference between feed offered and feed residual after 24 h (measured for concentrate and hay separately). Similar procedures were carried out for estimating supplement dry matter intake for the S1 and S2 treatments. Supplement and its residual (if any) were sampled weekly and pooled for dry matter estimation. Fortnightly, a further ten herbage quadrats were cut and a sub-sample obtained to estimate herbage quality. Samples were analysed for *in vitro* dry matter digestibility (Dig) (Tilley & Terry 1962), crude protein (CP) by Micro Kjeldhal method (A.O.A.C. 1960), and neutral and acid detergent fiber (NDF and ADF) (Goering & Van Soest 1970).

Treatments S2 and F were fed a maize-based mixture with 10% of brewer's grain plus 22 g urea d⁻¹ twice daily (8:00 am and 5:00 pm). S1 were fed 100 % of cracked maize only once a day (8:00). In F supplementation level and time were similar to S2. The composition of the dietary components is shown in Table 1.

Table 1. The percentage of dry matter digestibility, crude protein, neutral detergent fiber and acid detergent fiber of the dietary components.

Feeds	Dig (%)	CP (%)	NDF (%)	ADF (%)
Maize grain	84.6	8.8	-	3.0
Brewery grain	75.3	24.8	-	18.3
Hay	51.0	9.6	72.1	-
Barley hay	59.0	6.6	74.4	-

Dig= *in vitro* digestibility, CP=crude protein, NDF=neutral detergent fiber and ADF=acid detergent fiber.

Weather parameters were obtained from the nearby CHEI-Barrow Experimental Station. Liveweights and liveweight gains and the measurements of pasture were analysed using a repeated measures design. PROC MIXED procedure and

ESTIMATE statement for comparing means were used (Littell et al. 1998). Total live-weight gains and shrunk liveweights were analysed as a completely random design. Linear regressions were fitted between the different studied parameters. All analyses used SAS system (SAS/STAT 2001).

3. Results and Discussion

3.1. Weather and pasture conditions

During the study, rainfall was 18 % higher and potential evapotranspiration was 5 % lower than historical information for the same period. Pre-grazing herbage mass averaged 2630 ± 112 kg DM ha⁻¹ and as a result of how the treatments were allocated, a similar herbage use efficiency between treatments (43 ± 3 %) was observed. The required areas per grazed treatment were 17, 14 and 7 ha for P, S1 and S2 respectively. A higher carrying capacity of pastures is often the result when energy supplements are fed (Perry et al. 1972; Karnezos et al. 1994; Boom & Sheath 1998; Boom & Sheath 1999), but the level of improvement depends on the complex interaction between supplementation level, type of concentrate, sward conditions, animal requirements and season and their effects on substitution rate (Mayne 1988).

Estimates of herbage quality are shown in Table 2. Pasture quality during the first 60 days was lower than for the rest of the trial. Summer values of 15 to 20 % of CP are normally reported on pastures having similar characteristics (Kloster et al. 2000).

Table 2. Dry matter digestibility, neutral detergent fiber and crude protein of the herbage during the trial.

Days	Dig (%)	NDF (%)	CP (%)
6	60.3	52.0	12.7
32	56.4	56.7	12.2
58	61.6	50.2	12.6
98	64.1	55.4	19.1
120	72.5	47.7	22.3
140	75.0	42.0	24.0

Dig= in vitro digestibility, NDF=neutral detergent fiber and CP=crude protein.

3.2. Dry matter intake

Herbage intake (expressed as % LW) plus concentrate and hay intake (when present) were 2.9 ± 0.18 , 2.7 ± 0.12 , 2.9 ± 0.08 and 3.1 ± 0.05 for P, S1, S2 and F respectively. When less concentrate was fed, total dry matter intakes were more variable, with no significant differences ($P < 0.05$) between grazing treatments, but F had a higher value than S1. Associated to the readjustment method for feed allocation, supplement fed was 0.75, 1.46 and 1.46 % of LW for S1, S2 and F respectively, resulting in a lower level than originally planned. These results are important for future economic analysis, as normally these analyses are carried out with "planned figures" rather than recorded ones.

In the current study, an average of 2.7 and 4.7 kg maize d^{-1} were fed for S1 and S2 respectively. Herbage substitution rates (SR) were high and variable (0.81 and 1.03 for S1 and S2 respectively). Lower SR might be expected taking into account that stocking density was modified for each treatment (adjusting the grazed area) to obtain a similar herbage utilisation. Highly variable substitution rates (0.43 to 1.24) with differences between replicates were reported by Boom and Sheath (1998), who included maize levels of 0, 2, 4 and 6 kg d^{-1} in a grazing experiment during summer. These authors attributed this variation to differences in sward conditions between replicates (54 vs. 35 % of green leaf fractions). In a more recent study (Boom & Sheath 1999), 18-month steers were supplemented during summer with 0, 2 and 4 kg of protein-corrected cracked maize d^{-1} . Herbage intake was the same in the control and the 2 kg (0 SR) supplemented group, but it was 22 % lower at 4 kg of concentrate fed (0.69 SR). However, conclusions about SR and concentrate level are limited by the method used for dry matter intake estimation in

the present trial and by visual estimation in the previously quoted trials (Boom & Sheath 1998; Boom & Sheath 1999). Frequently when supplements are fed, the control group of animals achieves a lower LWG (thus becoming lighter than supplemented groups during the trial). This introduces a bias if herbage intake as recorded in the control is used for SR estimation. Although at present reliable techniques are available to record individual herbage and supplement intake using n-alkanes (Dove & Mayes 1996) or other alternatives such as ytterbium (Yb) (Holst et al. 1994), a more precise SR estimation was beyond the objectives of this pilot study.

3.3. Animal liveweight, liveweight gain and fasted LW loss

Changes in full liveweight during the trial are shown in Figure 1. Significant differences among treatments for total liveweight gain over the trial were detected ($P < 0.05$), being higher in S2 and F than in P and S1 (Table 3). The number of days required to reach 400 kg LW were 154, 119, 98 and 93 for P, S1, S2 and F, respectively. Only the S2 and F treatments avoided overlapping with the weaners entering the system in the autumn. When four levels of maize supplementation (zero, 33, 66 and 100 % of daily intake as concentrate) were fed to grazing steers of a similar live weight to the present trial during 135 days of spring-summer (Perry et al. 1972), a linear increase of live weight gain was reported (0.4, 0.8, 1.1 y 1.4 kg d⁻¹ respectively).

Table 3. Total liveweight gain and shrunk liveweight losses of the different treatments.

Parameter	P	S1	S2	F	#PSE
Initial LW (kg)	311	309	311	310	1.4
Total LWG (kg d ⁻¹)	0.62 ^a	0.72 ^a	0.90 ^b	0.90 ^b	0.027
15-h shrunk LW loss (% LW)	5.1 ^b	4.7 ^b	2.6 ^a	3.3 ^a	0.207

P= pasture only, S1= pasture plus supplement at 1% LW, S2= pasture plus supplement at 2% LW, F= supplement 2% LW plus hay in a feedlot, #PSE=pooled standard error and different letters within a row indicate significant differences ($P < 0.05$).

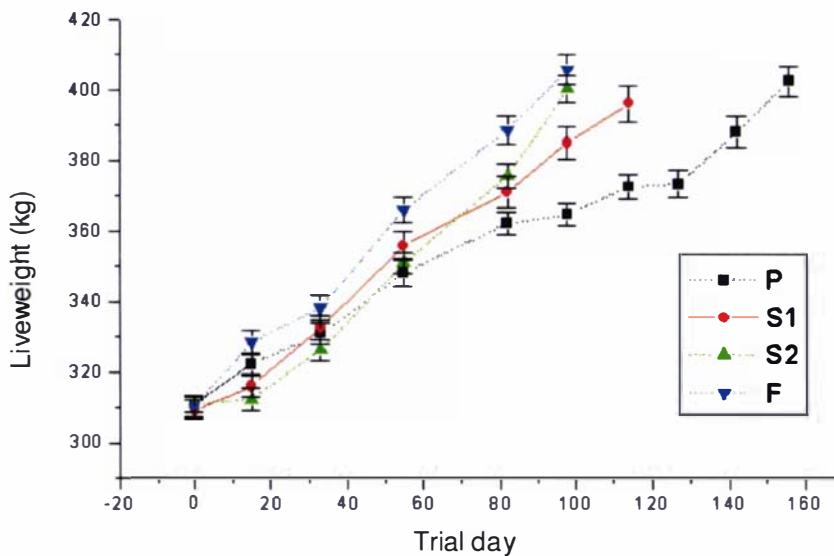


Figure 1. Average animal liveweights (\pm standard errors) of the treatments throughout the trial. P= pasture only, S1= pasture plus supplement at 1% LW, S2= pasture plus supplement at 2% LW and F= supplement 2% LW plus hay in a feedlot.

The most direct explanation for the improvement in animal performance that is usually observed when grain is fed to grazing animals, is likely to be associated with the extra energy provided (Horn & McCollum 1987; Mayne 1988). Additionally, a possible explanation for improved LWG in supplemented animals is better use of excess ruminal ammonia N (lower plasma urea nitrogen) and a higher microbial protein flow to the gut, as has been associated with the improved LWG of wether lambs grazing high protein herbage and fed with maize grain (Karnezos et al. 1994). However, some authors have reported LWG improvement in steers by supplementation in high quality pastures without a significant improvement in net ruminal microbial protein synthesis (Elizalde et al. 1998). Crude protein levels were relatively low (Table 2) on days 0 to 58 in comparison with those observed in other studies (Kloster et al. 2000), and although diet selection might improve these values, LWG improvement in this trial is probably not associated with a better use of protein in this period. However, it could be the case after day 58 of the trial, where level of protein (Table 2) and LWG response to maize feeding increased (Figure 1). Changes in selectivity and a different SR between maize grain levels have been mentioned as contributors to the non-linear effect of supplements on live weight gain (Petty et al. 1998). The extra liveweight gain due to supplement fitted to a linear regression was: Extra LWG = $0.60 \pm 0.04 + 0.06 \pm 0.01 S$; $R^2 = 0.97$

$P < 0.01$, where S is the supplement fed in kg d^{-1} . Higher extra LWG associated with supplements (0.17 kg d^{-1}) than the present results (0.06 kg d^{-1}) were obtained when 18-month steers at grazing were fed maize levels of 0, 2, 4 and 6 kg d^{-1} during summer (Boom & Sheath 1998). One factor that might contribute to this difference (further than the divergence in supplementation level), is the performance of the control group (0%), and so the potential response to supplementation on this condition. Control LWG was zero in the results of Boom and Sheath (1998), and was 0.62 kg d^{-1} in the present study (Table 3).

A trend to improve the supplement conversion from S1 to S2 was present. From average supplement intakes of 2.7 and 4.7 kg d^{-1} , extra LWG of 37 and 60 g d^{-1} were found for S1 and S2 respectively. Similarly, when wether lambs grazing irrigated alfalfa were fed with 0, 0.12 and 0.25 kg of cracked maize per day (Karnezos et al. 1994), feed conversion tended to improve with maize level.

Pasture only and S1 treatments resulted in a higher loss of gastrointestinal content on fasting ($P < 0.05$) than S2 and F (Table 3). Similar results were reported when wether lambs grazing irrigated alfalfa were supplemented with 0, 123 and 247 g d^{-1} of cracked maize (Karnezos et al. 1994) and loss of gastrointestinal content increased quadratically ($P < 0.01$) with maize level fed. Other authors have obtained in cattle a trend to a lower gastrointestinal fill with sorghum grain (Taylor & Gulbransen 1990) and maize grain (Reardon 1975). This emphasizes that the combination of LWG per hectare, associated with a lower gut fill should be considered when the economic value of supplementation is evaluated.

Conclusion and implications

Feeding maize grain under grazing and feedlot conditions increased liveweight gain and decreased fasted liveweight losses. Dry conditions during the summer make it difficult to achieve a satisfactory and predictable animal live weight gain. This led to a delay in animal sales and to nutritional requirement for finishing animals overlapping with weaners entering the system in the autumn. Overlapping with the entry of new weaners was avoided only in the treatment receiving the

highest level of grain at grazing (S2) and under feedlot conditions. This implies that a high level of supplement (1.4 % liveweight) might be needed to manage the predictability of the system. Variation in the quality and quantity of forage and in concentrate level might be involved in the response of grazing animals to grain feeding (Dixon & Stockdale 1999). Thus, detailed complementary studies would be needed to understand the trade-off between concentrate input and sward conditions, in order to improve the predictability of grain feeding responses.

From this pilot study, although results should be confirmed, it is concluded that a high level of maize feeding may be needed during summer to improve the predictability of finishing during the summer season. The feasibility of the technique should be assessed both from production and economic of the system perspective.

References

- A.O.A.C. 1960: *Official Methods of Analysis*. 9th ed. AOAC. Washington:957 p.
- Boom C. J.; Sheath G. W. 1998: Grain supplementation of finishing beef cattle. *Proceedings of the New Zealand Society of Animal Production* 58:239-242.
- Boom C. J.; Sheath G. W. 1999: Tactical supplementation of beef finishing cattle. *Proceedings of the New Zealand Society of Animal Production* 59:162-165.
- Dixon R. M.; Stockdale R. C. 1999: Associative effects between forages and grains: consequences for feed utilisation. *Australian Journal of Agricultural Research* 50:757-753.
- Dove H.; Mayes R. W. 1996: Plant wax components: a new approach to estimating intake and diet composition in herbivores: a review. *Journal of Nutrition* 126:13-26.
- Elizalde J. C.; Cremin J. D.; Faulkner D. B.; Merchen N. R. 1998: Performance and digestion by steers grazing tall fescue and supplemented with energy and protein. *Journal of Animal Science* 76: 1691-1701.
- Frame J. 1981: Herbage Mass. *In*: Hodgson, J.; Baker R.D; Davis, A.; Laidlaw,

- A.S. ; Leaver, J.D. Eds . *Sward Measurement Handbook*. British Grassland Society: Berkshire, UK. 35-70.
- Garcia S. C.; Santini F.; Castaño G. 1998: Producción de carne bajo pastoreo: Alternativas de intensificación. Material didáctico Nro 14. INTA, Cerbas.:52 p.
- Goering H. K.; Van Soest P. 1970: Forage fiber analysis (apparatus reagents, procedures and some applications). *Agriculture Handbook Nr 379, USDA. Washington, DC.* 20 p.
- Hodgson J. 1990: *Grazing Management: Science into Practice*. Longman Handbooks in agriculture, Longman Scientific and Technical co-published with John Wiley. New York: 203 p.
- Hodgson J.; Matthews P. N. P.; Matthew C.; Lucas R. J. 1999: Pasture measurements. In: White, J.& Hodgson, J. Eds. *New Zealand Pasture and Crop Science*. Oxford University press. 59-66.
- Holst P. J.; Curtis K. M. S.; Hall D. G. 1994: Methods of feeding grain supplements and measuring their intake by adult sheep. *Australian Journal of Experimental Agriculture* 34:345-348.
- Horn G. W.; McCollum F. T. 1987: Energy supplementation of grazing ruminants, July 23-24. *Proceedings of the Grazing Livestock Nutrition Conference* :125-136.
- Karnezos T. P.; Matches A. G.; Preston R. L.; Brown C. P. 1994: Corn supplementation of lambs grazing alfalfa. *Journal of Animal Science* 72:783-789.
- Kloster A. M.; Latimori N. J.; Amigone M. A. 2000: Evaluación de dos sistemas de pastoreo rotativo a dos niveles de asignación de forraje en una pastura de alfalfa y gramíneas. *Revista Argentina De Producción Animal* 20:187-198.
- Lake R. P.; Hildebrand R. L.; Clanton D. C.; Jones L. E. 1974: Limited energy supplementation of yearling steers grazing irrigated pasture and subsequent feedlot performance. *Journal of Animal Science* 39:5:827-833.

- Littell R. C.; Henry P. R.; Ammerman C. B. 1998: Statistical analysis of repeated measures data using SAS procedures. *Journal of Animal Science* 76:1216-1231.
- Mayne C. S. 1988: Effects of supplementation on the performance of both growing and lactating cattle at pasture. In: Frame, J. Ed. *Efficient Beef Production from Grass*. Occasional Symposium. No. 25, British Grassland Society, Berkshire, UK. 55-71.
- Perry T. W.; Huber D. A.; Mott G. O.; Rhykerd C. L.; Taylor R. W. 1972: Effect of level of pasture supplementation on pasture, drylot and total performance of beef cattle. II. Spring plus summer pasture. *Journal of Animal Science* 34:647-652.
- Petty S. R.; Poppi D. P.; Triglone T. 1998: Effect of maize supplementation, seasonal temperature and humidity on the liveweight gain of steers grazing irrigated *Leucaena leucocephala*/*Digitaria eriantha* pastures in north-west Australia. *Journal of Agricultural Science, Cambridge* 130:95-105.
- Prache S.; Bechet G.; Theriez M. 1990: Effects of concentrate supplementation and herbage allowance on the performance of grazing suckling lambs. *Grass and Forage Science* 45:423-429.
- Reardon T. F. 1975: Summer feeding of beef cattle. *Proceedings of the Ruakura Farmers' Conference* 27 :14-18.
- Rearte D. 1998: Beef cattle production and meat quality on grazing system in temperate regions. *Revista Argentina De Producción Animal* 18:129-142.
- SAS/STAT. 2001: Release. 8 SAS. *Inst. Inc., Cary, NC*.
- Stockdale R. C.; Callaghan A.; Trigg T. E. 1987: Feeding high energy supplements to pasture-fed dairy cows. *Australian Journal of Agricultural Research* 38:927-940.
- Stockdale R. C.; Trigg T. E. 1989: Effect of pasture feeding levels on the response of lactating dairy cows to high energy supplements. *Australian Journal of Experimental Agriculture* 29:605-611.

Taylor K. M.; Gulbransen B. 1990: Feeding grain for profitable finishing of grazing steers. *Proceedings of the Australian Society of Animal Production* 18:388-391.

Tilley J. M. A.; Terry R. A. 1962: two-stage technique for the in vitro digestion of forage crops. *Journal of the British Grassland Society* 18:104-111.

**Seasonal changes of herbage quality within a New
Zealand beef cattle finishing pasture**

Abstract

To estimate seasonal variation in herbage quality from a Friesian bull beef production system, fifty hand-plucked herbage samples were taken fortnightly from a paddock about to be grazed at the Tuapaka bull beef unit, Massey University, between November 1998 and March 2002. The pastures were perennial ryegrass and white clover. Herbage mass (kg DM ha^{-1}) was estimated using a calibrated rising plate meter. Herbage samples were assessed for crude protein (Protein), lipid (Lip), ash (ASH), acid detergent fiber (ADF), neutral detergent fiber (NDF), non-structural carbohydrates (NSC), and metabolisable energy content (ME) by NIRS. A correlation analysis between variables was performed and an analysis of variance was carried out by season using year as a block. Protein and ME were tested for fit to alternative linear equations. Additionally, Bayesian smoothing analysis was applied to the complete data sets of protein and ME. Fiber variables (NDF and ADF) had the strongest relationship between themselves and with other variables, and were negatively related to NSC, ME and protein. The content of non-structural carbohydrates was positively associated with herbage protein and ME. On average, herbage nutrient quality was maintained at a high standard though there was a significant decline in protein in summer and ME in summer and autumn. Non-structural carbohydrates had the highest variability (31 % coefficient of variation), followed by the fiber variables (15 and 16 % for ADF and NDF respectively). Winter gave the highest levels of ASH, OMD and ME, but lowest levels of NSC. The spring period gave the highest levels of herbage mass, protein, NSC, and ME. The lipid levels were higher in autumn and ADF was highest during winter. There were no differences between seasons for NDF. In the smoothing analysis, both protein and ME showed a seasonal behaviour with a tendency for herbage protein to peak before ME in spring. Both protein and ME adjusted significantly to 2nd order polynomials (R^2 of 0.88 and 0.66, respectively). From monthly averaged ME values, liveweight gains (LWG) of grazing 350-kg liveweight Friesian bulls were modelled at different levels of dry matter intake. The computed liveweight gains achieved lowest and highest values in March and September, respectively. Implications to animal performance are discussed, with particular reference to the influence of high herbage protein levels on protein and energy utilisation.

Keywords: Herbage quality; seasonal change; beef cattle; protein; energy

1. Introduction

New Zealand beef cattle production finishing systems evolved with high stocking rates of 5-7 hd ha⁻¹ to increase production per hectare through maximum herbage utilisation (Cosgrove et al. 2003). Recent changes in market characteristics (carcass grading, prices and the value of timing of supply) have produced a shift to a lower stocking rate and improving per animal yield with little decrease in per hectare yield (McRae 2003). In this new context, herbage quality is likely to be the major constraint for achieving high animal performance (Lambert & Litherland 2000).

Although earlier studies in New Zealand have focused on seasonal changes of herbage quality (Metson & Saunders 1978), herbage quantity has traditionally received more attention. Consequently, herbage quality has not been applied systematically in cattle feed management (Parker & Ulyatt 1996). More recently, some dairy cattle studies have concentrated on herbage quality (Moller 1997; Cosgrove et al. 1998) and systematic characterisation of herbage quality for different sheep and beef cattle farms in four regions of New Zealand has been undertaken (Litherland et al. 2002).

Herbage quality varies seasonally and is affected by many factors such as grazing management and fertilizer policy (Saul et al. 1999; Schlegel et al. 2000; Frame et al. 2002). Additionally, interpretation of herbage quality in terms of animal performance must be done carefully. The foraging animal can exploit sward spatial and temporal heterogeneity to consume a diet better than the herbage on offer to meet its requirements (Coleman & Barth 1973; Cohen & Garden 1983; Schlegel et al. 2000). Litherland et al. (2000) monitored the ME and CP content of both the offered pasture and hand plucked samples simulating the pasture selected by animals in four seasons and four regions of New Zealand. From their data, a mean improvement of 6 % in ME in hand plucked samples can be estimated. The magnitude of this effect has been explained as dependent on grazing management

(Hodgson 1990), which also affects herbage quality (Saul et al. 1999; Frame et al. 2002).

In order to define the variation caused by the year effect under a common grazing management and to minimize the difference between pasture on offer and that selected by the animals, an experiment was designed to describe the seasonal variation on herbage quality of hand-plucked pre-grazed herbage samples over three years from a Friesian bull beef production system.

2. Materials and methods

Fortnightly between November 1998 and March 2002, herbage samples were taken from the Massey University Tuapaka bull beef unit, located 10 km east of Palmerston North. This 111 ha teaching and research farm is stocked with 2.5 Friesian bulls per hectare purchased as weaners (100 kg liveweight in November) for slaughter at a target liveweight of 500 kg at approximately 18 months of age (McRae 1988; Coutinho et al. 1998). The pastures were perennial ryegrass and white clover based, and the area sampled was divided into 10 paddocks of approximately 4 ha. each. Fortnightly, fifty hand-plucked samples simulating “bites” (Moller 1997) were taken from a paddock ready to be grazed. Herbage mass (kg DM ha⁻¹) was estimated with a rising plate meter using a local equation (Coutinho 1998) obtained through a double sampling procedure (Earle & McGowan 1979). Herbage samples were transported within 30 minutes of sampling to the laboratory and oven dried for 72 h at 60 °C to a constant weight. Subsequently, they were assessed by Near Infra-Red Spectroscopy (NIRS) (Corson et al. 1999) for the following nutrients (brackets indicate the abbreviations used in the text hereafter): crude protein (protein), lipid (Lip), ash (ASH), acid detergent fiber (ADF), neutral detergent fiber (NDF), non-structural carbohydrates (NSC), organic matter digestibility (OMD) and metabolisable energy content (ME). Although both OMD and ME results are presented for reference, discussion is centred on ME. Additionally, protein to ME ratio was computed and analysed. Analysis of variance was carried out by season using year as a block. Monthly-averaged protein values and ME were analysed for curve fitting. All analyses used the SAS statistical analysis system (SAS/STAT 2001). Bayesian smoothing analysis was applied to

the complete data sets of ME and protein using Flexi 3.1 (Wheeler & Upsdell 2003), to reveal possible underlying seasonal trends. This smoothing technique employs a variance components model to fit a constant term describing the general level of the variable and a correlated random term to describe departures of the curve from this constant. A cycle of 365 days with fluctuating covariance (the cycle is not forced to repeat exactly) was used to model the data as:

$$\text{Total fit (Protein, ME)} = \text{Seasonal component} + \text{long-term component} + \text{error} \quad \text{Eqn. 1}$$

Graphs are presented with the confidence intervals (83 % as default of Flexi) for the fitted curve (Wheeler & Upsdell 2003).

To obtain a reference of the potentially achievable liveweight gains with the observed pasture qualities, the liveweight gain (LWG) of a grazing 350-kg liveweight Friesian bull was modelled using the performance model of Freer et al. (1997), with the monthly ME averages over a range of levels of DM intake (1.7 to 3.2 % LW). The pasture used for nutritional calculations was assumed to be a ryegrass pasture with a clover percentage of 30 % located at a latitude 40° S.

3. Results

Fiber variables (NDF and ADF) had the most significant relationships between themselves and with other variables. They were negatively correlated to NSC, ME and protein (Table 1). The non-structural carbohydrates content was positively associated with herbage ME and protein. Protein was negatively related to herbage mass and ASH, and Lip positively correlated with NDF. Overall means, coefficients of variation (CV) and herbage nutritive values by season are presented in Table 2. On average, herbage nutrient quality was maintained at a high standard, however there was a decline in summer for protein and in summer and autumn for ME (Table 2 and Figure 1). Winter gave the highest levels of ASH, ADF and ME, but the lowest level of NSC. The spring period gave the highest levels of herbage mass, protein, NSC, and ME. The Lipid levels were higher in autumn. There were no differences between seasons for NDF. Non-structural carbohydrates had the highest variation (31 % coefficient of variation), followed by fiber variables (15 and

16 % for ADF and NDF respectively).

Metabolisable energy content peaked around August, and reached its lowest value in January (Figure 1.a), with a trend of herbage protein to peak before ME (Figure 1.a and 1.b). Both ME and protein adjusted significantly ($P < 0.001$) to a 2nd order polynomial:

$$\text{ME} = 9.7 + 0.518X - 0.034X^2 \quad R^2=0.88 \quad P>0.01 \quad \text{Eqn. 2}$$

$$\text{Protein} = 22.8 + 1.75X - 0.158X^2 \quad R^2=0.66 \quad P>0.01 \quad \text{Eqn. 3}$$

Where X is month of the year (1= January). Maximum values for protein and ME occurred at months 5.6 and 7.6 in Eqns. 2 and 3, respectively. It is worth noting that the above equations are not continuous over years, unlike the seasonal smoothing (Figure 1).

Table 1. Overall correlation analysis of the indicated parameters in pre-grazing herbage samples (n=74).

	HM	Protein	Lip	ASH	ADF	NDF	NSC	ME
Herbage mass (HM)	1							
Protein	-0.32	1						
Lip	-0.14	0.27	1					
ASH	-0.07	0.17	-0.30	1				
ADF	0.08	-0.33	-0.10	0.44	1			
NDF	0.12	-0.27	0.27	0.01	0.80	1		
NSC	-0.05	-0.14	-0.13	-0.22	-0.70	-0.66	1	
ME	-0.03	0.44	0.03	0.27	-0.56	-0.59	0.55	1

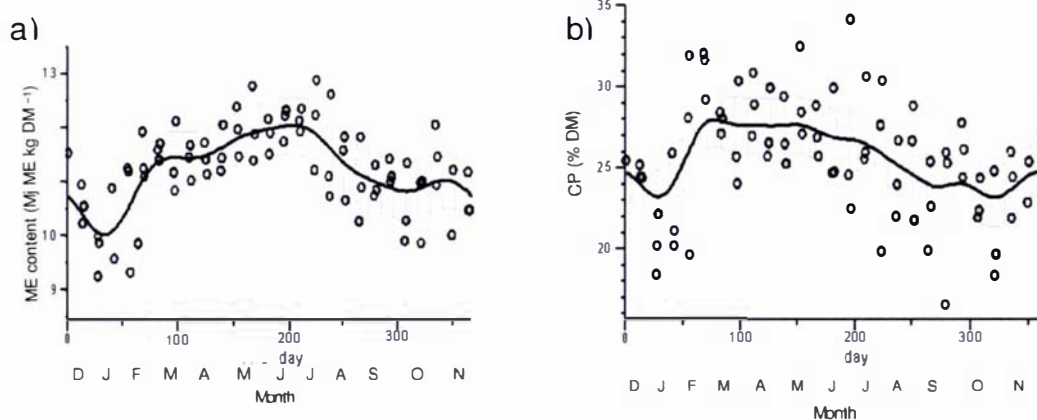
Sward mass = Kg DM ha⁻¹, Protein = crude protein (% DM), Lip = Lipids (% DM),
 ASH = ash (% DM), ADF = Acid detergent fiber (% DM), NDF = Neutral detergent fiber (% DM),
 NSC = non-structural carbohydrates (% DM), ME= metabolisable energy MJ kg DM⁻¹ and
 significant coefficients in bold ($P < 0.05$).

Table 2. Annual means and standard deviations of the overall dataset (n=74) and seasonal variation of means of the different herbage quality parameters in pre-grazing herbage samples.

	Mean	*CV	Autumn	Winter	Spring	Summer	#PSE
Protein	25.8	4.8	26.4 ^b	26.7 ^{bc}	26.9 ^c	23.1 ^a	0.80
Lip	4.1	0.5	4.2 ^b	4.1 ^{ab}	4.1 ^{ab}	3.9 ^a	0.10
Ash	12.0	0.4	11.2 ^{ab}	13.2 ^c	12.2 ^a	11.3 ^b	0.29
ADF	25.7	15.2	24.8 ^a	27.5 ^b	24.7 ^a	25.9 ^{ab}	0.88
NDF	39.9	16.4	40.4	40.8	38.8	39.8	1.24
NSC	8.3	31.8	7.9 ^{ab}	7.5 ^a	9.3 ^b	8.4 ^{ab}	0.65
ME	11.3	2.7	10.9 ^a	11.6 ^b	11.8 ^b	10.9 ^a	0.19
Protein:ME	22.7	13.0	24.1 ^b	23.1 ^b	22.7 ^b	21.3 ^a	0.56
Herbage mass	2250.0	6.2	2160 ^a	2250 ^a	2450 ^b	2140 ^a	69.88

*CV = coefficient of variation, #PSE pooled seasonal standard error, Protein = crude protein (% DM), Lip = Lipids (% DM), ASH = ash (% DM), ADF = Acid detergent fiber (% DM), NDF = Neutral detergent fiber (% DM), NSC = non-structural carbohydrates (% DM), ME = metabolisable energy kg DM⁻¹, Protein:ME = crude protein:metabolisable energy ratio, Herbage mass = kg DM ha⁻¹, means with different letters within rows indicates significant differences between seasons (P<0.05).

The computed liveweight gains achieved using the different monthly ME values of the pasture are shown in Figure 2. The lowest and the highest liveweight gains were in March and August-September, respectively. Herbage intake levels followed the same monthly trend throughout the year, with liveweight gains increasing as feed intake (% of liveweight) increased, reaching a value above 1.6 kg LW d⁻¹ or higher between August and October, for the highest DM intake level.

**Figure 1.** Seasonal change in herbage metabolisable energy (a) and crude protein (b) during the sampling period (November 1998-March 2002). Plotted confidence bands represent 83% probability.

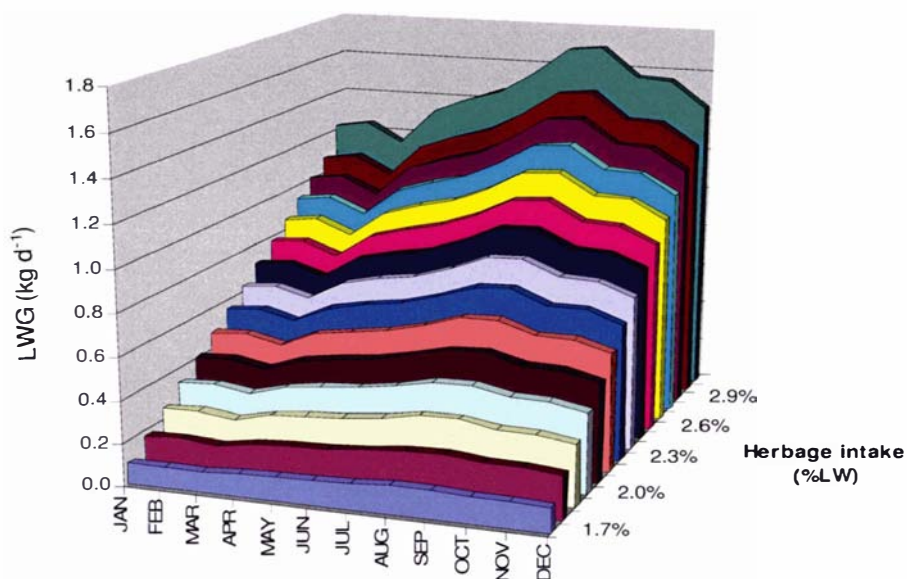


Figure 2. Energy-based predicted liveweight gains of a 350-kg LW Friesian bull fed at different levels of herbage intake during the year based on Freer et al. 1997).

The pasture used for nutritional calculations was assumed to be a perennial ryegrass-white clover pasture with a clover percentage of 30 % located at a latitude 40° S.

4. Discussion

4.1. General seasonal and year variation

Herbage quality from hand plucked herbage samples showed a clear seasonal variation, although it was maintained to a high standard throughout the seasons. There was a consistent pattern between years, as shown by the seasonal smoothings (Figure 1) and a consistent total fit adjustment over the sampling period (Figure 3). The inclusion of long term trends in the analysis, allows a better definition of the seasonal variation (Wheeler & Upsdell 2003), however as they have little biological meaning they are not presented. Typically the climate variation between years alters herbage quality where pastures are harvested at a similar stage of growth (Buxton & Fales 1994). However, the grazing management used on the bull beef unit might contribute to the consistency achieved between years. Intensive grazing may be the key element to moderate seasonal changes of nutritional value of pastures (Clark 1995). In a heavily stocked rotational grazed bull beef system (7.4 hd ha⁻¹) with two alternative managements during summer

and replicated over two years (Clark & Brougham 1979), protein and ME levels were consistently high throughout all seasons (with minimum values of 11 MJ ME kg DM⁻¹ and 18.3 % of protein recorded during summer). Intensive utilisation of the sward contributes to delay maturation and the consequent herbage quality decline (Hodgson & Brookes 1999). As an indication of level of maturity of the sward, pre-grazing herbage mass (mean 2250 kg DM ha⁻¹) in this study was low when compared with the value programmed by Coutinho et al. (1998) in the same bull beef experimental unit (2750 kg DM ha⁻¹). However, it was higher than the 1907 kg DM ha⁻¹ reported by Litherland et al. (2002) from monitored beef and sheep farms from four regions.

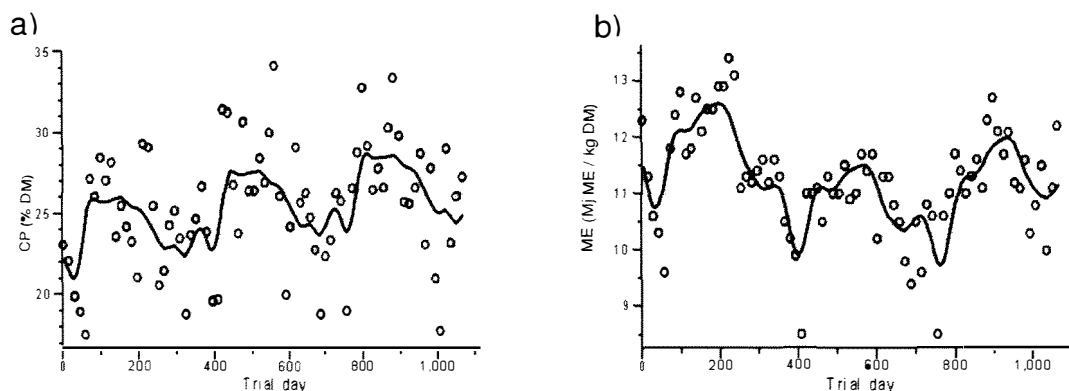


Figure 3. Total smoothing herbage metabolisable energy (a) and crude protein (b) during the sampling period (November 1998-March 2002).

Plotted confidence bands represent 83% probability.

4.2. Metabolisable energy and non-structural carbohydrates

Metabolisable energy had a very low seasonal variation (CV 2.7%). The ratio of summer to spring ME can be used as a measure of seasonal change of this variable and value of 0.92 was estimated from Clark & Brougham (1979) in a bull beef system sampled over two years, a similar value estimated to that in present trial. Both experiments compare favourably with the estimated value of 0.87 for summer:spring ME ratio from four regions of New Zealand beef cattle and sheep farms (Litherland et al. 2002). The lowest levels of ME were found in summer in each year, consistent with the values reported elsewhere (Clark & Brougham 1979; Moller 1997), and the decline extended onto autumn similar to that found by

Litherland et al. (2000) and Moller et al. (1996). In dry weather conditions, Boom and Sheath (1999) reported a low herbage quality ($8.7 \text{ MJ ME kg DM}^{-1}$). During the summer months, plant maturation decreases the leaf to stem ratio, decreases the quality of the stems and increases senescence of green material (Nelson & Moser 1994). Likewise an autumn minimum value of ME was obtained when sampling nineteen farms from four different regions of New Zealand, coinciding with an increase of dead material content in the sward (Litherland et al. 2002). In the current study, samples were hand-plucked and components were not assessed, but a possible increase in dead contribution is likely to explain the ME decline in this season.

Non-structural carbohydrate content was highest in spring, similar to that report of Moller (1997). However, this author obtained values of 12 % for summer and 10.2 % for the overall year value, which are higher than the present study (9.3 and 8.3 % for summer and the overall year, respectively). Non-structural carbohydrates are highly labile and sensitive to the prevailing weather conditions (Moore & Hatfield 1994), and it was the most variable parameter recorded in a study of the yearly seasonal variation of herbage quality in the lower North Island (Metson & Saunders 1978). In this study the variability was 31 % CV.

4.3. Protein

Herbage protein levels declined during summer, but they were consistently high throughout the year, which is in agreement with the report of Clark and Brougham (1979) and Metson and Saunders (1978). These authors described a sharp decrease in summer, and a more extended period of high nitrogen (i.e. crude protein) from late autumn to spring. In spite of the summer decline of protein previously mentioned, values reported here for this season were higher compared with the 14.6 % (average between treatment replicates) reported by Boom & Sheath (1998) and the 10.8 % found by Boom & Sheath (1999) under dry weather conditions. Higher average pre-grazing herbage masses in both quoted experiments (4250 for Boom & Sheath (1998) and 3350 kg DM ha^{-1} for Boom & Sheath (1999) respectively) than in this study may contribute to the differences. The values clearly exceeded the recommended protein content of herbage required for very young growing animals, i.e. 15-18% crude protein (Hodgson &

Brookes 1999), and this finding supports assumption of considering the protein level as non-limiting to animal response in the the model. The animal performance model used (Freer et al. 1997) described a protein deficit penalty which reduces potential herbage intake as a function of the ratio between the total intake of rumen degradable protein (RDPI) and the requirement for rumen degradable protein (RDPR), but has no factor when RDPR is in excess of that required by the animal. As the animal grows at a faster rate, protein requirements increased more rapidly than energy demand (Preston 1966). However, considering that the protein level averaged 25.8 % in the present study, it is unlikely that animals growing at a higher rate are able to utilise this amount of protein in the diet. The energy required to eliminate any excess of blood ammonia could be considerable, and has been estimated by Moore and Varga (1996) in dairy cattle as 1.3 MJ ME for each 100 g protein in excess.

The correlations between variables confirm previously reported relationships between the main quality parameters (Moller 1997). Protein and ME gave a similar seasonal pattern ($r=0.44$, Table 2), although protein had a clear trend to peak before ME content (Figure 1), and the fitted curves in Eqns. 2 and 3. Although both protein and ME declined significantly during summer, the former decreased relatively more than ME, as shown by the corresponding CP:ME ratio. To balance these nutrients, supplementing a high starch feed has been suggested to synchronize degradable crude protein and fermentable energy in the rumen in pasture-fed dairy cows (Kolver 2002) and in beef cattle grazing in high quality temperate pastures (Elizalde & Santini 1992; Elizalde et al. 1998). Feeding high starch feeds is not a common practice in the New Zealand beef cattle industry, although some research studies have reported on its use (Reardon 1975; Boom & Sheath 1998; Boom & Sheath 1999). A full evaluation of the potential benefits of concentrates in New Zealand beef cattle should be considered as a mean to a better use of protein levels found in pasture. Other authors have stated that more research should be carried out both in dairy (Moller 1997) and beef and sheep production (Litherland et al. 2002) to be able to identify adequately the potential effects of protein and NSC contents on animal performance levels.

4.4. Modelling of animal performance

The requirement model used in this study has been extensively validated and its prediction capability demonstrated under grazing conditions (Donnelly et al. 2002; Cohen et al. 2003). Modelling using energy content of the herbage predicted maximum LWG values in spring that were similar to those reviewed by Matthews et al. (1999) in a intensive bull beef system with animals eating to appetite (1.5-2.0 kg LW d⁻¹). As the same animal weight was used to model the performance in each season, differences in LWG over the seasons at the same level of intake were determined by the combination of the seasonal change in ME and the conversion efficiency of metabolisable energy to LWG (K_g), which is a seasonally affected factor with the lowest values in autumn and winter (Freer et al. 1997). Therefore, although summer and autumn herbage had a similar ME content, lowest LWG was predicted during March. Potential LWG was restricted during summer and autumn in a study reported for a warmer location (Waikato) where diet ME values between 9-9.1 MJ kg DM⁻¹ were obtained during these seasons (Litherland et al. 2002). Although with higher ME values for the same seasons, LWG predicted with intakes of 3.2 % LW in the current study gave a lowest value of 1.15 kg LW d⁻¹ in March, which indicates that observed ME are likely to be constraining potential LWG. In addition, if any additional constraint on herbage intake may be operating under this circumstance (Allen 1996; Hodgson & Brookes 1999), a lower animal performance may be obtained. In this situation, independence between quality and intake assumed in this simple modelling exercise can be questionable.

5. Conclusions and implications

This experiment provides an indication of the magnitude and consistency of seasonal variation of the main nutritional variables in a New Zealand beef cattle finishing pasture. The results show that under adequate grazing management herbage nutritive value can be of a high standard throughout the year. However two of the most important nutrients for animal performance (ME and protein) consistently declined during summer and in the case of ME, this was extended into autumn. Modelling the influence of herbage energy on animal performance indicated that during summer and autumn ME values might be constraining a

maximum LWG, whereas spring predictions are in agreement with liveweight gains reported from field studies. Protein was considered as non-limiting in the model, but it is clear that it was in excess to that required by the animals. A more complex model including herbage intake prediction and a penalty for excess protein in the diet might provide some extra understanding. More research into feed protein fractions is needed to quantify the implications of the high level of protein reported here on rumen metabolism and animal nutrition requirements.

References

- Allen S. A. 1996: Physical constraints on voluntary intake of forages by ruminants. *Journal of Animal Science* 74:3063-3075.
- Boom C. J.; Sheath G. W. 1998: Grain supplementation of finishing beef cattle. *Proceedings of the New Zealand Society of Animal Production* 58:239-242.
- Boom C. J.; Sheath G. W. 1999: Tactical supplementation of beef finishing cattle. *Proceedings of the New Zealand Society of Animal Production* 59:162-165.
- Buxton D. R.; Fales S. L. 1994: Plant-environment and quality. In: Fahey, G. C. Jr.; Collins, M.; Mertens, D.R.; Moser, L.E. Eds. *Forage Quality, Evaluation, and Utilization*. Published by the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America. 155-199.
- Clark D. A.; Brougham R. W. 1979: Feed intake of grazing Friesian bulls. *Proceedings of the New Zealand Society of Animal Production* 39:265-274.
- Clark E. A. 1995: Maintaining forage quality by intensive management. *Proceedings of the Western Canadian Dairy Seminar* 7: 135-146.
- Cohen R.; Garden D. 1983: Relationship between botanical composition of herbage on offer and herbage eaten by grazing beef cattle. *Proceedings of the XIV International Grassland Congress* : 678-681.
- Cohen R. D. H.; Stevens J. P.; Moore A. D.; Donnelly J. R. 2003: Validating and using the GrassGro decision support tool for a mixed grass/alfalfa pasture in western Canada. *Canadian Journal of Animal Science* 82:171-182.

- Coleman S. W.; Barth K. M. 1973: Quality of diets selected by grazing animals and its relation to quality of available forage and species composition of pastures. *Journal of Animal Science* 36:754-761.
- Corson D. C.; Waghorn G. C.; Ulyatt M. J.; Lee J. 1999: NIRS: Forage analysis and livestock feeding. *Proceeding of the New Zealand Grassland Association* 61:127-132.
- Cosgrove G. P.; Betteridge K.; Thomas V. J.; Corson D. C. 1998: A sampling strategy for estimating dairy pasture quality. *Proceedings of the New Zealand Society of Animal Production* 58:25-28.
- Cosgrove G. P.; Clark D. A.; Lambert M. G. 2003: High production dairy-beef cattle grazing systems: a review of research in the Manawatu. *Proceedings of the New Zealand Grassland Association* 65:17-20.
- Coutinho B. H. 1998: The effects of grazing management on pasture and bull production over the late-autumn to early-spring period. *Thesis of Master of Applied Sci. Massey University*. 96 p.
- Coutinho B. H.; Matthews P. N. P.; Morris S. T. 1998: The effect of grazing management on pasture and animal production in late autumn to early spring in a one year bull beef grazing system. *Proceedings of the New Zealand Society of Animal Production* 58:236-238.
- Donnelly J. R.; Freer M.; Salmon L.; Moore A. D.; Simpson R. J.; Dove H.; Bolger T. P. 2002: Evolution of the GRAZPLAN decision support tools and adoption by the grazing industry in temperate Australia. *Agricultural Systems* 74:115-139.
- Earle D.; McGowan A. 1979: Evaluation and calibration of an automated rising plate meter for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* 19:337-343.
- Elizalde J. C.; Cremin J. D.; Faulkner D. B.; Merchen N. R. 1998: Performance and digestion by steers grazing tall fescue and supplemented with energy and protein. *Journal of Animal Science* 76: 1691-1701.

- Elizalde J. C.; Santini F. J. 1992: Factores nutricionales que limitan las ganancias de peso en bovinos en el período otoño-invernal. *Cerbas, INTA. Boletín Técnico Nro 104* :36 p.
- Frame H.; Warn L.; McLarty G. 2002: Effects of grazing system and phosphorus application on pasture quality. *Wool Technology and Sheep Breeding* 50:465-470.
- Freer M.; Moore A. D.; Donnely J. R. 1997: GRAZPLAN: Decision Support System for Australian grazing enterprises - II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. *Agricultural Systems* 54:77-126.
- Hodgson J. 1990: *Grazing Management: Science into Practice*. Longman Handbooks in agriculture, Longman Scientific and Technical co-published with John Wiley. New York: 203 p.
- Hodgson J.; Brookes I. M. 1999: Nutrition of grazing animals. In: White, J.& Hodgson, J. Eds. *New Zealand Pasture and Crop Science*. Oxford University press. 117-132.
- Kolver E. S. 2002: Farming for profit from fresh pasture. *Bulletin of the International Dairy Federation* 373:15-23 .
- Lambert M. G.; Litherland A. J. 2000: A practitioner's guide to pasture quality. *Proceedings of the New Zealand Grassland Association* 62:11-115.
- Litherland A. J.; Woodward S. J. R.; Stevens D. R.; Mcdougal D. B.; Boom C. J.; Knight T. L.; Lambert M. G. 2002: Seasonal variations in pasture quality on New Zealand sheep and beef farms. *Proceedings of the New Zealand Society of Animal Production* 62:138-142.
- Matthews P. N. P.; Hodgson J.; White J. G. H. 1999: Livestock farming in New Zealand. In: White, J.& Hodgson, J. Eds. *New Zealand pasture and crop science*. Oxford University press. 133-151.
- McRae A. F. 1988: Bull beef production: "Tuapaka" experience. *Proceedings of the New Zealand Grassland Association* 49:41-45.

- McRae A. F. 2003: Historical and practical aspects of profitability in commercial beef production systems. *Proceedings of the New Zealand Grassland Association* 65:29-34.
- Metson A. J.; Saunders W. 1978: Seasonal variation in chemical composition of pasture. *New Zealand Journal of Agricultural Research* 21:355-364.
- Moller S. N. 1997: An evaluation of major nutrients in dairy pasture in New Zealand and their effects on milk production and herd reproductive performance. *PhD Thesis. Massey University, Palmerston North, New Zealand* :342 p.
- Moller S. N.; Parker W. J.; Eduards N. J. 1996: Within-year variation in pasture quality has implications for dairy cow nutrition. *Proceedings of the New Zealand Grassland Association* 57:173-177.
- Moore D. A.; Varga G. 1996: BUN and MUN: urea nitrogen testing in dairy cattle . *Compendium on Continuing Education for the Practicing Veterinarian* 18:712-720.
- Moore K. J.; Hatfield R. D. 1994: Carbohydrates and forage quality. Fahey, J.R. Ed. In: *Forage Quality, Evaluation and Utilization*. 229-280.
- Nelson C. J.; Moser L. E. 1994: Plant factors affecting forage quality. In: Fahey, G. C. Jr.; Collins, M.; Mertens, D.R.; Moser, L.E. Eds. *Forage Quality, Evaluation, and Utilization*. American Society of Agronomy:115-154.
- Parker W. J.; Ulyatt, M.J. 1996: Feed quality measurement and its application to sheep and beef cattle farm management. *Proceedings of the Central Districts Sheep&Beef Cattle Farmer's Conference* 5:77-85.
- Preston R. L. 1966: Protein requirements of growing-finishing cattle and lambs. *Journal of Nutrition* 90:157-160.
- Reardon T. F. 1975: Summer feeding of beef cattle. *Proceedings of the Ruakura Farmers' Conference* 27 :14-18.
- SAS/STAT. 2001: Release. 8 SAS. *Inst. Inc., Cary, NC*.

- Saul G. R.; Kearney G. A.; Flinn P. C.; Lescun C. L. 1999: Effects of superphosphate fertiliser and stocking rate on the nutritive value of perennial ryegrass and subterranean clover herbage. *Australian Journal of Agricultural Research* 50: 537-545.
- Schlegel M. L.; Wachenheim C. J.; Benson M. E.; Ames N. K.; Rust S. R. 2000: Grazing methods and stocking rates for direct-seeded alfalfa pastures: II. Pasture quality and diet selection. *Journal of Animal Science* 78:2202-2208.
- Wheeler D. M.; Upsdell M. P. 2003: Flexi 3.0. Bayesian Smoother. *Reference Manual* :306 p.