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Effects of stocking rate and supplementation on the productivity and profitability of Argentine dairy systems

A thesis presented in partial fulfilment

of the requirements for the degree of

Master of Applied Science in Animal Production

at Massey University, Palmerston North

New Zealand

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2006

Dedicated to my beloved wife, Ana

Abstract

Dairy production in Argentina is based on grazed pastures, with the inclusion of supplements as a secondary source of feed. The average milk production per hectare in Argentine dairy farms is low and this affects the profitability of the farms. The low efficiency of production per hectare appears to be associated with low stocking rate and low utilisation of the cheapest source of feed, which is grazed pasture. Data reviewed in the present study suggested that stocking rate (SR) and the amount of imported feed are factors with significant influence on dairy farm productivity and profitability in Argentina, as is also the case in New Zealand and Australia.

Stocking rate, expressed as the number of cows per hectare, is a simplification of the relationship between feed demand and feed supply. This relationship can be better expressed as kilograms of live weight per tonne of dry matter total feed supply, defined as comparative stocking rate. The aim of this thesis was to quantify the effects of comparative SR and supplementation (imported feed) on the productivity and profitability of Argentine dairy farms.

A simulation model was developed to predict pasture dry matter (DM) intake and the harvesting efficiency of grazing dairy cows in Argentina (Chapter 3). In validation tests, using data from cows grazing lucerne in Argentina and ryegrass-clover in Ireland, the model predicted satisfactorily. Following this, a simulation model was developed to predict milksolids (MS) production and live weight (Lwt) change of Argentine Holstein cows in grazing dairy systems, given a determined intake of metabolisable energy (Chapter 4).

Finally, a whole-farm simulation model called the Argentine Dairy System Model (ADSM) was developed (Chapter 5), by integrating the models developed in Chapter 3 and 4, together with a pre-existent economic model for Argentine dairy farms. Model validation was conducted by comparing results from the model against data form eight Argentine dairy farms. The accuracy of model predictions was satisfactory.

Twenty-two dairy systems were tested with ADSM, in order to allow the effects of comparative SR and supplementation to be explored. The cow type used was the Argentine Holstein (550 kg Lwt and 6.8% MS content).

The present study suggests that the low MS production of Argentine dairy farms could be increased by increasing both comparative SR and the amount of supplements

imported into the farm. Model predictions indicated that MS production per hectare would be maximised at a comparative SR of approximately 100 kg Lwt/t DM, economic farm surplus ($US/ha) at 90 kg Lwt/t DM, and return on assets at 80 kg Lwt/t DM. Additionally, the model predicted that cows stocked at a comparative SR of about 80 kg Lwt/t DM will neither increase nor decrease Lwt change over a complete season (lactating and dry periods). These results suggest that the optimum comparative SR, in terms of both economic and sustainable physical performance for the Argentine Holstein cows seems to be around 80 kg Lwt/t DM. Annual pasture utilization values were 70%, 76%, and 81% for comparative SRs of 80, 90, and 100 kg Lwt /t DM, respectively.

At the milk payout and concentrates price used in this study, it would be profitable to increase the amount of imported feed up to 3.6 t DM per hectare, provided that SR is simultaneously increased, in order to achieve pasture utilisation of 70% or higher. A dairy system with 8.6 t DM/ha/year produced on-farm, importing 3.6 t DM concentrates per year and stocked at 81 kg Lwt/t DM (1.8 cows/ha) would be able to utilise 71% of pasture and produce 626 kg MS/ha/year, which is about two-fold the average MS production of Argentine farms. Changing either the price of milk or the cost of concentrates by 10% did not alter the relative profitability of the different systems.

Acknowledgements

I offer my thanks to the Ministry of Foreign Affairs of New Zealand for the scholarship which has made possible this thesis.

Thanks are specially given to my supervisors: Nicolás Lopez-Villalobos, Colin Holmes, Ian Brookes and Peter Kemp for their commitment to this thesis. Nicolás, I thank you for your bright and wise orientation and your constant encouragement throughout my work on this thesis. Colin, I thank you for your unconditional and enormous help and also for sharing with me ideas from your very clear mind. I have learnt a great deal about dairying from both of you but above all even more about human values.

My 'dairy friends': Matias Peluffo and Gonzalo Tuñon, I thank you for sharing your knowledge and friendship with me. Thanks to my 'family in New Zealand': Federico Riet Sapriza, Elisa Peirano, Alan and Carola Bannister, Vicky Jauregui, Gerardo and Caro Canales, Felipe and Silvana Apablaza, Norman and Marcela Russ and family, Andres and Jorgelina Patiño and family, Nicolas Lyons, Belen Lazzarini, Dario Rossi, Nacho Carnevale, Carlos and Gisela Cuadrado and family, Gareth and Susan Evans and family. Meeting all of you was one of the biggest treasures I have discovered in New Zealand.

My thanks to John Hodgson, Nicola Shadbolt, Kevin Macdonald and Yani Garcia for taking the time to read the draft of this thesis and for making valuable comments. Special thanks to Jeremy Bryant for your help.

Thanks to the outstanding people from the Massey University staff for your constant support: Allain Scott, Wendy Graham, Kathy Hamilton and Susan Flynn.

Thanks to the authorities and staff of the 'Facultad de Ciencias Agrarias de Esperanza' for their support, and help by providing me with data from Argentina. Thanks to Hugo Erbetta, Luis Ristra, Daniel Sanchez, Miguel Pilatti, June Thomas, Pablo Ghiberto, Alberto Quiñonez, Francisco Candiotti, Pedro Weidmann, Ana Maria Cursack, Maria Isabel Castigniani and many others. Muchisímas gracias.

Thanks to Jose Luis Maccari, Eduardo Comeron, Luis Romero, Brendan Horan, Jock Campbell, Luis Peluffo, Javier Zubizarreta, Guillermo Schroeder and Hugo Quatrocci for helping me to collect the data necessary for this thesis.

A massive thanks to my family back home in Argentina. Gracias viejos, hermanas suegros, cuñados, abuelos, tíos y sobrinos; gracias por su incondicional afecto, gracias por alentar mis esfuerzos!

Ana, my bright and brave wife, I thank you for being so supportive always, everywhere and for everything. Te re amo. To Francisco, my beloved son, thanks for the miracle of your life that shines on our lives. Te amo chiquitin.

I thank God, for allowing me to meet all these marvellous people in my journey.

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List of Abbreviations

Abbreviations

BCS	Body condition score
BW	Breeding worth
DM	Dry matter
DMI	Dry matter intake
EC_p	Energy concentration of pasture
EC_s	Energy concentration of supplements
EFS	Economic farm surplus
GF	Availability of green herbage
Ha	Hectare
HF	Holstein-Friesian
Kg	Kilogram
K_g	Efficiency of utilisation of metabolisable energy for live weight gain
K_l	Efficiency of utilisation of metabolisable energy for lactation
Km	Efficiency of utilisation of metabolisable energy for maintenance
K_p	Efficiency of utilisation of metabolisable energy for gestation
Lwt	Live weight
M/D	Metabolisable energy content per kilogram of feed DM
ME	Metabolisable energy
ME_l	Metabolisable energy for milk synthesis
MELwt	Metabolisable energy per kilogram of live weight change
ME_m	Metabolisable energy for maintenance
ME_p	Metabolisable energy for pregnancy
MJ	Mega joule
MS	Milk solids (milk fat plus milk protein)
MY	Milk yield
N	Nitrogen
NAHF	North American Holstein-Friesian
NDF	Neutral detergent fibre
NEL	Net energy concentration per litre of milk
NELwt	Net energy per kilogram of live weight change
NZHF	New Zealand Holstein-Friesian
OS	Overseas
P	Potential milk yield
$PotDMI_e$	Potential dry matter intake (physiological limit)
$PotDMI_r$	Potential dry matter intake (physical limit)
PPI	Potential pasture intake
PPI_e	Potential pasture intake (physiological limit)
PPI_r	Potential pasture intake (physical limit)

Abbreviations (cont.)

r	ratio of milk produced from the n^{th} MJ of NE to milk produced from the $(n-1)^{th}$ MJ of NE
R	Total ME requirements per cow per day
RAPPI	Ratio allowance: Potential pasture intake
SOL	Stage of lactation
SR	Stocking rate
t	Tonne
TMR	Total mixed rations
X	Average net energy intake above maintenance
Y	Actual milk yield (litres/day of 4% fat corrected milk)

Statistical terms

A	Actual pasture dry matter intake
P	Predicted pasture dry matter intake
MPE	Mean prediction error
MSPE	Mean-square prediction error
R^2	Coefficient of determination

Chapter 1

General Introduction

This chapter presents an overview of the Argentine dairy system, the research problem to be studied and the rationale and objectives of this thesis. More detailed introductions are given at the start of each chapter.

1.1. Introduction to Argentine dairy systems

Dairy is a major industry in Argentina. The national annual production of milk is approximately 9,300 million litres (SAGPYA, 2005). Argentina occupies the 11th and 6th position in the world ranking, in terms of milk produced and exported, respectively (AACREA, 2005).

Dairy production in Argentina is based on grazed pastures (usually lucerne), with reserves and concentrates, either produced on-farm or imported, comprising 11% and 22% of the average cow's diet, respectively (Castillo and Gallardo, 1995; Gambuzzi *et al.*, 2003). The Argentine dairy system must be based on pastures, because pastures are the cheapest source of feed, feeding is one of the main cost of production and the milk price in Argentina is one of the lowest in the world (Hemme and Deeken, 2005).

The temperate and relatively moist climate, together with naturally fertile soils, allows pasture and crops to grow all year round (Peluffo, 2005). Cows graze and calve all year round, but calving is relatively concentrated in autumn and spring (Garcia, 1997). More than 90% of the milk is produced in only three provinces: Santa Fe, Buenos Aires and Cordoba, which are the main provinces of the Pampas region (Ostrowski and Deblitz, 2003). The Pampas is a flat region of Argentina that comprises more than 50 million hectares of arable lands for crop and cattle production. Rainfall regimes vary from 700 to 1000 (Viglizzo *et al.*, 2003).

A survey of 966 Argentine dairy farms (Gambuzzi *et al.*, 2003) estimated that the average Argentine dairy farm has 147 hectares for cows (lactating and dry) and a stocking rate (SR) of 1.15 cows/hectare. The average milk production per lactation is approximately 4,208 litres of milk with 6.8% milksolids. This gives yields of 334 kg of milksolids (MS) per hectare. In the same survey, it was estimated that approximately 4,091 kg dry matter (DM) of pasture are consumed per hectare per year, which is low in comparison to grazing dairy systems in temperate countries.

1.2. Statement of the problem

In grazing dairy systems, efficiency is measured as the output of saleable product per unit of resource utilised. Milksolids are the main output and land is the main resource utilised in grazing dairy systems (Penno *et al.*, 1996). Therefore, MS production per hectare is the most sensible index to express the efficiency of grazing dairy systems. Milksolid is defined as the summation of milk protein and milkfat.

The average MS production per hectare in Argentine dairy farms is low and this affects the profitability of farms. In recent years, the number of dairy farms has decreased sharply, which was mainly due to the conversion of dairy farms to crop farms, which are 'presumably' more profitable. The low efficiency of MS production per hectare is principally a consequence of low feed intake per hectare, which results from low feed supply (pasture and supplements) and low pasture utilisation, estimated to be less than 65% (Guaita and Gallardo, 1995; Romero *et al.*, 1998).

Stocking rate is the management practice with the greatest influence on the productivity of the grazing dairy system (McMeekan, 1961; Penno, 1999). Pasture utilisation, pasture intake and MS production per hectare increases as SR increases, whilst pasture intake and MS production per cow decreases (Penno, 1999; Macdonald *et al.*, 2001). Furthermore, the effects of SR on the system performance are influenced by the inclusion of supplements. Imported supplements allows an increase in SR, whilst simultaneously maintaining reasonably high MS production per cow (Macdonald, 1999).

Stocking rate, expressed as the number of cows per hectare, is a simplification of the relationship between feed demand and feed supply. The ratio of total herd live weight (Lwt) to total feed supply is a more accurate measure of the SR relationship. This could be expressed as kg Lwt per t DM total feed supply, defined as comparative stocking rate (Penno, 1999).

The effects of comparative SR (kg Lwt/t DM) and the effects of its interaction with supplementation on the productivity and profitability of the whole-farm have not been studied in Argentina. Some studies have simulated the productivity and profitability of dairy systems with different SR (cows/ha) and feed supply, suggesting that moderated increases of SR and imported supplements would increase the productivity and profitability of the system (Comeron, 2003; Comeron and Schilder, 1997; Schneider *et* *al.*, 2003). However, in these studies, all treatments had relatively similar comparative SRs, expressed as kg Lwt/t DM of feed supply. In addition, these studies assumed predetermined values of pasture utilisation and MS production per cow, and only explored a maximum of six alternatives. Indeed, the relationship between production per animal and production per hectare as a function of comparative SR has not been studied for Argentine dairy systems.

1.3. Rationale for the study

The lack of experiments exploring the effects of SR and supplementation on the whole-farm in Argentina may be partially explained by the huge requirements of research resources necessary to test treatments with different SRs and different levels of supplementation in whole-farm trials. The complex interrelationship among a large number of factors in dairy systems makes it difficult to determine the costs and benefits of implementing management or technological alternatives. Mathematical models are increasingly being used in animal research both independently and in conjunction with experimental research (Shalloo *et al.*, 2004). Farm simulation models can make a major contribution to guiding experimental research, because they can identify critical gaps in knowledge and develop improved systems of production (Bywater and Cacho, 1994). Given the complexity of grazing systems, an interest in modelling grazing systems is not only justified, but perhaps, it also represents the only way to accommodate the complexity of the system (Dove, 1996).

Therefore, a simulation model developed for Argentine dairy farms would enable the complexity of the system to be studied. Furthermore, the results of this simulation modelling study may guide future experimental research.

1.4. Objectives

The general objective of this study was to quantify the effects of comparative SR and supplementation (feed imported) on farm productivity and profitability for Argentine dairy farms. These effects were studied with a simulation model developed to predict the DM intake per cow, MS production per cow, Lwt change per cow and economic farm performance, at different comparative SRs and levels of supplementation.

In **Chapter 2**, a review of the effects of comparative SR and supplementation on the productivity and profitability of the dairy system is provided, with a focus on whole-farm studies carried out in New Zealand and Australia.

The objective of **Chapter 3** was to develop and validate a model to predict pasture DM intake of grazing dairy cows in Argentina.

Chapter 4 presents a model to predict MS production and Lwt change of Argentine Holstein cows.

In **Chapter 5**, a model called the Argentine Dairy System Model (ADSM) was developed, by integrating the models developed in Chapter 3 and 4, together with a pre-existent economic model for Argentine dairy farms. Twenty-two dairy systems were tested with ADSM, in order to explore the effects of comparative SR and supplementation.

Finally, in **Chapter 6**, an overview of the thesis is presented, and the general results are discussed with emphasis on the whole-system.

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Chapter 2

Effects of stocking rate and supplementation on the productivity and profitability of grazing dairy systems: A review

Abstract

The effects of stocking rate (SR) and supplementation on dry matter (DM) intake, pasture utilisation, productivity per cow, per hectare and economic performance of dairy systems are reviewed. The efficiency of a grazing dairy system can be measured through its annual productivity, expressed as kilograms of milksolids per hectare. This depends strongly on the intake of DM per cow and per hectare. Herbage allowance is the factor which exerts the greatest effect on DM intake (DMI) and on the utilisation of pasture at each grazing. Stocking rate determines the average herbage allowance per cow and therefore, it is one of the factors with the most influence on the productivity and profitability of grazing dairy systems.

As SR increases, feed demand per hectare, pasture utilisation, and milk yield per hectare increases. However, there is usually an accompanied reduction in milk yield per cow, due to lower intakes per cow because of decreases in pasture allowance at the high SR. Very high SR causes further increases in pasture utilisation, but it may lead to a decrease in milk yield per hectare, because of the very high proportion of the energy consumed being used for cow maintenance. The traditional definition of stocking rate, expressed as number of cows per hectare could be improved, particularly for systems that use additional supplements, if it is expressed as kg live weight per tonne of DM offered (comparative SR). For New Zealand dairy systems, the comparative SR that seems to maximise economic performance is approximately 85 kg live weight/t DM for cows in the years 1995 to 2005.

The use of supplements can improve the productivity and profitability of dairy systems. However, milk response to supplements and the price of supplements relative to the price of milk define whether supplementation is profitable. The response to supplements depends basically on factors affecting energy partitioning of extra feed towards either milk synthesis or body weight and on the substitution effect of supplements (kilograms of pasture dry matter intake reduction per kilogram supplement consumed). The size of the deficit, between the cow actual milk yield and its potential milk production, affects both energy partitioning and substitution rate. As this relative feed deficit increases, substitution rate decreases and a higher proportion of extra energy consumed is partitioned towards milk synthesis. The relative feed deficit increases as potential feed demand increases and/or actual feed supply decreases. Stage of lactation, cow's genetic potential for milk production and body condition score (BCS) affect feed demand and

therefore, the relative feed deficit. On the other hand, pasture allowance, pasture quality, the amount of supplements offered and supplement quality are the main factors affecting feed supply. Stocking rate and dates of calving and drying-off can modify either feed supply or feed demand and they can consequently modify the feed deficit, thus, affecting the final response to supplementation.

Experiments in Australia and New Zealand have demonstrated that the inclusion of supplements, with a concomitant increase in SR, may have synergistic effects in improving the productivity and profitability of grazing dairy systems, probably through their simultaneous effects on feed supply and feed demand.

2.1. Introduction

In pastoral dairy systems, one measure of efficiency is the output of saleable product per unit of resource utilised. Milksolids (MS) are the main output and land is the main resource of grazing dairy systems (Penno *et al.*, 1996). Therefore, MS production per hectare is the most sensible index to express the efficiency of pastoral dairy systems.

In pastoral dairy systems, the efficiency of milksolids production is a function of annual pasture production, the efficiency of pasture utilisation and the efficiency of conversion of pasture into MS. The amount of MS produced from pasture per hectare can be expressed following the equation proposed by Holmes *et al.* (2002):

MS production = Pasture grown x Pasture utilisation x Feed conversion efficiency

Pasture utilisation is defined as the ratio between pasture eaten per hectare and pasture grown per hectare, whilst feed conversion efficiency is defined as the ratio between kilograms of MS produced per cow and tonnes of feed consumed per cow.

The link between the pasture and animal components of grazing dairy systems is the stocking rate (SR), traditionally defined as the number of animals per unit of area for a period of time, usually one year (Hodgson, 1990). Stocking rate can influence all three components of productivity in the pastoral dairy system: pasture growth, pasture utilisation and feed conversion efficiency, the latter through its effect on the level of feeding of the herd and consequently on milk production (Holmes *et al.*, 2002).

At a low SR, cows are fed generously and produce more MS per cow than at a high SR. However, more pasture is wasted (not eaten) and therefore, MS yield per hectare is lower. In contrast, at a higher SR, more pasture is eaten per hectare and less is wasted, MS yield per cow is lower and cows are predisposed to lose more live weight (Lwt), but MS yield per hectare tends to be higher (Bryant *et al.*, 2003).

Maximising the efficiency of feed utilisation requires a high proportion of the available pasture to be harvested at each grazing. The herd will graze harder, as cows become increasingly underfed relative to their feed requirements. Therefore, achieving high levels of feed utilisation requires the feed demand of the herd to be in excess of the actual feed supply. The balance between feed supply and feed demand is crucially important in dairy systems worldwide (Bryant *et al.*, 2003). The SR is the single most important decision which influences productivity, because it affects the balance between feed supply and feed demand in the farm (Holmes *et al.*, 2002). It has been stated that "no more powerful force exists for good or evil than the control of stocking rate in grassland farming" (McMeekan, 1961).

The inclusion of supplementary feeds should balance the dual objective of adequate feeding, in order to achieve high levels of efficiency of milk production per cow, whilst enabling a high SR to achieve high levels of pasture utilisation, to meet the overall objective of optimising farm profitability (Penno, 1999). The present review deals with the effects of SR and supplementation on dairy system's performance and it is based mainly on data from whole-farm trials in New Zealand and Australia. Data from Argentina, Ireland, France, The Netherlands, the United States and the United Kingdom is also included. This review is focused on the whole system, rather than on the individual cow.

2.2. Factors affecting herbage intake at grazing

Herbage intake per cow and per hectare is closely associated with dairy farm productivity and profitability. Therefore, the main factors affecting herbage intake need to be understood before discussing the effects of SR and supplementation on dairy farm productivity and profitability.

Factors affecting pasture intake by grazing animals can be broadly classified as nutritional and non-nutritional. Nutritional factors are related to the rumen fill effect and the physiological energy demand of the animal. Non-nutritional factors affect the rate of intake through effects on diet selection, grazing time, bite weight and rate of biting. Pasture allowance (defined as the amount of pasture allocated to livestock, usually expressed as kilogram of DM per cow per day) is the factor determining whether nutritional or non-nutritional factors are more important (Poppi *et al.*, 1987).

Non-nutritional factors appear to be the most important limiting factors of intake at low pasture allowances. At high levels of pasture allowance, the relationship between allowance and intake becomes asymptotic and nutritional factors become the most important in limiting intake (Figure 2.1a). At this stage, pasture quality and the metabolic demands of the animal appear to be controlling intake through two basic mechanisms: rumen fill and metabolic regulation of intake (Poppi *et al.*, 1987).

Daily herbage intake can be considered as the product of bite weight, biting rate and grazing time (Allden and Whittaker, 1970). Bite weight (or intake per bite) has been identified as one of the basic determinants of daily pasture DM intake (DMI). Sward height has been shown to be the main factor influencing bite weight through its impact on bite depth, with greater bite weight in taller swards (Griffiths *et al.*, 2003; McGilloway *et al.*, 1999).

Animal and sward factors can affect the rate of intake (non-nutritional regulation) and/or the upper limit to the intake of grazing cows (nutritional regulation). Demment *et al.* (1995) described energy demand and body size as the main animal factors and pasture allowance, pasture species and stage of growth, season, water content and sward biomass as the main sward factors influencing herbage intake.

2.2.1. Herbage allowance

The effects of herbage allowance on herbage intake have been widely studied. The relationship between herbage allowance and herbage intake is essentially asymptotic. Herbage intake increases as herbage allowance increases, reaching a plateau determined by nutritional factors, which is reached at different pasture allowances, according to different studies (Leaver, 1985).

As suggested in a recent review (Bargo *et al.*, 2003), it is unclear what pasture allowance is required to maximize DMI. Leaver (1985) reported that experiments investigating the response curve of herbage intake to pasture allowance, showed maximum DMI at 45-55 g DM/kg Lwt (27-33 kg DM/cow/day for a 600 kg cow), although many other studies have found maximum DMI at much higher herbage allowances.

Thus, in Australian experiments with ryegrass-clover pastures, it was found that DMI increased up to allowances of 90 kg DM/cow/d (600 kg Lwt cow) (Doyle *et al.*, 1996), and 70 kg DM/cow/d (Dalley *et al.*, 1999). Similarly Wales *et al.* (1999) reported that pasture DMI increased up to pasture allowance of 70 kg MD/cow/day.

Based on data from New Zealand and United Kingdom, Hodgson and White (2000) suggested that a plateau at an allowance of 10-12% of Lwt is reached in ryegrass-clover pastures (60 to 72 kg DM for a 600 kg cow). For cows grazing orchard grass pastures, Bargo *et al.* (2002) found in the United States of America that pasture DMI increased from 17.5 to 20.6 as pasture allowance increased from 25 to 40 kg DM/cow/day.

Variations in the herbage allowance at which the maximum intake is achieved may be attributed to the different techniques employed to measure herbage intake (Demment *et al.*, 1995; Leaver, 1985). Furthermore, the height of herbage cutting, above which herbage allowance is expressed, is an essential factor influencing the relationship between herbage allowance and herbage intake. Herbage allowance is commonly measured above ground level in some countries, such as New Zealand and Australia, but it is usually measured at 4 or 5 cm above ground level in countries such as Argentina and Ireland (Romero *et al.*, 1995b). In ryegrass-clover pastures, herbage masses between 1000 and 2000 kg DM/ha may be measured below 4 cm ground level (Hodgson and White, 2000). This factor is not always taken into account in comparisons of the effect of herbage allowance on herbage intake between different experiments, but it will be accounted for in this thesis.

The relationship between herbage allowance and herbage intake is plotted in Figure 2.1b, using an equation reported by Bargo *et al.* (2003), which was derived from the analysis of seven studies for grazing cows fed sole pasture (Bargo *et al.*, 2002; Dalley *et al.*, 1999; Dalley *et al.*, 2001; Delaby *et al.*, 2001; Peyraud *et al.*, 1996; Stockdale, 2000a; Wales *et al.*, 2001). In those experiments, pasture allowance was measured above ground level. This equation predicts that maximum pasture DMI (21.9 kg DM/cow/day) is reached at 110 kg DM/cow/day of pasture allowance and that DMI increased by 0.26 kg/kg of increase in pasture allowance (Bargo *et al.*, 2003). Based on these results, it was concluded that maximum DMI may be achieved at pasture allowance of three to five times the expected pasture DMI (Ryegrass-based pastures).

For dairy cows grazing lucerne in Argentina, Romero *et al.* (1995b) and Castro *et al.* (1993) suggested that DMI increased up to pasture allowance of 55-60 g DM/kg Lwt (33 to 36 kg DM/cow for a 600 kg cow), which is about 1.75 to 2 times the expected pasture DMI. However, Castillo and Gallardo (1998) suggested that DMI increased up to pasture allowances of 7.5% Lwt (45 kg DM/ cow for a 550 kg Lwt cow) for cows grazing lucerne in Argentina. All measured at 4 cm above ground level.

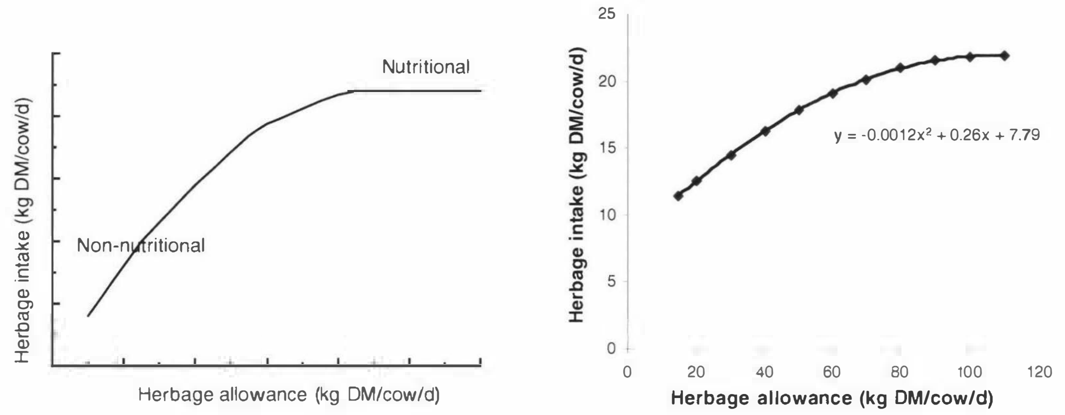

Figure 2.1: Relationship between herbage allowance and herbage intake. (a) Schematic representation (Poppi *et al.*, 1987). (b) Empirical equation reported by Bargo *et al.* (2003), derived from the analysis of seven studies for dairy cows grazing on pastures as sole feed.

2.2.2. Energy demand

The overall energy requirements of the animal affects herbage intake at grazing. Intake is increased in lactating cows, when compared to dry cows (Demment *et al.*, 1995). Furthermore, intake is increased as the stage of lactation progresses after parturition, until it reaches a plateau; then it decreases slowly. This is related to changes in the potential of milk production and the rumen capacity as lactation progresses. As the potential for milk production and the energy concentration of the milk increases, the demand for energy increases, so herbage intake increases (Holmes *et al.*, 2002).

The genetic potential for milk production affects herbage intake. Cows which are genetically capable of producing large quantities of milk usually eat larger quantities of feed than low genetic merit cows (for milk production) of the same size and physiological state. Differences of 20 to 30% in milk production for similar cows (except potential for milk production) have been associated with differences of 5 to 15% in intake (Holmes *et al.*, 2002).

2.2.3. Body size (live weight)

Large cows consume more than small cows in order to meet the increased maintenance demands of a larger tissue mass (Hodgson & White, 2000). Animals decrease grazing time and biting rate as size increases. However, as body size increases, bite weight increases at a rate which enables daily intake to be increased (Demment *et al.*, 1995).

2.2.4. Forage species and stage of plant maturity

The species and stage of maturity of plants can affect cow intake, mainly through the effects of the concentration of neutral detergent fibre (NDF), which may differ among species with the same digestibility and which increases as the stage of maturity increases (Demment *et al.*, 1995). Neutral detergent fibre is a parameter of the plant which is highly correlated to the space-occupying or fill effect of the diet in the animal (Mertens, 1987).

At a common digestibility, intake of legumes is greater than that of grasses and within grasses considerable variability exists (Demment *et al.*, 1995). Herbage intake decreases as the stage of maturity advances, due to increases in NDF and decreases in bite dimensions that affect the instantaneous intake rate (Demment *et al.*, 1995; Prache and Peyraud, 2001). Neutral detergent fibre can indirectly reflect non-nutritional factors such as the amount of green or dead material present in a sward (higher NDF in dead material) and the breaking strength of plant material. These non-nutritional factors, related to NDF, may limit bite weight and consequently daily intake. Thus, NDF may influence herbage intake as a non-nutritional factor at low pasture allowances (affecting ingestion) and as a nutritional factor (affecting digestion) at high pasture allowances.

2.2.5. Herbage mass

Herbage mass influences DMI, primarily by altering pasture height and pasture density, which are both components of sward structure. This influences the ability of the cow to prehend the pasture and hence, the rate of pasture intake and daily intake (Poppi *et al.*, 1987). Higher herbage mass is usually associated with higher sward heights.

Dry matter intake by set stocked cows is strongly influenced by the height, or mass, of the pasture on which they are grazing. However, for rotationally grazed cows, DMI was not affected consistently by the height of pasture or herbage mass, in a range of 2 to 4 t DM/ha, measured above ground level (Holmes, 1987).

Herbage mass is associated with the composition of the pasture (higher mass, lower digestibility) and this may confound the effects of herbage mass on DMI. It was found that at a common value for pasture allowance, DMI is about 20% lower in summer than in spring, for cows grazing ryegrass-clover pastures in New Zealand. It seems probable that the seasonal differences in pasture composition can explain the difference in DMI. Pastures generally contain a lower percentage of leaf and a higher percentage of stem and dead material in summer than in winter and spring and this could cause lower DMI in summer than in winter and spring (Holmes, 1987).

2.2.6. Season

It was found that herbage intake of grazing dairy cows in autumn was 19% lower than in spring, at the same digestibility of herbage. It is likely that, as the season progresses (for spring calving systems), dead material in the sward increases, thus, leading to lower intake per bite and finally lower daily DMI (Holmes, 1987).

2.2.7. Water content in the sward

The water content of fresh herbage includes both the internal and surface water. Studies with housed cows showed that herbage intake decreased by 1 kg per 4% fall in DM content under a critical value of 18%. This reduction may arise from the physical limitation caused by the excess of water in the rumen. Dry matter intake would be reduced for high producing dairy cows grazing sward with a DM content lower than 14-15% (Demment *et al.*, 1995).

2.3. Feed supply and feed demand

At the farm level, annual herbage intake reflects the balance between feed supply and feed demand. Feed supply is determined by the total pasture (or crop) grown on-farm, the total amount of imported feed and the total feed offered to cows through grazing-off. Pasture grown on-farm is the main source of feed in grazing dairy systems. On the other hand, feed demand is determined by the number of cows and their requirements, basically determined by their Lwt and their milk yields. Calving and drying-off dates influence the distribution of feed demand over the year, and also total demand, via effects on days in milk.

2.4. Effects of stocking rate on farm productivity

Stocking rate is recognized as one of the most powerful management tools available for dairy farmers in pastoral systems, allowing them to regulate the amount of feed available for animals throughout the year (McMeekan, 1961; White, 1987; Wright and Pringle, 1983). The influences of SR on herbage intake are mediated through its effects on herbage allowance (Leaver, 1985).

For a given pasture production per hectare per year, SR indirectly affects the amount of pasture allowed per cow, given that increases in the number of cows reduces the amount of pasture available per cow. Inevitably, pasture allowance (averaged over the whole year) decreases as SR increases (Holmes, 1987). Therefore, SR influences MS production per cow and per hectare, through its effects on DMI.

In addition, SR may influence pasture growth rate and pasture quality. Pasture growth rate depends on herbage mass and the stage of maturity of plant tissue, amongst other factors. Stocking rate affects the level of pasture defoliation and different levels of defoliation affect pasture growth rates and pasture quality.

2.4.1. Comparative Stocking rate

Stocking rate, expressed as the number of cows per hectare, is a simplification of the relationship between feed demand and feed supply. The number of cows gives a measure of the annual feed demand, whilst a hectare provides a measure of the amount of feed (pasture) available. Herd Lwt would provide a better measure of the potential feed demand than the number of cows, because Lwt is highly correlated to the maintenance requirements of the cow and to potential milk yield. On the other hand, the total amount of feed provided rather than the area farmed gives a more accurate quantification of feed supply. This suggests that a ratio of total herd Lwt to total feed supply is a more useful measure of the SR relationship. This can be expressed as kg Lwt per tonne of DM total feed supply, an expression known as comparative SR (Penno, 1999).

A further improvement could be achieved by considering not only the quantity of feed, but also its quality. Although Lwt is an improved expression of feed demand in comparison to the number of cows, it is still not expressing the feed demand accurately, because it does not consider the effect of genetic potential for milk yield of the cows on feed demand (Holmes *et al.*, 2002).

2.4.2. Effects of stocking rate on individual and per hectare performance

A general overview of the effects of SR on pasture production, pasture utilisation, energy partitioning and productivity can be illustrated with data from a New Zealand study that investigated the effects of SR on dairy farm efficiency (Macdonald *et al.*, 2001). This was a two-year study designed to determine the efficiency of MS production when annual DMI and subsequently, MS production are increased within a whole-farm system. Five treatments were created by stocking five farmlet systems with a different number of cows on an only-pasture based system. Details of this experiment are shown in Table 2.1.

Comparative SR in this experiment was calculated considering the initial Lwt of cows (500 kg) and expected pasture production of 18 t DM/ha. However, it should be noted that as the trial progressed, pasture production and Lwt differed between farmlets. If the actual values of Lwt and pasture production were used to calculate comparative SR, then the values would differ slightly from those presented in Table 2.1.

Table 2.1: The effects of comparative SR on pasture production and utilisation, lactation length, MS production per cow and per hectare, using Holstein-Friesian cows with an initial Lwt of 500 kg/cow in pasture-only systems. Results from Macdonald *et al.* (2001).

Target kg Lwt/t DM	62	76	90	103	120
Stocking rate (cows/ha)	2.2	2.7	3.2	3.7	4.2
Net herbage accum.(t DM/ha/year)	17.5	17.9	18.8	18.3	19.8
Pasture quality (MJ ME/kgDM)	11.3	11.4	11.5	11.6	11.6
Pasture utilisation (%)	64	70	72	81	81
Days in milk	296	278	260	238	222
Milk yield (kg MS/cow)	435	380	353	309	274
Milk yield (kg MS/ha)	967	1043	1105	1145	1168
Feed conversion eff. (kg MS/ t DM eaten)	86	83	81	77	73
Live weight (kg/cow - end of the trial)	489	475	472	467	448
Economic farm surplus (NZ$/ha)	2884	2960	3054	2940	2751

As SR was increased, net herbage accumulation, herbage utilisation and herbage quality increased, resulting in an increase of MS production per hectare. However, performance per cow deteriorated as SR increased. Thus, the days in lactation were reduced, MS production per cow was decreased and Lwt loss increased. The effects of SR on MS production per cow and per hectare are shown in Figure 2.2. The highest Lwt loss at high SR may have a negative impact on the reproductive performance of cows (Macdonald *et al.*, 2001).

Although production of MS per cow decreased by 37 % as comparative SR increased from 62 to 120 kg Lwt/t DM, the productivity per hectare increased continuously by 21 % from 62 to 120 kg Lwt/t DM. The increase in MS production per hectare is the result of higher net herbage accumulation, higher energy content in the pasture, more cows per hectare and higher pasture utilisation (Table 2.1).

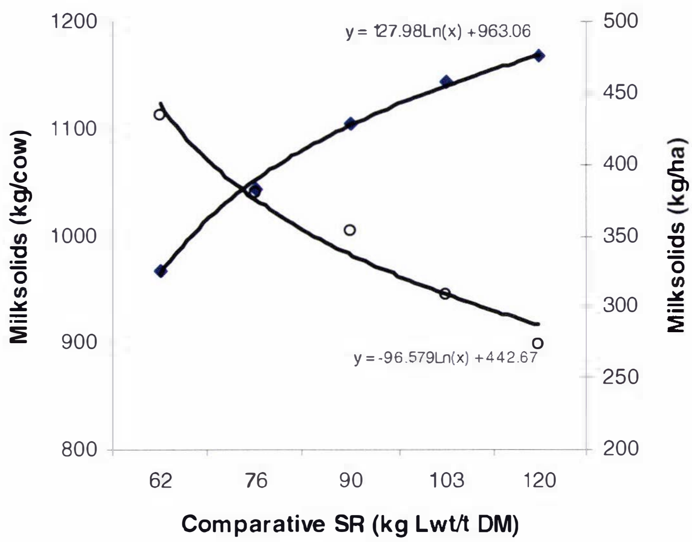

Figure 2.2: The effects of comparative stocking rate on MS production per cow (○) and per hectare (●). Redrawn from Macdonald *et al.* (2001).

Figure 2.3 shows the amount and the fate of the metabolisable energy (ME) supplied from pasture per hectare per year. As comparative SR increased, pasture utilisation increased, so a decreasing proportion of the energy produced from pasture was wasted in the form of pasture not eaten. The amount of energy used for MS production per hectare per year increased as comparative SR increased. Energy costs for maintenance increased as the system progressed from low to high comparative SR. This was the result of more cows per hectare producing less MS per cow.

Therefore, as the system progressed from low to high comparative SR, feed conversion efficiency decreased from 86 to 73 kg MS/ t DM eaten (Table 2.1). The efficiency of energy utilisation within the cow, measured as ME retained in milk as a percentage of the ME eaten, decreased from 52% to 42% as SR increased from 2.2 to 4.2 cows/ha.

The amount of energy required by the cow for maintenance, growth and pregnancy are almost independent of milk yield and it is met before the requirements of milk production. Therefore, as the MS yield of a cow increases, the proportion of feed eaten that is used for milk production also increases, thus making the cow more efficient (Penno, 1999).

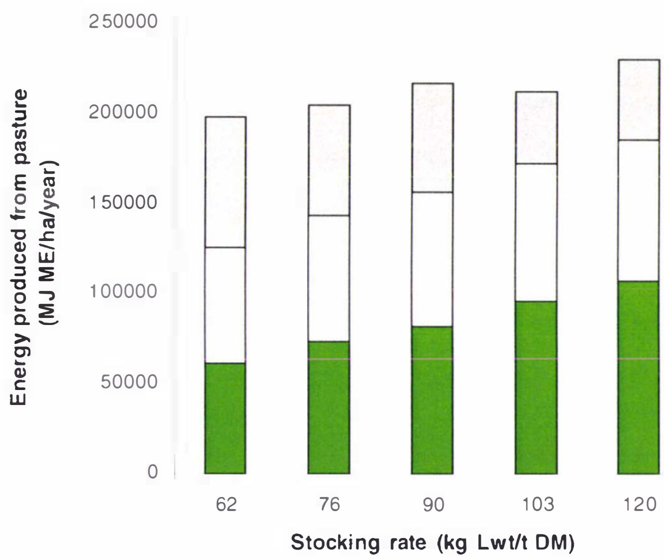

Figure 2.3: Fate of the metabolisable energy (ME) supplied from net herbage accumulation in a pasture-only system. Data from Macdonald *et al.* (2001), assuming that 67 MJ ME were retained per kg MS synthesised. The entire bar represents the amount of ME produced from pasture per hectare per year; (■) ME not consumed; (□) ME consumed and converted into milk and (■) ME used for cows' maintenance.

As comparative SR increases, there is a point at which the reduction in the efficiency of production per animal is more important than the increase in efficiency of pasture utilisation. From this point on, MS production per hectare starts to decrease (Penno, 1999). However, the reduction in MS production per hectare was not observed in the experiment described in Table 2.1 and Figure 2.2. Possibly, a higher comparative SR should have been tested in this experiment in order to find a reduction in MS per hectare at high comparative SR.

The effects of SR on MS production per cow and per hectare, reported in experiments carried out in Australia and New Zealand between 1958 and 1980, were summarised by Holmes and McMillan (1982). They found that production per cow decreased and production per hectare increased as SR increased. The mean values for the changes in production per cow and per ha, caused by one unit increase in SR (cow/ha), were - 17.7 kg milkfat/cow and + 69.8 kg milkfat/ha. Stocking rate varied from 2.2 to 5.6 cows per hectare in these experiments.

The same trends were observed in a review of trials conducted in the period 1958-1999 in New Zealand and Victoria (Australia) and designed to explore the effect of SR on MS production per cow and per ha (Penno, 1999). However, in earlier trials (before 1980) the reduction in MS production per cow was always less important than the effect of the increase in cows per hectare and consequently, MS production per hectare increased as SR increased. It is interesting to note that increasing SR always resulted in increased productivity per hectare in trials carried up to 1980. However, in experiments published since 1980, only 3 out of 16 comparisons have resulted in an increased productivity per hectare as SR increased. Furthermore, in recent years, high SRs have sometimes resulted in a reduction in overall farm efficiency. This may be explained by the fact that the range of SR explored in early experiments (before 1980) was lower than the range explored in recent experiments (after 1980). Indeed, the average lowest SR treatments were 3.1 and 3.8 and the highest SR treatments 4.2 and 4.7 for earlier and recent experiments, respectively.

Another reason which explains the different findings between earlier and recent experiments may be that cows used in earlier experiments presented lower genetic merit (and lower Lwt) than cows used in recent experiments and therefore, lower feed demand. Thus, the increment in feed demand, resulting from the increase of 1 cow per hectare, would have been higher in the more recent experiments.

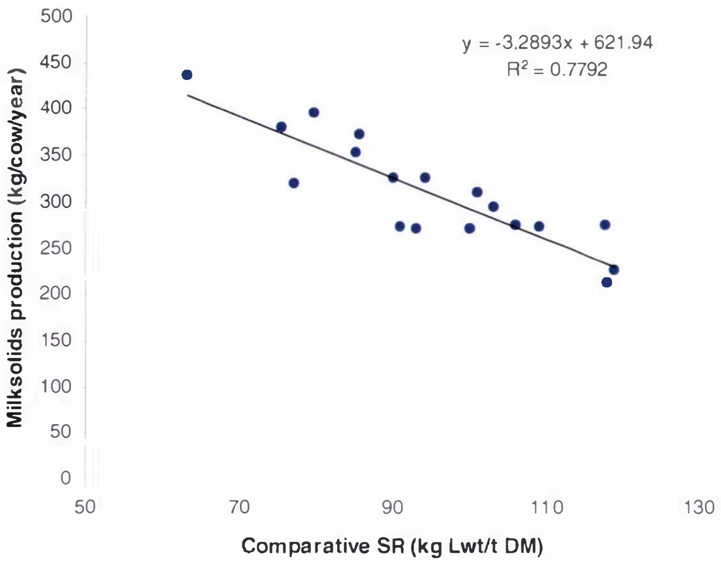

Figure 2.4: Effect of SR on MS yield per cow. Data from New Zealand experiments (Macdonald, 1999b; McGrath *et al.*, 1998; Thomson, N. A. *et al.*, 1988; Thomson, N.A. *et al.*, 1989), redrawn from Penno (1999).

2.4.3. Effects of stocking rate on pasture production

Perennial plants species present a complex pattern of production, in which the growth of new tissue and the loss of mature tissue to senescence and decomposition occur in parallel (Hodgson and White, 2000). The pattern of tissue turnover associated with different herbage allowances can be observed in Figure 2.5. Data for Figure 2.5 were obtained from rotationally grazed swards (ryegrass-clover) managed with different SRs (Hodgson, 1990). Low herbage allowances are the result of high SR, whereas high herbage allowance throughout the year results from low SR.

The relatively high herbage allowance which must be maintained to ensure high herbage growth rates, inevitably results in high senescence losses. The highest rate of net herbage accumulation is unlikely to be achieved, either by a management which maximises growth rate or by one which minimises the rate of loss (Figure 2.5).

Very high SR (low allowance) may create defoliation so intense, or so frequent, with subsequent low herbage mass (Korte *et al.*, 1987). The resultant reduction in leaf area can result in reduced interception of solar radiation and reduced herbage accumulation. The carbohydrate reserves in the roots and crowns of plants may also be reduced (White, 1987). Pasture growth rates are often reduced at very high SR (figure 2.5).

However, the quality of the pasture will be increased because the proportion of new tissues will be greater (Korte *et al.*, 1987).

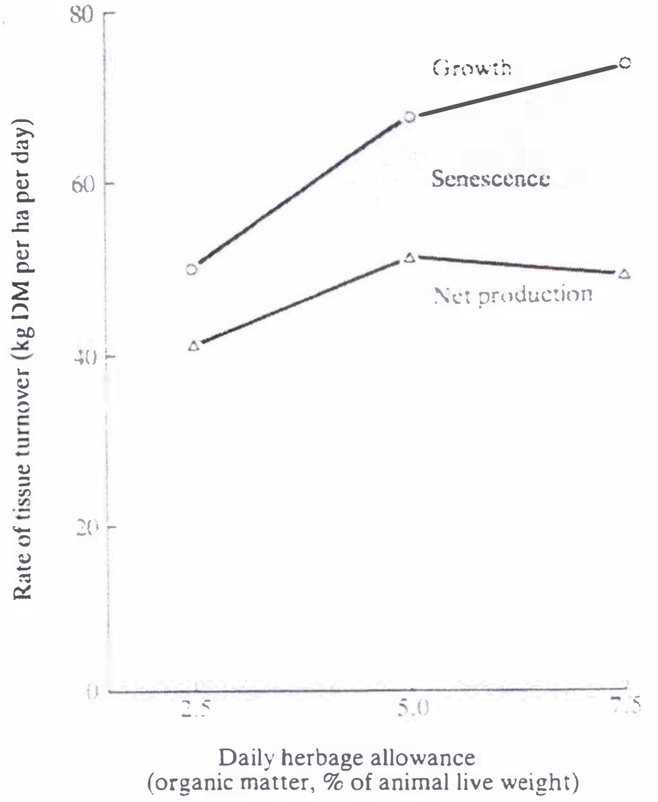

Figure 2.5: The influence of herbage allowance on rates of herbage growth, senescence and net production on rotationally grazed swards (Hodgson, 1990).

Alternatively, lax or infrequent defoliation, associated with low SR, may create pastures with very high herbage mass, thus, causing high senescence losses and reducing the rate of net herbage accumulation in tall swards (Korte *et al.*, 1987). Between these extremes of herbage mass, net growth rates are usually not greatly affected by SR (White, 1987).

The experiment of Macdonald *et al.* (2001) showed that as SR increased from 2.2 to 4.3 cows/ha, net herbage accumulation increased (Table 2.1). It is possible that, in this experiment, the higher SR was not so extreme and therefore it allowed pastures to stay closer to their optimum herbage mass. Stockdale and King (1980) reported a decrease in herbage accumulation of irrigated ryegrass pastures in Australia, as SR increased from 4.4 to 8.6 cows per hectare. Herbage accumulation decreased as a result of the excessively high pressure exerted on pasture by the high SRs tested in this latter experiment.

Comeron *et al.* (1997) studied the effect of SR on lucerne pastures production and persistency under rotational grazing. The main characteristics and results of their study are shown in Table 2.2.

Table 2.2: Characteristics and results of a study investigating the effects of SR on the production and persistency of lucerne in Argentina (Comeron *et al.*, 1997).

Treatment	High SR	Medium SR	Low SR
Stocking rate (cows/ha)	4.21	1.61	1.08
Total herbage accumulation (kg DM/ha)[1]	30,068	35,026	34,850
Annual herbage accumulation (kg DM/ha)	13,363	15,567	15,488
Plant density (plants/m2)	35	42	45
Root weight (g DM/plant)	7.45	8.35	10.35

[1]Total accumulation from April 1994 to July 1996.

Pasture production and plant density were lower for the high SR treatment than in the other treatments ($P<0.05$). Final root weight was higher for the low SR in comparison with the other treatments. As suggested by the authors, this study did not identified the SR at which pasture production and persistency decreases, given that there was no treatment with a SR intermediate between 1.61 and 4.21. However, it is clear that very high SR has a negative impact on lucerne pastures production and persistency, whereas there were no differences in pasture production between the two lower SRs.

Both ryegrass-clover and lucerne based pastures seem to be adversely affected by excessively high SR, through reductions in net herbage accumulation and depletion of non-structural carbohydrates reserves.

2.4.4. Effects of stocking rate on pasture quality

Stocking rate can also influence the nutritive value of pastures. The digestibility and crude protein concentration of herbage can be increased by increasing SR in ryegrass-clover pastures (Holmes and McMillan, 1982). Metabolisable energy per kilogram of DM (which is associated with digestibility) increased as SR increased (Table 2.1). This is a consequence of lower herbage mass, which is associated with a higher proportion of new tissue in ryegrass-clover pastures. Differences in botanical composition may develop as SR increases. At a higher SR, an increment in the content of clover in the pastures is frequently found (Holmes and McMillan, 1982).

Herbage accumulation rates were measured on rotationally grazing ryegrass-clover pastures at two SRs (2.8 and 4.3 cows/ha); and at three levels of defoliation: hard, moderated and lax, in an experiment performed by L'Huillier (1987). High SR resulted in swards with higher tiller densities, higher content of clover, lower herbage mass and lower content of dead material, than swards grazed with low SR. The rate of total herbage accumulation was significantly greater in lax than in hard-grazed swards.

On the other hand, in legume based pastures, i.e. lucerne, as SR increases, a double effect take place. Firstly, similar to the events in ryegrass-based pastures, cows at high SR keep pastures in earlier stage of maturity, resulting in pastures with higher quality. Secondly, at higher SR, harvesting efficiency increases and consequently, cows graze lower layers of the pasture, which have markedly lower nutritive value than higher layers, basically due to a higher proportion of stem and a lower proportion of leaves (Romero *et al.*, 1995a).

2.4.5. Effects of stocking rate on the economic farm performance

The SR that gives the greatest production per hectare (SR_{max}) is not the one of ultimate interest. The most useful SR is that which gives the maximum profitability per ha. This SR is called optimum SR (SR_{opt}) and it is the SR at which the difference between incomes and costs is maximised, as shown in Figure 2.6 (Wright and Pringle, 1983). The critical SR (SR_{crit}) is that above which the MS production per cow starts to decline progressively. The SR_{opt} lies between SR_{crit} and SR_{max}. In practical terms, this means that some depression in per cow performance is required in order to farm with economic efficiency (McMeekan, 1961; Wright and Pringle, 1983).

These principles can be illustrated through the results of the trial performed by Macdonald, *et al.* (2001) shown in Table 2.1. The maximum economic farm surplus (EFS) occurred at a comparative SR of 90 kg LW/t DM. At lower SR, the effect of low pasture utilisation was more important than the benefit of higher MS production per cow, in terms of economic benefit. At the other extreme, at higher SR, the benefit of higher pasture utilisation was not enough to compensate for the diminished feed conversion efficiency of the cows. Additionally, total farm costs increase at higher SR, because each extra cow requires expenditure on labour, health and production (Holmes *et al.*, 2002).

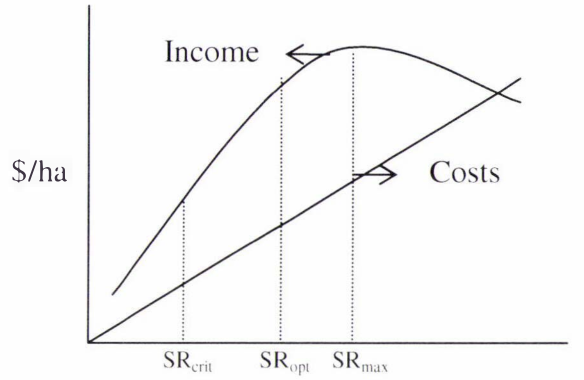

Figure 2.6: The stocking rate for maximum gross margin per hectare. Redrawn from Wright and Pringle (1983).

Stocking rate for maximum economic performance of Holstein-Friesian (HF) and Jersey cows were predicted for New Zealand conditions by Penno (1999), based on previous New Zealand trials (Ahlborn and Bryant, 1992; McGrath *et al.*, 1998). For a dairy farm producing 16 t DM/ha/year, the SRs (cows/ha) that maximised EFS were 3.61 and 2.73 cows per ha for Jersey and HF cows, respectively. These SR are equivalent to 84 and 85 kg Lwt/t DM for Jersey and HF cows, respectively.

Using the Equation plotted in Figure 2.2, it was calculated that as SR progresses from 60 (low SR) to 85 kg Lwt/ t DM (optimum SR) a reduction of 20 % in individual MS production occurs (from 425 to 342 kg MS/cow). The equation shown in Figure 2.4 predicts a reduction of 16 % in MS/cow, as comparative SR increase from 60 to 85 kg Lwt. However, to maximise MS production per hectare, much higher reductions in individual performance were reported. Penno (1999) found that MS production per hectare appeared to be maximised at a SR equivalent to 105 kg Lwt/t DM. Equations from Figure 2.2 and 2.4 predict a reduction on individual performance of 30% and 35% respectively, as SR changes from 60 to 105 kg Lwt/t DM.

These reductions in the individual performance of dairy cows, at maximum yield per hectare, are greater than that reported for beef cattle. The long-term effects of changes in SR on individual animal performance for growing cattle were reviewed by Jones and Sandland (1974). They reported that individual animal performance declined linearly with increasing SR, reflecting reductions in herbage intake. They concluded that with growing beef cattle, Lwt gain per hectare was maximised after a reduction of 24 % in individual animal performance, relative to the maximum achievable at low SR.

2.4.6. Effects of stocking rate on reproductive performance

Higher SR results in lower levels of feeding per cow. The adverse effects of low nutrition on reproductive performance may be important at very high SR (McGowan, 1981).

The effects of SR on postpartum anoestrous were studied on grazing dairy cows by McDougall *et al.* (1995). Two levels of SR were used with either HF (3.0 and 4.0 cows/ha) or Jersey (3.5 and 4.5 cows/ha) cows. The high SR herds finished the trial with a reduced BCS, Lwt and milk production compared to the low SR herds. In this experiment, increases in SR were associated with reductions in individual intake and with longer periods of postpartum anoestrus. Body condition score and MS production were inversely related to the interval calving-postpartum ovulation. Holstein-Friesian cows had longer intervals from calving to first postpartum ovulation than Jersey cows, for both SR. This study suggested that HF cows may be more sensitive to the effects of nutritional restriction (indirectly SR) on the resumption of cyclic activity than Jerseys and that partition of nutrients may differ between the breeds (McDougall *et al.*, 1995).

2.4.7. Interactions between stocking rate and Holstein-Friesian strains

A trial carried out at Dexcel (New Zealand) compared HF genetics from modern New Zealand cows (NZ 90s) with New Zealand cows from the 1970s (NZ 70s) and with 1990s North American HF (NA 90s) (Kolver *et al.*, 2004). Cows were tested under a seasonal calving system. Annual feed allowances ranged from 4.5 t DM/cow (only pasture) to 7.0 t DM/cow (pasture, maize silage and maize grain). Cows were dried-off at specified values for BCS. NZ 90s and NA 90s had similar breeding worth (BW). The BW is an economic index that measures net farm income per 4.5 t of pasture DM consumed. The BW is calculated as the sum of the breeding values for Lwt, somatic cell score, longevity and lactation yields of milk, fat and protein, each weighted by an economic value (Harris, 2005).

Since NA 90s lost more BCS during lactation, they were dried-off earlier and consequently, had less days in milk (Table 2.3)

Table 2.3: Average daily MS production and days in milk of 1990s high breeding worth New Zealand and overseas HF (NZ 90s and NA 90s), and low breeding worth 1970s New Zealand HF (NZ 70s) for 2002/2003 (Kolver *et al.*, 2004).

Feed allowance	NZ 70s	NZ 90s	NA 90s	NZ 70s	NZ 90s	NA 90s
(t DM/cow/year)	Milk yield (MS/lactation)			Days in milk		
4.5	311			259		
5.0		365			243	
5.5	364	398	355	276	257	232
6.0	357	433	371	290	283	244
6.5		474	415		284	258
7.0			428			256

According to these results, the last thirty years of selective breeding in New Zealand dairy herds has significantly improved the type of cow. Modern NZHF cows (NZ 90s) produced more MS and generated $539 extra EFS than NZ 70s in the season 2002/2003 across all the systems tested (Table 2.3) (Kolver *et al.*, 2004).

Under the conditions of this trial, NZ 90s produced more MS than NA 90s and generated an extra $435 EFS across all the pasture-based systems evaluated (Table 2.3). The largest penalty against NA 90s' performance resulted from the earlier dry-off date due to low BCS. Milking on for longer, drying off at a low BCS and then feeding at high levels during the dry period in order to regain BCS may allow NA 90s cows to perform better in pasture-based systems. However, this means that the NA 90s will require more imported feed during the dry period in order to achieve the desired calving condition (Kolver *et al.*, 2004).

Figure 2.7 shows that, at the same comparative SR, strains performed differently but the NZ 90s always had higher EFS per hectare than either NA 90s or NZ 70s. It is also clear that the highest EFS per hectare for each strain occurred at different feeding levels. EFS per hectare was maximised at a SR of 92 kg Lwt/t DM (5.5 t DM/cow) for NZ 70s cows, 85 kg Lwt/t DM (6 t DM/cow) for NZ 90s and at 85 kg Lwt/t DM (6.5 t DM/cow) for NA 90s. This shows that the NA 90s required more feed and more supplementary feed in the form of maize silage and maize grain, in order to generate profits comparable with NZ 90s cows and NZ 70s cows which required minimal levels of supplements to maximise profits.

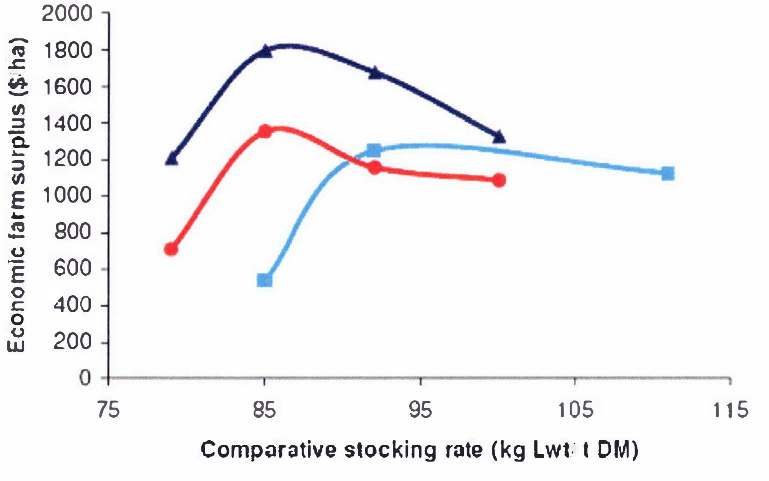

Figure 2.7: Economic farm surplus per hectare of high breeding worth (—▲—) New Zealand HF (NZ90s), (—●—) North American HF (NA 90s), and low breeding worth (—■—) New Zealand HF (NZ70s) farmed in systems ranging from all-grass (high SR) to high input (low SR). Data from (2002/2003) at a $3.60/kg MS payout (Kolver *et al.*, 2004).

The key results found in the New Zealand studies have been confirmed by similar long-term studies at Moorepark, Ireland (Horan *et al.*, 2005; Linnane *et al.*, 2004) in three seasonal pasture-based systems with concentrate inputs ranging from 350 kg/cow to 1500 kg/cow.

2.5. Potential intake and potential milk production from pastures

Cows with high potential for milk production cannot express their potential when fed sole pasture at grazing. The level of intake on pasture is usually less than that achieved when concentrates comprise a substantial proportion of the diet. This must be a result of physical constraints, such as the amount of time available per day to graze. Additionally, the rate at which ingested material is removed from the rumen is an important factor. Finally, the intake of water associated with the forage may approach 70-90 kg/d and this can also contribute to limit intake (Kolver, 2003).

Mayne and Wright (1988) suggested that pasture DMI could reach 3.5% of Lwt for cows grazing high quality pastures as sole feed. Daily milk yields up to 30 kg/cow are theoretically obtainable from feeding cows with high quality pasture as their only feed (Mayne *et al.*, 2000).

Non-supplemented grazing dairy cows consumed 20.5 kg DM/cow/day (3.4% Lwt) with a pasture allowance of 40 kg and produced 22.2 kg milk/day (Bargo *et al.*, 2002). Castillo and Gallardo (1998) reported that milk production of 18.3 litres of milk per day (6.8% MS) can be achieved as an average of the lactation for cows fed only lucerne under grazing conditions. In a whole lactation (305 days), a milk production of 5,600 litres would be achieved (approximately 6.8% MS).

It was reported that Jersey dairy cows in New Zealand consumed 4% Lwt under optimal grazing conditions (Holmes, 1987). Kolver *et al.* (2002), studying high producing dairy cows reported that cows in early lactation consumed 3.57 and 3.26% Lwt (NZHF and NAHF, respectively) when fed pasture-only (good quality and 60 kg DM/cow pasture allowance). Milksolid yields in early lactation were 2.02 and 1.92 kg MS/cow/day for the NZHF and NAHF cows, respectively. However, they reported that cows fed total mixed rations (TMR) consumed 4.01 and 4.07% Lwt (NZHF and NAHF, respectively). Details of this experiment are shown in Table 2.4.

Table 2.4: DMI and animal performance of cows fed either total mixed rations (TMR) or pasture (Kolver *et al.*, 2002).

	Grass		TMR	
Holstein Friesian strain	NZHF	NAHF	NZHF	NAHF
Feed quality (MJ/ Kg DM)	11.7		11.8	
Mean live weight (kg/cow)	495	565	565	634
Average intake in early lactation (% Lwt)	3.57	3.26	4.01	4.07
Average intake early lactation (kg DM/cow/d)	16.6	17.3	20.4	24.0
Lwt change during lactation	+44	-20	+92	+77
Milk yield in whole-lactation (kg MS/cow)	465	459	602	720

Dry matter intake and milk production were lower for cows fed a pasture-only diet than for those fed TMR (Table 2.4). Restrictions imposed by pastures were more important for cows of higher potential milk yield (NAHF), as judged from the DMI expressed as a percentage of Lwt (Table 2.4).

The data presented above suggests that DMI and the consequent milk yields are restricted for cows grazing pastures in comparison with cows fed TMR, particularly when pasture allowance is limited in order to achieve high pasture utilisation. Furthermore, cows with high potential for milk yield, i.e. NAHF, can have their performance excessively restricted relative to their very high feed demand on pasture-only diets.

2.6. Effects of the inclusion of supplementary feeds in the system

The inclusion of supplementary feeds in the dairy system affects the pasture intake of cows and therefore, the productivity and profitability of the system. In this review, the terms *supplementary feeds* and *supplements* refers to concentrates and conserved forages either imported or produced on-farm.

2.6.1. Rationale for the inclusion of supplementary feeds

In grazing dairy systems, cows optimise their milk production when they are allowed to be highly selective. However, as discussed above, this leads to an increase in the residual herbage mass and consequently, a wastage of pasture. On the other hand, pasture utilisation and milk production per hectare can be maximised in grazing dairy systems with high SR, thus preventing cows from being selective. This invariably leads to low production per cow (Kellaway and Harrington, 2004). Thus, SR creates a conflict between production per cow and per hectare (Stockdale *et al.*, 1998). Supplements have the potential to achieve the dual objective of maintaining good individual performance (productive and healthy cows), whilst still allowing pasture to be well utilised (Stockdale *et al.*, 1998).

2.6.2. Milk response to supplementation

Responses to supplementary feeds are highly variable. This is because they depend on a wide range of both cow and feed factors, such as the stage of lactation, genetic potential for milk production, feeding level in relation to milk potential, pasture availability and quality, supplements availability and quality among others (Kellaway and Harrington, 2004).

2.6.3. Short- and long-term responses to supplementation

The increase in milk production which occurs during the period of feeding supplements is known as the *immediate effect*. On the other hand, the expression *carry-over effect* describes the extra milk produced over a long period (after supplementation) (Stockdale, 1999). When the immediate and the carry-over effect of including supplements in a pastoral system are added together, the total response to extra feed will almost always be smaller than the expected theoretical response. Some of extra nutrients are lost in the form of the pasture wasted, and/or extra Lwt which is never converted into milk (Holmes and Mathews, 2001).

The effects of the inclusion of supplements in a grazing dairy system are illustrated in Figure 2.8. DM offered as supplement can initially be wasted because animals usually do not consume 100% of the feed offered. The DM effectively consumed can increase total DMI and subsequently, be converted either into MS (immediate effect) or into extra Lwt.

Extra Lwt gain resulting from supplements can remain as body tissue or alternatively can be used to produce milk thus contributing to the carry-over effect. Simultaneously, pastures undergo changes when extra feed is introduced into the system. Thus, when supplements are introduced, some pasture can be spared. This pasture can be subsequently conserved, consumed by cows, or finally wasted (Figure 2.8).

Typically, the carry-over effect is equal to, or greater than, the immediate effect. Nevertheless, the size of the carry-over effect depends on the subsequent utilisation of any *substituted pasture* and/or any *saved Lwt* (Macdonald, 1999b). Substituted pasture will only be utilised if shortage of pasture in the farm still exists by the time that cows again graze the paddock where pasture was substituted (Macdonald, 1999b).

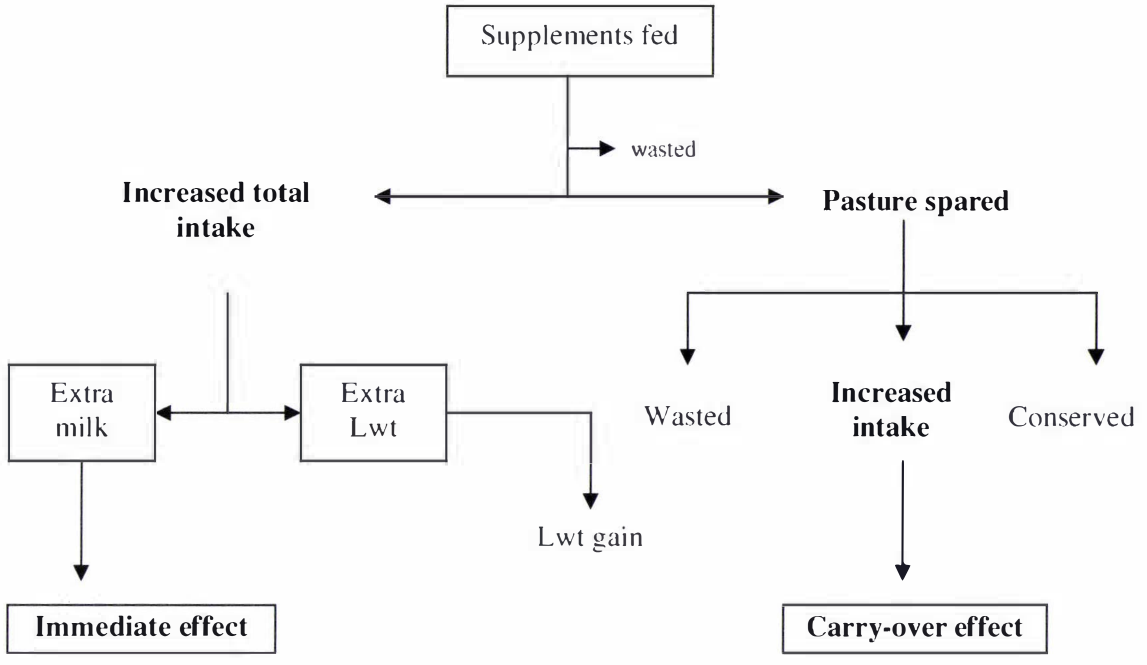

Figure 2.8: Immediate and carry-over effects of feeding supplements. Modified from Brookes (1996).

2.6.3.1. Theoretical milk response to supplements

In theory, if all the ME from extra feed consumed is absorbed by the udder and converted into milk, one kilogram MS would be produced with approximately one extra intake of 68 MJ ME for a Friesian cow (Holmes *et al.*, 2002). However, in practice, intake of energy as a supplement should be greater than 68 MJ ME, in order to produce one kilogram MS. This is because the consumption of supplementary feed usually causes some decrease in pasture consumption and some increase in Lwt gain, as shown in Figure 2.8 (Holmes *et al.*, 2002).

2.6.3.2. Practical milk responses to supplements

Kellaway and Porta (1993) reviewed the use of supplementary feeds in Australia and concluded that when pasture was restricted, offering energy concentrates was likely to result in an immediate effect of 0.5 kg milk/kg concentrate fed (about 41 g MS/kg DM). They also estimated that the carry-over effects resulted in an additional 0.5 kg milk/kg concentrate fed.

Penno (2001) summarised some of the few full lactation feeding studies that have been made in grazing dairy systems. Responses measured in whole-lactation averaged a value of 78 g MS/ kg DM, which is about two-fold greater than the 45 g MS/kg DM response found in a summary of short-term studies with grazing dairy cows since 1978 (Penno, 2001). MS responses in whole lactation studies were not only greater but also more consistent than in short-term studies.

Bargo *et al.* (2003), in a review of grazing experiments, found that milk production increased linearly as the amount of concentrate increased from 1.2 to 10 kg DM/cow/day, with an overall milk response of 1 kg milk/kg concentrate. Compared with pasture-only diets, increasing the amount of concentrate supplementation up to 10 kg DM/day increased total DMI by 24%, milk production by 22% and milk protein percentage by 4%, but reduced milk fat percentage by 6% (Bargo *et al.*, 2003).

Theoretically, 12 MJ of energy consumed should give a MS response of 176 gMS (12 MJ/ 68 MJ x 100). The average response of 78 g MS/kg DM supplemented (12 MJ ME) obtained in whole-lactation experiments is much less than the theoretical maximum response. Factors explaining the differences between observed and theoretical responses are discussed in the following sections.

2.6.4. Substitution effect

When supplements are consumed by cows, DMI from pasture is usually reduced. This effect is called substitution, because supplement is substituted for pasture. Substitution rate defines the extent by which a supplement replaces a pasture in the diet; a value of zero means that pasture intake remains the same, a value of one means that the supplement completely replaces the pasture (Clark, 1993).

The substitution effect is apparently caused by reduction in grazing time (Bargo *et al.*, 2002) and negative associative effects in the rumen (Dixon and Stockdale, 1999), the first being the main factor. The rate of substitution is affected by many factors. However, the main factor is the cow's overall level of feeding relative to her potential intake (Holmes and Mathews, 2001).

A negative relationship exists between substitution rate and milk response. Lower substitution rates are associated with higher total DMI and consequently higher milk response to supplements. In the efficient intensive grazing system, the substitution effect should be used deliberately to *save* pasture during a feed deficit, whilst simultaneously maintaining the cow's level of feeding with supplementary feeds. In this case the substitution is deliberately managed by the farmer and not by the cow (Holmes and Mathews, 2001).

2.6.5. Factors affecting milk response to supplementation

The size of the response to extra feed depends mainly on the need for extra feed by the cow or by the system. Large responses will be achieved only if the current performance of the cows, or the system, are being severely limited by the lack of feed (Holmes and Mathews, 2001). The main factors affecting milk response to supplementation are discussed in the following sections.

2.6.5.1. Stage of lactation

The stage of lactation affects the magnitude of milk response to supplements because energy partitioning changes as lactation progress. Energy is partitioned more towards BCS as lactation progresses. Therefore, the immediate response is usually greater in early lactation, decreasing thereafter (Kellaway and Harrington, 2004), at least for stalled cows fed ad-libitum.

In confinement studies, additional energy increased milk production (immediate response) by an average of 0.5 kg milk/kg DM supplemented (Stockdale *et al.*, 1998). On the other hand, several recent studies carried out in grazing systems in New Zealand, showed that the best responses to supplementary feeding occurred in summer or autumn, which corresponds to mid-late lactation for the seasonal-spring calving systems of this country. Extra feed in summer/autumn allowed the cows to continue to lactate (instead of being dried-off).

Penno *et al.* (1998) carried out a trial in New Zealand in order to study the effects of stage of lactation on MS response to supplementary feed. Three nutritional treatments with restricted pasture allowance were evaluated: one with no supplementary feeding, another with 50 MJ ME/cow/day as maize grain and the last with 50 MJ ME/cow/day as a balanced mixture of supplementary feeds. These treatments were evaluated in early, mid and late lactation, in the four seasons of the year using a non-seasonal dairy farm. The results of this study indicated that the stage of lactation or the form of supplement had no significant effect ($P<0.05$) on MS response to supplementation. The average total long-term response to supplements in this experiment was 62 g MS/kg DM.

Similar results were obtained in a previous New Zealand experiment, designed to measure immediate and carry-over responses of dairy cows fed pasture silage at different times of the year Clark (1993). Cows were fed with 5 kg DM pasture silage per day either in spring, autumn, or summer and their performance was compared with cows non-supplemented. MS responses were 26, 16 and 66 g MS/kg DM silage in spring, summer and autumn, respectively. These results indicate that in grazing dairy systems, when cows are fed restricted pasture allowance, there is room for a big response to supplementation, regardless of the stage of lactation.

In the studies of Penno *et al.* (1998) and Clark (1993), the poor pasture quality in summer-autumn increased the feed energy deficit relative to potential milk yield and this allowed high responses to supplements. This trend was also found by Stockdale *et al.* (1998) in Australia, who reported a negative correlation coefficient of 0.74 between marginal MS responses to extra feeding and the ME concentration of pasture consumed by cows.

Penno *et al.* (2001) developed a conceptual model to predict milk response from grazing dairy cows to supplementary feeds. They reported that the factor exerting the greatest influence on marginal MS response to supplementary feeds is the reduction in MS yield (relative to the potential milk yield) that occurs as restricted pasture allowance are imposed to cows, irrespective of the stage of lactation. The reduction in MS yield, that occurs as pasture allowance is restricted, reflects indirectly the feed deficit and was called *relative feed deficit* in that study.

The studies discussed above suggest that cows fed ad-libitum with good quality feeds, as stalled cows, are likely to show a higher response to supplements in early lactation than in late lactation, because they are in a bigger relative feed deficit. However, grazing cows generally undergo restrictions in either pasture availability (in order to harvest pastures efficiently) or quality, thus affecting their nutrient intake. Therefore, this feed deficit enables milk response to supplements that are independent of stage of lactation.

2.6.5.2. Genetic potential for milk production

Genetically improved cows (for milk production) partition a greater proportion of energy from feed consumed into milk production and less into BCS. This enables them to express greater marginal responses to supplementary feeds than low genetic merit cows (Holmes *et al.*, 2002). The higher the cow's potential for milk yield, the greater will be her response to increased feed intake.

The greater responses of high yielding cows may reflect greater behavioural constraints on biting rate and grazing time, in comparison with low yielding cows. As milk yield increases, the incremental increase in herbage DMI tends to decrease and consequently, the incremental increase in intake provides only approximately half or two-thirds of the net energy requirement per kilogram of additional milk produced for high yielding cows (Mayne *et al.*, 2000).

The MS response to supplementation of grazing HF cows with different potential for milk production was clearly addressed in a recent study carried out in New Zealand (Kolver *et al.*, 2004). New Zealand HF (NZHF) and North American HF (NAHF) cows were compared under three levels of feeding (0, 3 or 6 kg DM concentrate per cow/day). All cows had similar breeding worth (BW). The six groups of cows were offered generous pasture allowance. Results of this study are shown in Table 2.5.

NAHF cows were larger, produced more milk with lower MS concentration and lost more BCS during lactation than NZHF. On the other hand, NZHF cows had higher DMI (as % of Lwt) when fed generously on pasture (Table 2.5). These results agree with previous findings of Kolver *et al.* (2002), who reported that when cows were generously fed pasture only, NAHF were less efficient at producing a kilogram of MS (kg MS/kg $LW^{0.75}$) and produced similar MS yield to the NZHF. However, when fed TMR, NAHF, they were more efficient at producing a kilogram of MS (kg MS/kg $LW^{0.75}$) and produced more milk yield and MS than NZHF (Kolver *et al.*, 2002).

Cows from the NAHF strain gave much greater MS responses to concentrates than NZHF and the size of the responses were not significantly diminished at high levels of concentrate feeding for NAHF (Table 2.5). This may be explained by the fact that NAHF animals had a greater relative feed deficit compared to NZHF, when fed generously on pasture. However, the greater BCS loss by NAHF cows during the lactation means that greater feed input is required in the dry period, thereby reducing their total efficiency advantage (Kolver *et al.*, 2004).

Similar results were found in Ireland, in a trial comparing two strains of NAHF (high durability, HD and high productivity, HP) with the strain NZHF, during three complete lactations (Horan *et al.*, 2005; Linnane *et al.*, 2004). Milk responses to concentrates were 1.1, 1.0 and 0.55 kg milk/kg concentrate for the NAHF (high productivity strain), NAHF (high durability strain) and NZHF, respectively. Data from Table 2.5 shows that cows of one breed, but from two different strains had different relative feed deficits when fed well on pasture and consequently they showed different responses to supplementary feed.

Table 2.5: Production of North American HF and New Zealand HF cows with similar genetic merit, fed pasture generously, plus 0, 3, or 6 kg concentrate DM/cow/day. Average results of season 2002/2003 and season 2003/2004, only to 14 April (Kolver *et al.*, 2004).

	NZHF			NAHF		
	Concentrate (kg DM/cow/day)			Concentrate (kg DM/cow/day)		
	0	3	6	0	3	6
Lactation length (days)	278	269	279	267	264	269
Milk yield (Kg MS/cow)	437	476	492	431	485	529
Live weight (average kg/cow)	478	491	502	577	570	579
BCS change (scale 1-10)	-0.5	-0.1	+1.4	-1.9	-1.8	+0.2
Live weight change (kg/cow)	-21	+20	+44	-47	-19	+1
Efficiency (g MS/kg Lwt)	90	97	96	78	89	93
Response (g MS/kg concentrate)		51	36		72	67

2.6.5.3. Body condition score

Cows in poor BCS give smaller responses in milk yield to supplementary feeds than cows in good BCS (Kellaway and Harrington, 2004). This is because cows in poorer BCS partition a greater proportion of feed energy towards Lwt gain than cows in good BCS. The greater partition towards Lwt gain is ultimately at the expense of MS production (Mackle *et al.*, 1996).

The effects of BCS at calving and the level of feeding after calving on milk production and reproductive performance of grazing dairy cows were studied by Grainger *et al.*

(1982). Improved BCS at calving increased milk production by causing a more favourable partitioning of energy into milk synthesis, at the expense of Lwt gain. Increasing the plane of nutrition in early lactation allowed higher levels of milk production and reduced the need for cows to mobilise body reserves. The input-output relationship calculated by Grainger *et al.* (1982), showed that the response to additional feeding after calving was higher than the response to extra feeding to improve BCS before calving.

2.6.5.4. Feeding level in relation to milk potential

A high proportion of the nutrients consumed will be partitioned to produce extra milk, if the cow's potential milk yield is much higher than her current actual milk yield because of a relative feed deficit (Holmes and Mathews, 2001). The bigger the *relative feed deficit* is, the bigger will be the milk response to supplementary feeds. In a grazing dairy system, the deficit may occur naturally, for example because of a dry season, or it can be created artificially, for instance, by increasing the SR (Macdonald, 1999b).

The size of any feed deficit can be defined by the potential MS production of the system and the availability and quality of feeds (Penno *et al.*, 2001). Factors affecting the potential MS production were discussed in previous sections. The effects of factors related to feed supply and feed quality on MS responses to supplements will be discussed in the following sections.

2.6.5.5. Pasture availability and quality

The nature of milk response to supplements is markedly affected by the level of pasture availability. As pasture allowance increases, pasture DMI also increases and the response to supplementary feeds is likely to decrease (Penno *et al.*, 2001; Stockdale, 2000b; Stockdale *et al.*, 1998). This is the result of a higher substitution rate and probably more energy from supplements partitioned towards Lwt (which will depend on the genetic merit of the cow).

Bargo *et al.* (2003), in a review of studies of the effect of supplementation on pasture DMI of grazing dairy cows, stratified treatments in those studies as either low pasture allowance (<25 kg DM/cow/day) or high pasture allowance (>25 kg DM/cow/day). They found that the substitution rate averaged 0.20 kg pasture/kg concentrate (range: 0 to 0.31) at low pasture allowance and 0.62 kg pasture/kg concentrate (range: 0.55 to

0.69) at high pasture allowance. A negative relationship between the substitution rate and MS response was found in all the studies reviewed by Bargo *et al.* (2003).

When animals are restricted in their pasture intake, much larger MS responses to extra feed per extra unit of energy are possible. This principle was demonstrated with stall-fed dairy cows, by Stockdale and Trigg (1989). The response in MS production per extra kg concentrate was 1.8 kg milk/kg concentrate for cows fed low levels of pasture (consuming 6.8 kg DM/day), whilst the response was 0.6 kg milk/kg concentrate for cows fed higher levels of pasture (consuming 11.6 kg DM/day).

The higher the quality of the pasture for milk production, the lower will be the response to supplements (Macdonald, 1999b). The attributes that make a pasture more suitable for milk production are basically: high metabolisable energy (ME) concentration (10.7 to 11.7 MJ ME); high crude protein concentration (18-25%) (Clark and Kanneganti, 1998); and good balance between rumen degradable protein and rumen undergradable protein (Macdonald, 1999b). The greatest responses to supplement will be obtained from cows that are being fed on low quality pastures at a reduced allowance, by giving them ad-libitum supplements that balance their base diet.

2.6.5.6. Quantity of supplementary feeds

As supplementary feeds are introduced in the pastoral system, so energy intake is increased, a declining proportion of the extra energy is partitioned towards milk production and an increasing proportion is partitioned towards body reserves (Penno *et al.*, 2001). Therefore, as the level of supplementation increases, the marginal MS response decreases. This can cause a curvilinear response of MS production to concentrate, instead of a linear response (Kellaway and Harrington, 2004). Table 2.5 shows that, as the level of supplementation increases for both NZHF and NAHF cows, the MS response per kilogram supplement decreases. However, the reduction in MS response was smaller for high potential milk yield cows (NAHF).

The reduction in the marginal response to the addition of supplements may be attributed, not only, to partitioning of nutrients within the cow but also to increasing substitution rate as the amount of supplements is increased.

It was found that the substitution rate increased as the amount of concentrate was increased (Meijs and Hoekstra, 1984). However, inconsistent results have been found regarding the effect of increasing amount of supplements and substitution rate (Bargo *et al.*, 2003). Thomas (1987) suggested that, for silage based diets, there was no evidence of increased substitution rate as the amount of concentrates fed increased. Furthermore, Stockdale and Trigg (1985) found a decrease in substitution rate as the level of supplementary feeding was increased. The quality of the basal diet and the type of supplement may create inconsistent relationships between the amount of supplements fed, substitution rate and milk responses. On balance, as suggested by Penno (2001), there is sufficient evidence to assume that when cows are consuming high quality forages, the substitution rate increases and milksolid response decreases as the energy intake of the cow increases.

2.6.5.7. Type and quality of supplementary feeds

Forage and concentrate supplements

Grazing cows usually show higher substitution rates when supplemented with forages than when supplemented with concentrates. This mainly occurs in situations of high herbage allowance (Mayne *et al.*, 2000). Stockdale (2000b) reported that the substitution rate for feeding forage supplements, such as hay and maize silage, was 0.08 kg DM/kg DM higher than that from feeding concentrates at any given level of un-supplemented pasture intake, based on a review of 39 experiments with grazing dairy cows.

The higher levels of substitution, that occurred when supplementing with forages, appear to result from large reductions in grazing time. This is probably due to the bulk associated with many forage supplements and their potentially slow rate of intake and digestion in the rumen, together with their relatively poor whole tract digestibility. However, it was suggested that variations in the level of substitution attributed to different supplements is most likely to be an issue when supplement feeding levels and pasture allowances are high (Stockdale, 2000b).

Supplementing grazing dairy cows with concentrates can, on occasions, lead to much higher levels of substitution than those observed when feeding forage supplements. This may be attributed to perturbation of rumen fermentation, i.e. decrease in pH, resulting in diminished rates of fibre digestion in the rumen and reduced rates of passage of digesta (Stockdale, 2000b).

Any supplement has the potential to increase MS production, when fed to dairy cows experiencing high feed deficits. However, the response will be greater if the quality of the supplement is higher. Moreover, the response to supplements will increase for supplements which contain the nutrients to complement the base diet. For example, cows fed with summer pasture and supplemented with a large proportion of maize silage may have a poor response to energetic supplements because of the lack of protein in the diet (Macdonald, 1999b).

Energy and protein supplements

Energy is the nutrient which usually limits milk production in grazing dairy systems based on temperate pastures (Macdonald, 1999a; Macdonald *et al.*, 1998). Therefore, the most important nutritional characteristic of a supplement is its concentration of ME (Holmes *et al.*, 2002). Supplementary feeds must supply high ME at low cost (Penno *et al.*, 1998). However, protein may limit MS production under particular situations in pastoral dairy systems.

Stockdale *et al.* (1998) suggested that, according to current research, protein supplementation does not often appear to be an issue in the pasture-based dairy systems of Australia. It is usually assumed that pasture availability and energy concentration in the pasture limit milk production from grazing cows rather than protein concentration in pastures (Macdonald *et al.*, 1998). However, as the proportion of pasture in the diet decrease, protein deficiencies in the diet may appear.

A trial set up in New Zealand investigated the effectiveness of three sources of protein in order to increase MS production when maize silage was fed to cows grazing on pasture in summer (Macdonald *et al.*, 1998). In this experiment, urea, fishmeal and soybean meal were given to different groups of cows and compared with a control treatment (no protein supplement). Soybean meal increased milk protein production by 60 g per cow/day in both summer and autumn. Fishmeal increased milk protein production by 60, 10 and 80 g per cow/day in spring, autumn and summer, respectively. In contrast, the addition of urea had no effect on milk, milkfat or milkprotein production. The authors suggested that the lack of response from urea may be due to the asynchrony between energy released from maize silage and the ammonia released from urea in the rumen. Indeed, experiments in which urea has improved MS production were generally conducted under total mixed rations, where urea and maize silage were mixed.

Therefore, when supplementing grazing dairy cows which experience deficiency of protein in the diet, the form of nitrogen is important. Nitrogen from high quality proteins (such as soybean meal and fishmeal) is more valuable than non-protein nitrogen (urea). However, the profitability of this practice will depend on the price of the milk and the cost of protein supplements (Macdonald *et al.*, 1998). This trial demonstrated that the use of soybean meal or fish meal was not profitable for New Zealand, at the time that the experiment was performed.

2.7. Combined effects of stocking rate and supplements

The use of supplements can, paradoxically, improve pasture utilisation in the long-term for the whole system because it gives the manager the confidence to increase grazing pressure, through increases in SR. This ensures that pasture can be kept in a leafy and rapidly growing phase. Higher SR creates high feed demand, which in turn increases pasture utilisation, mainly in spring (Macdonald, 1999b). Additionally, higher SR with the same feed supply would create higher levels of animal underfeeding, which will subsequently boost the need for, and therefore, the response to supplementation.

A commercial dairy farm in the Waikato region of New Zealand was split into two farmlets: one stocked at 3.2 Friesian cows/ha and the other at 3.6 Friesian cows/ha in order to study the effects of SR and supplementation. Cows in the farmlet with higher SR were fed 430 kg DM maize silage per cow/year. Increased SR, combined with purchased maize silage, increased MS production by 103 kg MS/ha/year, as well as EFS between 10.7 and 12.7%, depending on the milk price considered (Glassey *et al.*, 2001).

Several grazing experiments in Australia are in agreement with the findings of Glassey *et al.* (2001). Increased SR (4 cows per hectare instead of 2.5 cows/ha), supported with more nitrogen fertiliser and more supplements, was proven to improve profitability at Macalister Research Farm (1994-1995) in Australia (Stockdale *et al.*, 1998). Another Australian whole-farm experiment, comparing different systems, was the A, B, C farmlet demonstration (1992-1995), set up in Ellinbank Dairy Research Institute (Stockdale *et al.*, 1998). Farmlet A was low input, farmlet C was high input and farmlet B was intermediate. Nitrogen fertiliser, supplements and summer crop were the variables responsible for farmlet intensification. Over three years, farmlet A obtained

91-96 % of feed requirement from on-farm sources, compared with 69-86 % and 51-78 % for farms B and C, respectively. Relevant data from this trial are shown in Table 2.6.

Averaged over three years, the highest gross margin occurred in farmlet B. However, the ranking of the farmlets changed through the years depending on the relative prices of milk and concentrates. Furthermore, farmlet C had the highest gross margin in two out of three years, but not over the entire three years.

Farmlet B and C showed that it is possible to increase SR and simultaneously maintain or increase MS yield per cow (Table 2.6), provided that extra feed is supplied to cows.

Table 2.6: Physical and economic indicators of the A, B, C farmlet demonstration in Ellinbank Dairy Research Institute, Australia. Average data over three years (Stockdale *et al.*, 1998).

	Farmlet A	Farmlet B	Farmlet C
Stocking rate (cows/ha)	1.4	2.4	3.9
Milk yield (kg MS/cow/year)	400	436	392
Milk yield (MS/ha/year)	560	1,046	1,517
Grain imported (% ME required) [1]	4-5%	10-29%	14-35%
Silage imported (% ME required) [1]	-	-	8-14%
Increase in gross margin ($/ha) [2]	-	+ 18%	+12%

[1]Off farm feed supplied as percentage of the total energy required. Range over three years.

[2]Increase in gross margin in relation to the farm A (low input). Average over three years.

The experiments discussed above show that simultaneously increasing SR and feed supply can improve the entire performance of the farm (higher pasture utilisation, higher MS/ha, similar or higher MS/cow, higher gross margin and better BCS). Nevertheless, high increases in SR and imported concentrates, as demonstrated in farmlet C (Table 2.6), may not be profitable in some years, depending on relative prices of milk and supplements.

The effects of supplementation on dairy systems with high SR (4.41 cows/ha) are also well illustrated from the New Zealand experiment summarised in Table 2.7 (Penno *et al.*, 1999). This study was designed to compare the effect of maize grain, maize silage and a balanced supplement on MS yield of dairy cows at high SR.

In spite of reduced net herbage accumulation, the non-supplemented herd (control) tended to have greater herbage annual intake (per hectare) than the supplemented herds (Table 2.7). This could be explained because pasture was substituted by supplements in the supplemented herds. However, the total DMI was greater in the supplemented herds than in the non-supplemented herd. Offering maize grain, maize silage and balanced supplement resulted in 98, 77 and 99 g MS/kg DM, respectively. This relatively high response may be explained by the fact that this was a whole-year experiment and therefore, it accounted for both short- and long-term responses of milk yield to supplementary feed. Additionally, the high SR used in this experiment granted that every kg DM imported as supplement was used efficiently in the system.

Table 2.7: Main characteristics and results of the effects of supplementation on dairy systems with high stocking rate (Penno *et al.*, 1999).

Farmlet	Control	Maize grain	Maize silage	Balanced ration
Stocking rate (cows/ha)	4.41	4.41	4.41	4.41
[1]Comparative SR (kg Lwt/t DM)	118	88	89	84
Supplements fed (t DM/cow)	0.07	1.4	1.3	1.5
Net herbage accum. (t DM/ha/year)	18.3	18.9	19.2	19.6
Herbage intake (t DM/ha/year)	17.9	17.3	16.8	17.1
Herbage intake (t DM/cow/year)	4.2	5.3	5.1	5.4
Lactation length (days)	217	283	277	291
Milk yield (kg MS/ha)	1188	1763	1601	1797
Response (g MS/kg DM)		98	77	99

[1]Assuming average 500 kg Lwt per cow (not reported in the trial).

Another New Zealand whole-farm trial can illustrate the effects of different combinations of feed supply and feed demand on the productivity and profitability of the system (Penno *et al.*, 1996). Two levels of SR were combined with three levels of feed supply, created through 0, 200 and 400 kg of N/ha. When needed, cows were fed with imported supplements, in order to maintain the post-grazing herbage mass in a pre-fixed range (deliberately reducing the cow's pasture supply), a practice known as *managed substitution* (Holmes *et al.*, 2002). A treatment with neither nitrogen nor supplements was included as a control. Results of this experiment are shown in Table 2.8 and Figure 2.9.

MS production per hectare was higher for the farmlets with higher SR and higher feed supply (Figure 2.9). However, only one farmlet (No 3, low SR) showed higher EFS than the control farmlet, under the economic environment analysed (Table 2.8). The poorer EFS achieved by farmlets with high SR in this experiment, shows that the cost of supporting more cows with expensive supplementary feeds was not justified by the benefits of producing more MS production per hectare.

Table 2.8: Results of a whole-farm experiment undertaken in New Zealand combining two levels of SR with three levels of feed supply (Penno *et al.*, 1996).

Treatments	1	2	3	4	5	6	7
Stocking rate	Low	Low	Low	Low	High	High	High
Nitrogen (kg N/ha/y)	0	0	200	400	0	200	400
Stocking rate (cows/ha)	3.24	3.24	3.24	3.24	4.48	4.48	4.48
Milk yield (kg MS/cow)	347	402	410	418	374	404	405
Milk yield (kg MS/ha)	1123	1299	1328	1354	1718	1808	1812
Lactation length (days)	247	289	284	288	288	284	286
% anoestrous cows	33	14	10	5	10	17	31
Change in EFS ($/ha)	-	- 12%	+3%	0%	- 61%	- 22%	- 25%

The Australian and New Zealand whole-farm experiments analysed suggest that the most profitable systems are those in which SR is high enough to ensure high pasture utilisation, but it is still not so high to affect the production per cow. For Australian experiments, it seems to be that the most profitable systems are those with high SR and those systems using imported supplements to maintain relatively high per cow productions. However, this is apparently not the case in New Zealand, possibly because of the higher cost of supplements than in Australia.

The physical and financial performance of commercial dairy farms, that differed in the amount of extra feed used, were studied in New Zealand (Silva-Villacorta *et al.*, 2005). Data from 626 dairy farms were classified according to the extra feed used per cow, in either high input (740-940 kg extra DM /cow/year) or low input farms (20 kg extra DM /cow/year). Extra feed comprised imported supplements, winter grazing and maize silage grown on the farm. The high input farms produced higher gross farm incomes per hectare, but they had higher farm working expenses per hectare, so that EFS per hectare was not higher for high input farms. The authors concluded that high management skills and control of costs are necessary for profit to be increased by the use of extra feeds.

Similarly, the trial performed by Penno *et al.* (1996) in New Zealand, summarised in Table 2.8 and Figure 2.9, showed that high input systems (with high nitrogen fertiliser and use of supplements) did not increase profitability, in comparison to the control system with neither nitrogen nor supplements. However, as stated above, the profitability of different systems will depend on the price of milk relative to the price of supplements.

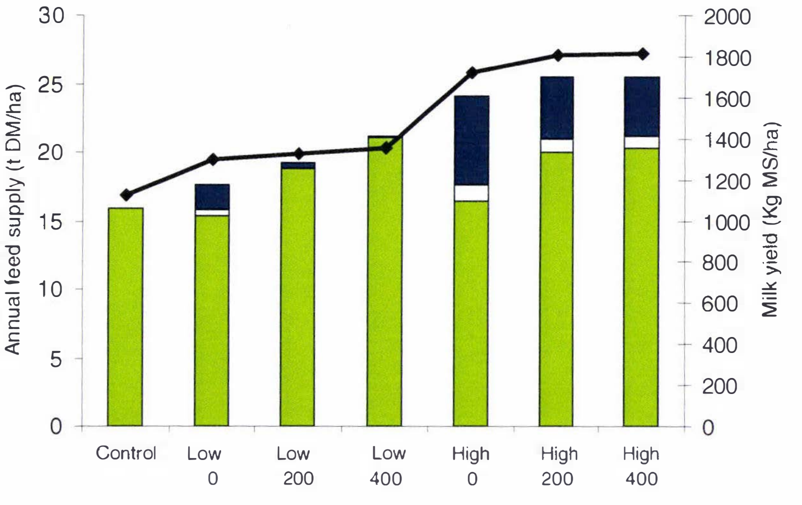

Figure 2.9: Feed supply and MS production per hectare for different combinations of SR, nitrogen fertiliser, and supplements. Pasture (■), Silage (□), Grain (■) and MS yield per hectare (—♦—) (Penno, 1996).

2.8. Factors interacting with stocking rate and supplementation

Factors affecting feed demand or feed supply throughout the year interact with the effects of SR and supplements on the productivity and profitability of the system. The dates of calving and drying-off and nitrogen fertilisers are two important factors interacting with the effect of SR and supplements.

2.8.1. Calving and drying-off dates

The season of calving and the distribution of calving dates within the herd have major effects on the herd's pattern of feed demand through the year (Garcia and Holmes, 1999). Calving and drying-off dates determine the shape of animal requirements through the year. Thus, SR and the level of supplementation should be decided in coordination with the pattern of calving and drying-off.

The ability to simultaneously meet a good pasture growth rate, high harvesting efficiency, controllable changes in body weight and well fed cows, will determine the level of MS production per cow and per hectare. Calving and drying-off dates play an essential role in the synchronisation of all these variables.

2.8.2. Nitrogen fertilisers

The inclusion of fertilisers in grazing dairy systems may have effects that are similar to those of supplementary feeds. In fact, the desired effect of fertilisers is to increase pasture production, which in turn, means extra feed. In this review, the effects of fertiliser will be illustrated through the effects of nitrogen fertiliser on dairy systems based on ryegrass-clover pastures.

McGrath *et al.* (1998) investigated the profitability of using nitrogen fertiliser to increase pasture supply and MS production at two levels of SR: low (3.34 cows/ha) and high (4.42 cows/ha) and two rates of fertiliser: 200 or 400 kg N/ha/year, plus a control treatment with no fertiliser and low SR. The results of this study are shown in Table 2.9 and Figure 2.10. An interaction between the level of nitrogen fertiliser applied and annual SR on the whole farm is evident from Figure 2.10. More pasture was grown per hectare at low SR when 200 kg nitrogen per hectare were applied, whilst high SR resulted in more pasture grown, when 400 kg nitrogen per hectare were applied.

The key to understanding the interaction between nitrogen fertiliser and SR in this trial is the balance between feed supply and feed demand. When 200 kg nitrogen per hectare was applied, the high SR imposed an excessively high feed demand, resulting in over grazing and subsequently, reducing pasture accumulation in comparison to the low SR. On the other hand, when 400 kg nitrogen per hectare was applied, the high SR was more adequate to match feed supply. The lower SR with 400 kg nitrogen per hectare exerted lower demand throughout the year, which possibly led to an excessively high herbage mass, thus reducing herbage growth rate.

Table 2.9: Combined effects of SR and nitrogen fertiliser for a dairy system based on ryegrass-clover pastures (McGrath *et al.*, 1998).

Farmlet	Control	Low SR 200N	Low SR 400N	High SR 200N	High SR 400N
Nitrogen applied (kg/ha)	0	204	428	204	424
Stocking rate (cows/ha)	3.34	3.34	3.34	4.40	4.40
[1]Comparative SR (kg Lwt/ t DM)	94	83	77	115	101
Pasture response (kg DM/kg N)		8.6	7.5	4.7	8.4
Milksolids (kg/cow/year)	325	372	394	275	293
Milksolids (kg/ha/year)	1084	1242	1316	1210	1289
EFS ($/ha)	1842	+ 8.1%	+1.3%	-14.7%	-13.3%

[1]Assuming average 500 kg Lwt per cow (not reported in the trial).

Increasing SR reduced MS production per cow and profitability, at both rates of nitrogen application. The poorer performance of higher stocked farmlets probably indicate that total farm efficiency is being compromised through low per animal productivity, in an attempt to maximise pasture utilisation (McGrath *et al.*, 1998). Indeed, the estimated SR were 115 and 101 kg Lwt/t DM for the high stocked farmlets, which according to the findings of Penno (1999) is far above the SR that maximise EFS/ha.

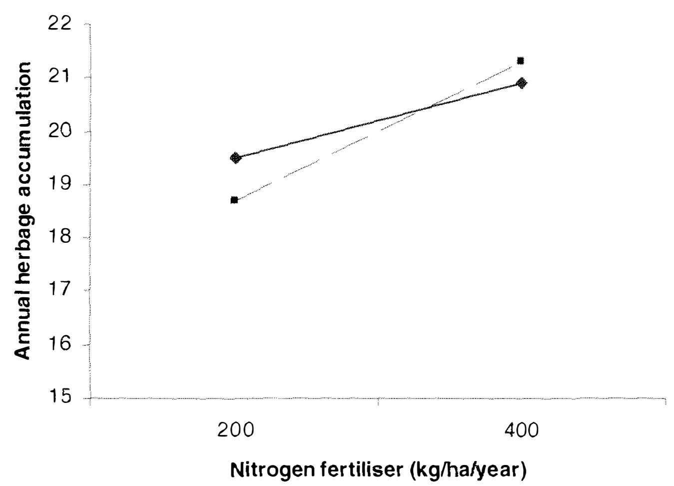

Figure 2.10: Interactions between stocking rate and nitrogen fertiliser in a dairy system based on ryegrass-clover pastures. (—♦—) Low SR and (- -■- -) High SR (McGrath *et al.*, 1998).

Stockdale and King (1980) studied the effects of SR and nitrogen fertiliser on the productivity of irrigated perennial pastures in Australia and they found that increases in SR resulted in reduced pasture growth and in a concomitant reduction in the response to nitrogen fertiliser. However, the five levels of SR tested in that trial were excessively high, ranging from 4.4 to 8.6 cows/ha. The comparative SR estimated for this trial (not reported) may have been higher than 100 kg Lwt/t DM total feed supply in the treatment with the lowest SR (4.4 cows/ha). The lower response to nitrogen fertiliser as SR increased was a consequence of lower pasture production as SR increased, as reported for 200 kg N/ha in Figure 2.10. The authors suggested that the decreasing pasture production as SR increased was the result of the increased severity of defoliation, which reduced the photosynthetic area of the pasture and consequently, reduced growth rate.

2.9. Conclusions

Dry matter intake per cow and per hectare is strongly associated with the productivity and profitability of dairy farms. Herbage allowance is the factor exerting the greatest effect on DMI per cow and pasture utilisation at each grazing. On an annual basis, SR determines the average pasture allowance per cow. This is why SR is so important for the productivity and profitability of grazing dairy systems.

The traditional ratio called SR, expressed as number of cows per hectare, could be better defined as comparative SR, expressed as kg Lwt/t DM of total feed supply. The comparative SR that maximises MS production per hectare for New Zealand conditions is approximately 105 kg Lwt/t DM, whilst that which maximise profitability is around 85 kg Lwt/t DM.

Cows fed abundant high-quality pastures may achieve relatively high individual performance in grazing systems. However, in order to maximise MS production and profitability per hectare, SR must be increased. This inevitably causes a reduction in performance per cow. For New Zealand conditions, a reduction in MS production of between 30% and 35% in MS production per cow seems to be associated with maximum MS production per hectare. Similarly, a reduction of between 16% and 20% in MS/cow appears to correspond to maximum profitability.

Cows with high potential for milk yield, i.e., high genetic merit cows such as NAHF, show higher milk responses to supplementary feeds, as a consequence of their higher relative feed deficits in grazing dairy systems, compared to cows of lower potential for milk yield.

Milk response to supplements is highly variable. Partitioning of energy within the cow and substitution rate seem to be the underlying mechanisms that explain differences in milk responses to supplementary feeds. Partitioning of energy and substitution rate are markedly affected by the energy deficit of the cow relative to her potential energy demand. This energy deficit is markedly affected by pasture allowance, the amount of supplements fed and the genetic potential for milk production of the cow. Total average long-term responses around 80 g MS/kg supplement were found in whole-farm experiments.

The stage of lactation seems to strongly affect the response to supplements in confinement systems. However, whole-farm trials in grazing dairy systems found no effect of the stage of lactation on milk response to supplementary feeds, with the response being greater when the pasture deficit was greater.

Australian and New Zealand experiments provide strong evidence of the synergistic effect of increasing the SR and including supplementary feeds. This combination markedly increases pasture utilisation and MS production per hectare. Simultaneously, this practice enables per cow performance to be maintained. This generally results in higher profitability for Australian systems but not always for New Zealand systems. However, the optimum combination (in economic terms) of increased SR and use of supplements depends on the price of milk and the cost of supplements.

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Chapter 3

Development of a model to predict pasture intake for grazing dairy cows in Argentina

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Accepted for publication in

The Proceedings of the New Zealand Society of Animal Production

Abstract

Milk production in Argentina is based on grazed pastures and supplementary feeds. Pasture dry matter intake affects markedly the performance of grazing dairy systems. The objective of this study was to develop a simple model to predict daily pasture dry matter intake (DMI) of grazing dairy cows in Argentina, which in turn, would enable the effects of stocking rate on pasture DMI, farm productivity and profitability to be explored. The model assumed that potential DMI of cows fed only pasture is initially limited by either rumen fill or energy demand. Cow live weight, stage of lactation, and concentration of neutral detergent fibre in the pasture account for the rumen fill effect, while requirements for maintenance, pregnancy, and potential milk production influence the cow's energy demand. Potential pasture intake is then estimated from the potential DMI, by taking into account the reduction in potential intake that occurs when supplements are consumed. Finally, actual pasture intake is estimated as a function of pasture allowance and potential pasture intake, based on an empirical equation derived from grazing experiments in Argentina, mainly with lucerne pastures. The fitness of the model was evaluated by the square root of the mean-square prediction error (RMSPE), expressed as a percentage of the mean actual pasture intake. The accuracy of the model was satisfactory, with RMSPE of 9.6% and 7.3% for two Argentine datasets (lucerne pastures), and 8.1% for one Irish dataset (ryegrass-clover pastures). The model can be used as a part of a whole-farm model to predict the effects of stocking rate on farm productivity and profitability.

Keywords: pasture intake, prediction, grazing, dairy cow.

Introduction

Dairy production in Argentina is based on grazed pastures, with conserved forages and concentrates comprising approximately 33% of the cow's diet. Productivity and profitability of grazing dairy systems are highly dependant on cows' pasture dry matter intake (DMI). Herbage allowance (kg DM offered/cow/day) is the factor exerting the greatest effect on pasture DMI in grazing dairy systems (Hodgson et al., 1994; Holmes, 1987; Leaver, 1985).

Factors affecting herbage intake by grazing animals can be broadly classified as nutritional and non-nutritional. Nutritional factors include physical satiety and physiological energy demand of the animal, and these limit pasture intake at high herbage allowances. Non-nutritional factors constrain grazing activities and the rate of intake, basically through their effects on bite weight and grazing time, and these limit pasture intake at low herbage allowances (P●ppi et al., 1987).

Neutral detergent fibre (NDF) is an important nutritional factor through its effects on digestion and rumen fill, but NDF can indirectly reflect non-nutritional factors such as the amount of green or dead material, and the breaking strength of plant material, which usually increases with the stage of maturity of plants. Mechanical properties of herbage may influence the rate of intake. Mechanical properties of the herbage could be predicted by an index of fibrosity such as NDF (Prache & Peyraud, 2001).

The animal can be regarded as having an upper limit to intake, or 'potential intake'. Physiological demand for energy and physical limitation of the rumen capacity have been described as the two basic mechanisms explaining intake regulation when animals have unlimited access to feed (Forbes, 1995). With diets containing high concentrations of NDF, intake is limited by the physical capacity of the animal, and becomes a function primarily of dietary characteristics. With diets containing low concentrations of NDF, intake is controlled by the physiological energy demand of the animal, and is principally a function of animal characteristics (Mertens, 1987). Simple mathematical equations describing intake regulation were derived by Mertens (1987). His model, the NDF-energy system, is based on the concept that, in animals with unlimited access to feed, feed intake is regulated by metabolic and physical control. This theoretical approach was used in the present model to predict potential DMI.

The objective of this study was to develop a model to predict daily pasture DMI for grazing dairy cows in Argentina. The model integrated nutritional and non-nutritional factors, and was based on sward and animal parameters usually measured in Argentine grazing studies. There are no similar models to predict intake of grazing dairy cows in Argentina.

Methods

Description of the model

A theoretical-mechanistic framework combined with an empirical equation was used in the present model to predict daily pasture DMI. Potential DMI (PotDMI) is initially predicted, assuming that cows have access to unlimited amounts of pasture as a sole feed. Potential pasture DMI (PPI) is then estimated from the potential DMI, by taking into account the reduction in potential DMI that occurs when supplements are consumed. Two possible values for both PotDMI and PPI are calculated, assuming that intake is limited by either physiological energy demand (PotDMIe and PPIe), or by rumen fill (PotDMIr and PPIr). The lowest value of PPIe and PPIr is then selected as the predicted PPI of the cow. Finally, actual pasture intake is estimated as a function of the actual pasture allowance and PPI, based on an empirical equation derived from data from grazing experiments in Argentina.

Sward structure, herbage mass and botanical composition, although known to be important, were not included in the present model for the sake of simplicity.

Physiological limit

The model of Mertens (1987) proposed that when intake is limited by physiological energy demand, daily PotDMIe (kg DM/day) multiplied by the metabolisable energy (ME) content of the diet (EC) equals the animal's daily ME requirements (R):

$$R = PotDMIe \times EC \qquad (1)$$

For grazing cows fed supplements, Equation 1 can be disaggregated, and expressed as:

R = (DMIs x ECs) + (PPIe x ECp) (2)

Where DMIs and ECs are DMI and ME concentration of supplements, PPIe is the potential pasture intake when energy demand limits intake, and ECp is the ME concentration of pastures. This can be re-arranged to calculate potential pasture intake as follows:

$$PPI_e = \frac{R - (DMI_S \times EC_S)}{EC_p} \quad (3)$$

Prediction of total requirements of metabolisable energy

Total requirements of metabolisable energy are estimated using Equation 4:

R = MEm + MEp + (MEL x Y) (4)

Where MEm and MEp are the ME required for maintenance and pregnancy, respectively. MEL is the ME required to synthesize one litre of milk, and Y is the potential milk yield per cow (litres/day). Requirements for MEm, MEp and MEL are calculated according to recommendations of SCA (1990). The exponential model proposed by Wilmink (1987) is used to predict potential milk yield at any day of the lactation period (Equation 5).

Yt = a + be-0.05t + ct (5)

Where Yt is the potential yield of milk in the tth day of lactation. Parameters a, b, and c determine the overall shape of the curve. The values for parameters a, b, and c used in this model were extracted from the results of a study investigating the effects of strain of Holstein-Friesian cows, feeding system and parity on lactation curves of dairy cows in Ireland (Horan et al., 2005a). Parameters used in this model were those corresponding to the treatment with high productivity cows offered a high concentrate diet. Parameter a was increased arbitrarily by 5% in order to represent a curve of potential milk yield for high-yielding Holstein cows. The values for parameters a, b, and c used in this model were 43.26, -22.9, and -0.0889 for a, b and c, respectively. These values give a milk yield of 8,599 litres per cow (4% fat corrected) in 305 days of lactation.

Physical limit

Mathematically, the physical limitation theory of Mertens (1987) states that daily potential intake (PotDMIr) times the fill effect (F) of the diet equals a constant daily intake capacity (C):

$$C = PotDMIr \times F \qquad (6)$$

This equation can be re-arranged to obtain potential DMI intake:

$$PotDMIr = C/F \qquad (7)$$

Based on equation 7, a theoretical equation is proposed to predict the potential DMI (kg DM/day) when intake is controlled physically in grazing dairy cows, with unlimited access to pasture as sole feed.

$$PotDMIr = \frac{1.65\% \times Liveweight}{\% \text{ pasture NDF}} \times SOL \qquad (8)$$

The term 1.65% x live weight (Lwt) accounts for the filling capacity of the animal (C) and the % pasture NDF for the filling effect of the ration (F) when only pasture is fed. Vazquez and Smith (2000) found that, at high pasture allowance, the average daily intake of NDF was: 1.65% x Lwt. SOL is a coefficient accounting for the effect of stage of lactation on rumen capacity, which is defined in Equation 9, as proposed by Hulme et al. (1986):

$$SOL = 0.67 + (4.0401 \times Log(w) - 0.095 \times w) \times 0.0972 \qquad (9)$$

where w is the week of lactation.

Equation 10 enables the calculation of potential pasture intake (PPIr) when rumen fill limits intake, accounting for the reduction in the animal's capacity when supplements are consumed.

$$PPIr = PotDMIr\ (kg\ DM/d) - Supplements\ eaten\ (kg\ DM/d) \qquad (10)$$

It should be noted that 1 kg DM consumed as supplement reduces potential pasture intake (PPIr) by 1 kg, but actual intake is not necessarily reduced by 1 kg, as shown in the results below.

Integration of physiological and physical intake control

Because NDF is related to both the filling effect and the energy density of feeds, it can be used to relate the two mechanisms of intake regulation on a common scale, as shown in Figure 1. In the example shown in Figure 1, the intercept point between the two mechanisms of intake regulation is approximately 38% NDF for a cow with a potential milk production of 30 kg/day. At this point, PPIe equals PPIr. At higher NDF concentrations, intake would be limited by rumen fill, while at lower pasture NDFs intake would be limited by energy demand, for a cow with a potential milk yield of 30 kg per day. Therefore, PPI= min (PPIe, PPIr).

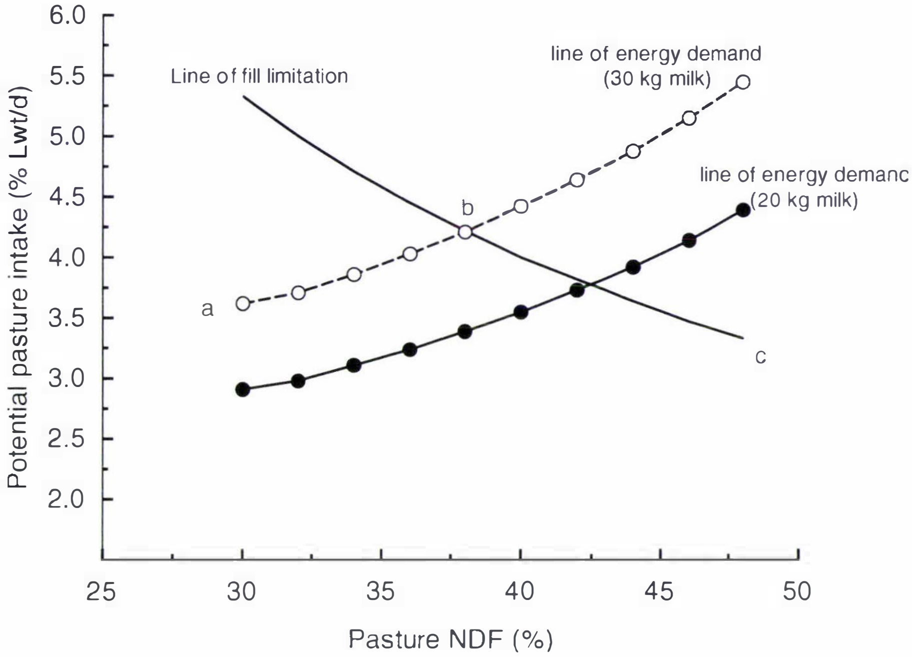

Figure 1: Predictions of potential pasture intake according to the current model, adapted from the NDF-energy system proposed by Mertens (1987). Example for a cow of 550 kg Lwt, in the 2[nd] month of lactation, fed only pasture. Theoretical intake limitation by rumen fill (——). Theoretical intake limitation by energy demand for a cow with potential of 30 kg milk (- -○- -), and 20 kg milk of 4% fat corrected (—●—). Line a to b represents potential intake limited by energy demand of the animal. Line b to c represents potential intake limited by the fill effect of the diet. Section above the point b in both lines represent unattainable intake, as predicted by the theoretical equations.

Prediction of actual pasture intake and harvesting efficiency

The extent to which the cow achieves her PPI depends on pasture allowance. The ratio of pasture allowance to PPI (RAPPI) is a measure of the pasture offered relative to the cow's demand for pasture, and is used to predict actual pasture intake. For instance, assuming a pasture allowance of 25 kg DM and a PPI of 19.3 kg DM, the RAPPI will be:

$$\text{RAPPI} = \frac{\text{Pasture allowance}}{\text{PPI}} = \frac{25.0\,\text{kg}}{19.3\,\text{kg}} = 1.30 \qquad (11)$$

This theoretical framework was used to calculate the PPI and the RAPPI for 12 grazing studies in Argentina. In Figure 2, the RAPPI is plotted against the harvesting efficiency (ratio pasture consumed: pasture allowance) actually measured in those experiments.

The empirical equation derived from data presented in Figure 2 is used in the prediction of actual pasture intake and harvesting efficiency. Using the example given in Equation 11 (RAPPI = 1.30), harvesting efficiency and actual pasture intake can be predicted as follows:

Harvesting efficiency (y) = -0.322 x Ln (1.30) + 0.7128 = 0.63

Actual pasture DMI = allowance x harvesting efficiency = 25 x 0.63 = 15.8 kg DM/cow

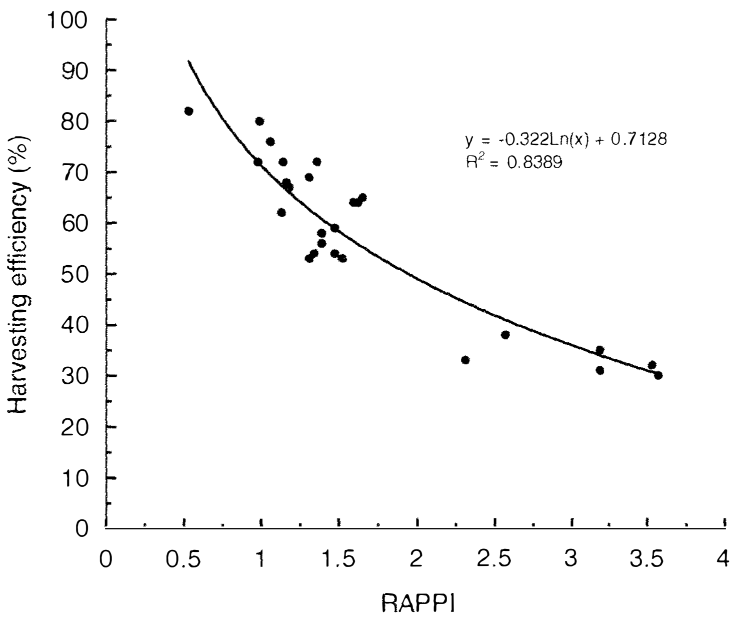

Figure 2: Harvesting efficiency (pasture consumed:pasture allowance x 100) as a function of the ratio allowance: PPI (RAPPI), using data from 12 grazing experiments in Argentina (all on lucerne, except one on ryegrass-clover). Pasture allowance was measured 4 cm above ground level and pasture consumed was calculated as the difference between pre and post-grazing herbage mass, in all the studies. Pasture NDF ranged from 35.2% to 58.3%.

Validation data

Two datasets from Argentina, different from data used in Figure 2, were used to validate the model. Dataset 1 included 19 observations of intake by group of cows in commercial dairy farms under research programmes of INTA Rafaela. Average values of this dataset were: 550 kg Lwt, 14.1 kg pasture allowance, 43.0% pasture NDF, and 8.4 kg supplements consumed/cow daily (concentrates and conserved forages). The pasture used was lucerne (Medicago sativa L.).

Dataset 2 includes data for one year from a dairy research farm in Argentina (Tambo Roca, INTA Rafaela). The average herd intakes of each month of the year were compared with model predictions. Average values of this dataset were: 570 kg Lwt, 13.6 kg pasture allowance (lucerne), 44.9% pasture NDF (ranging from 43.3% to 47.7%), and 6.6 kg supplements consumed/cow daily.

Additionally, the present model was validated against a dataset from a trial with three strains of Holstein-Friesian cows grazing ryegrass-clover pastures in Ireland, with 849 individual measurements of intake (Horan et al., 2005b). Data were grouped by month of lactation and strain of cow, resulting in 28 values of average intakes. Average values for this dataset were: 526 kg Lwt, 25.1 kg pasture allowance (ryegrass-clover), 45.3% pasture NDF (ranging from 32.6% to 52.1%), and 1.4 kg supplements consumed/cow/day. Pasture allowance was measured at 4 cm above ground level for the three datasets.

In the Argentine datasets, intake was measured as the difference between pre and post-grazing herbage mass and only a small amount of data was available for validation. Therefore, the Irish dataset was included, in order to test the model with a wider range of data, measured with greater accuracy (n-alkane technique).

Statistical analysis

Predicted pasture DMIs (P) were compared against actual observed pasture DMIs (A) using the mean-square prediction error (MSPE) defined as:

$$\text{MSPE} = \frac{1}{n}\sum(A - P)^2$$

where n is the number of pairs of values of A and P being compared. The fitness of the model was evaluated by the square root of the mean-square prediction error (RMSPE), expressed as a percentage of the mean actual pasture intake. The accuracy of the prediction was considered satisfactory when the RMSPE was lower than 10% of the mean actual intake, relatively good for RMSPE between 10 and 20%, and unsatisfactory for RMSPE greater than 20% (Fuentes Pila et al., 1996).

The concordance correlation coefficient (CCC) (Lin, 1989) was also calculated, in order to quantify the degree of deviation from the total agreement, namely the 45° line (A=P), and the deviation between A and P. The mean of the differences between A and P values divided by the mean actual intake was used to define the percentage of under or over prediction of the model.

Results

Model predictions

Actual pasture DMIs were predicted for different levels of pasture allowance and supplementation (Figure 3).

Predicted pasture DMI increased curvilinearly as pasture allowance increased, reaching a plateau at approximately 45, 40, 35, and 30 kg DM/day, for cows eating 0, 2, 4, and 6 kg DM/day of supplements, respectively. Similarly, model predictions indicated that pasture intake increased from 12.5, 12.0, 11.5 and 10.9 kg DM, up to 21.5, 19.7, 17.7, and 15.6 kg DM per cow/day as pasture allowance increased from 15 to that which maximised total DMI for cows fed 0, 2, 4, and 6 kg DM supplements, respectively. This represents an average increment of 0.31 kg DM of pasture per kg DM extra pasture allowance. Average substitution rates were 0.26, 0.43, 0.63 and 0.97 kg DM of pasture per kg DM of supplement at 15, 25, 35 and 45 kg DM pasture allowances, respectively.

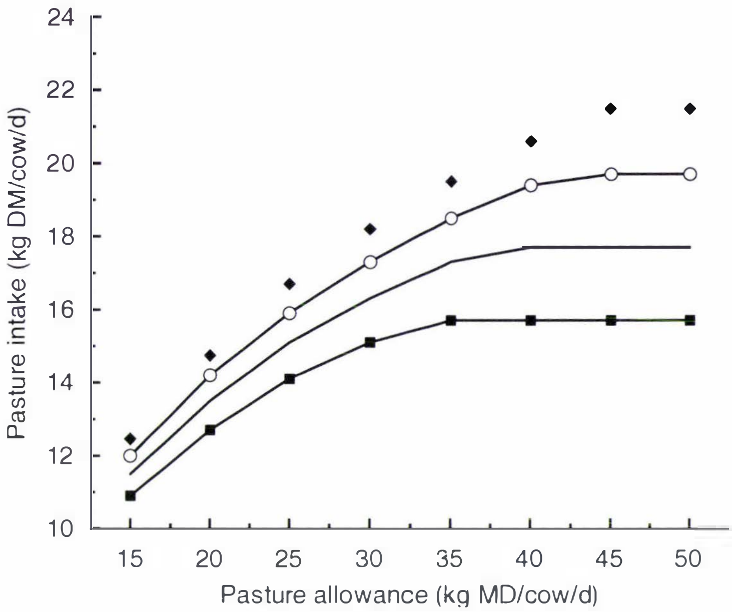

Figure 3: Model predictions showing the effect of pasture allowance on pasture intake at different levels of supplement intake. (—■—) 6 kg DM supplements/cow, (——) 4 kg DM supplements/cow, (—O—) 2 kg DM supplements/cow, and (◆) unsupplemented cows. Calculations were based on a 550 kg Lwt cow, in the week 10th of lactation (30 kg potential milk yield), and a pasture with 42% NDF. Pasture allowance at 4 cm above ground level.

Model validation

The average predictions overestimated pasture DMI by 3.6% for Argentine dataset 1, and underestimated pasture DMI by 2.2% for Argentine dataset 2, and by 5.9% for the Irish dataset. The RMSPE (expressed as a percentage of the mean actual intake) were 9.6% and 7.3% for the Argentine datasets 1 and 2, respectively, and 8.1% for the Irish dataset. Measured intakes were close to predicted intakes, with CCC of 0.9122, 0.9361 and 0.7850 for the Argentine datasets 1 and 2, and the Irish dataset, respectively (Figures 4, 5 and 6).

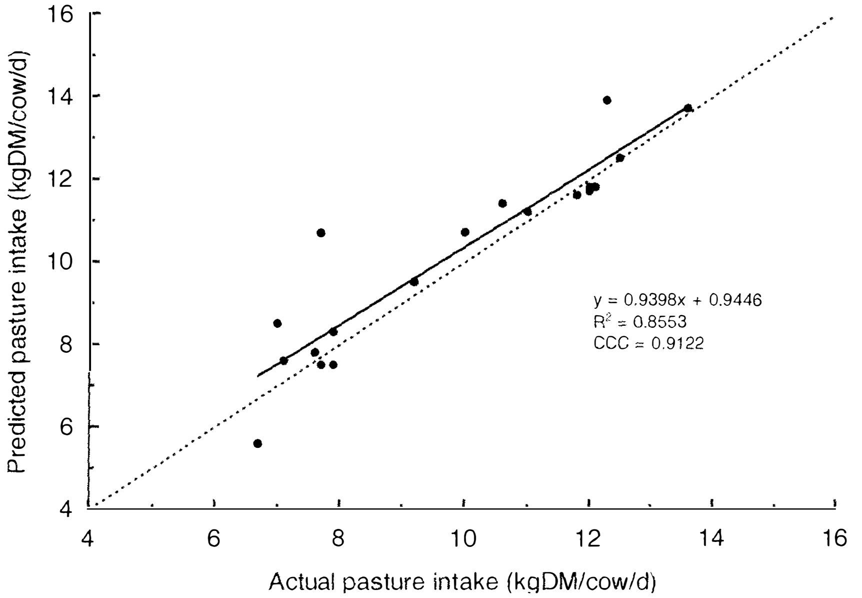

Figure.4: Actual and predicted pasture DMI of grazing dairy cows for the Argentine dataset 1 (lucerne pastures). The dashed line indicates x=y. The solid line indicates the fitted regression equation.

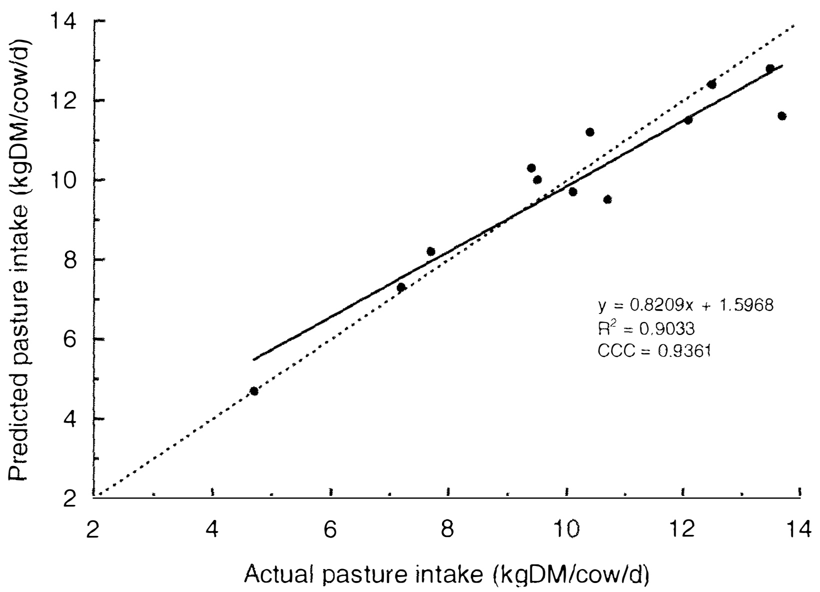

Figure 5: Actual and predicted pasture DMI of grazing dairy cows for the Argentine dataset 2 (lucerne pastures). The dashed line indicates x=y. The solid line indicates the fitted regression equation.

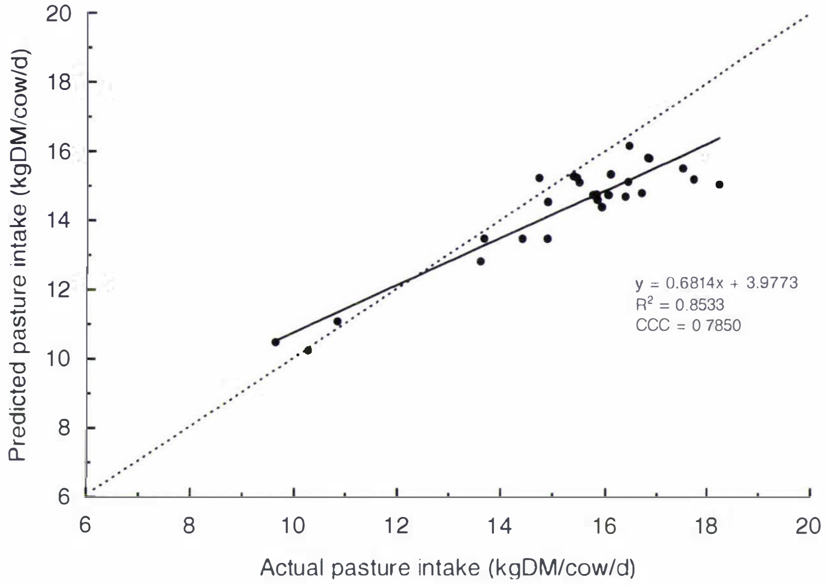

Figure 6: Actual and predicted pasture DMI of grazing dairy cows for the Irish dataset (ryegrass-clover pastures). The dashed line indicates x=y. The solid line indicates the fitted regression equation.

Discussion

The current model represents a simple approach to the prediction of daily pasture DMI, with more emphasis on animal factors than on sward factors.

The strong effect of pasture allowance on pasture DMI reflected by the current model is in agreement with the findings of many other studies (Holmes, 1987; Meijs & Hoekstra, 1984; Romero et al., 1995).

The model predicted that pasture DMI reached a plateau at 45 kg DM pasture allowance, resulting in a high intake (21.5 kg DM/cow/day) for unsupplemented cows. For unsupplemented dairy cows grazing lucerne pastures in Argentina, it was reported that pasture DMI increased up to pasture allowances of 30-33 kg DM (Comeron et al., 1995) and up to pasture allowances of 45 kg DM (7.5% Lwt) for 550 kg Lwt cows (Castillo & Gallardo, 1995). The model may have overestimated pasture DMI at high allowances for unsupplemented cows, because it does not consider physical constraints such as the amount of time available for grazing, which can prevent very high pasture DMI at grazing (Kolver, 2003). The allowances reported in this study will be lower than those reported from grazing studies in New Zealand and Australia, because the model, and Argentine studies, consider allowance at 4 cm above ground level, in contrast to New Zealand and Australia, where allowance is usually measured at ground level.

For every extra kg DM increase in pasture allowance, an increment of 0.5 kg DMI was reported for cows grazing lucerne pastures in Argentina, with 2,500 kg DM/ha or more as pre-grazing herbage mass (Romero et al., 1995). The model predicted an average increase of 0.31 kg DM per kg extra pasture allowance, but the equation used in the present model (Figure 2) was derived from studies with pre-grazing herbage mass from 1300 kg DM/ha (all expressed at 4 cm above ground level).

Meijs and Hoekstra (1984) reported substitution rates of 0.5 for cows grazing ryegrass-clover pastures in the Netherlands, at 24 kg organic matter pasture allowance (4 cm above ground level). This is similar to the substitution rate of 0.43 predicted for a pasture allowance of 25 kg DM.

High values for CCC were obtained in the validation of the model. However, the present model overestimated pasture DMI at lower DMIs, and underestimated pasture DMI at higher DMIs in the Argentine dataset 2 and the Irish dataset. Possibly, the simplification of the effects of sward factors on pasture intake in the present model reduced the accuracy of model predictions. However, the predictive accuracy of the model, tested by the RMSPE as a percentage of the mean actual pasture intake, was satisfactory (<10%) for both the Argentine and the Irish dataset.

Conclusions

The variables used in the model explained most of the variation observed in the datasets from Argentina on lucerne and Ireland on ryegrass-clover pastures. Predictions for grazing conditions other than Argentina may be improved by using data from particular grazing conditions in the empirical equation relating potential pasture intake and pasture allowance. The predicted values for DMI, harvesting efficiency and substitution rates for grazing dairy cows in Argentina will be useful for dairy farmers in deciding on the level of supplements and the stocking rates to be used. Additionally, the model can be used as part of a whole-farm model to predict the effects of stocking rate on farm productivity and profitability.

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Chapter 4

Development of a model to predict milk production and live weight change for Argentine Holstein cows

Abstract

A simulation model was developed to predict daily milk production and live weight (Lwt) change of Argentine Holstein cows in grazing dairy systems, given a determined daily intake of metabolisable energy (ME). Energy available for milk synthesis and Lwt gain is calculated by subtracting the amount of energy used for maintenance and pregnancy from the total energy intake (energy above maintenance). Firstly, milk synthesis is predicted based on a curve of potential milk yield, the energy above maintenance, the body condition score and the stage of lactation of the cow. Secondly, Lwt change is predicted. If the difference between energy partitioned towards milk synthesis and energy above maintenance is negative, Lwt mobilisation will occur. In contrast, if the difference is positive, Lwt gain will occur.

Calculations of milk synthesis and Lwt change are presented in this chapter as examples of the use of the model. An Argentine Holstein Friesian cow, of 550 kg Lwt consuming either 14, 16, or 18 kg DM per day (10.5 MJ ME/kg DM), was used in the example. However, the current model was not validated against actual data. This is the first model specifically designed to predict milk synthesis and Lwt change for Argentine Holstein cows. This model is a useful tool for further modelling studies of the productivity and profitability of grazing dairy systems in Argentina.

4.1. Introduction

Many models have been developed to answer questions related to dairying in different countries. These models have approached the 'energy partitioning problem' within the cow in a variety of ways. Most of the models developed in countries of the Northern hemisphere assumed that cows will be fed to achieve a specified lactation curve and that milk production is dependant only on the cow's inherent factors. In the dairy systems of these countries, the cow is the limiting factor to production rather than the availability of feeds. Conversely, in the dairy systems of countries such as Australia, New Zealand and Argentina, the production of milk is mainly driven by pasture growth and pasture intake (Larcombe, 1989). Hence, predetermined lactation curves for cows grazing pasture must be modified, according to the energy that can be consumed by the cow in the grazing system. In the present model, a potential lactation curve is initially defined to set the cow's upper limit for milk production. Then, the extent to which this lactation curve is achieved depends on the level of energy intake above maintenance and pregnancy.

4.2. Prediction of energy partitioning

It is widely recognised that responses in milk production to incremental increases in energy intake above maintenance are not constant and that a curve of diminishing returns applies due to the increasing partition of nutrients into body tissue. In addition, cows with a high genetic potential for milk production produce more milk per unit increase in energy intake than cows with a low potential for milk production (Hulme *et al.*, 1986). These factors are accounted for in Equations 1 and 2 of the present model.

The pathway of energy in the current model is shown in Figure 4.1. Energy available for milk synthesis and live weight (Lwt) gain is calculated by subtracting the amount of energy used for maintenance and pregnancy from the total energy intake of the cow. This is called energy above maintenance.

The model initially predicts the energy that will be partitioned towards milk synthesis, as a function of the potential milk production of the cow, the amount of energy above maintenance and the body condition score (BCS) of the cow. Then, if the difference between energy partitioned to milk synthesis and energy above maintenance is negative, Lwt mobilisation will occur. In contrast, if the difference is positive, Lwt gain will occur.

4.2.1. Prediction of milk production as a function of energy intake

The following asymptotic equation proposed by Hulme et at. (1986), based on empirical data, is used to predict actual milk production, given a potential milk production:

$$Y = P(1 - r^{x}) + P \times 0.1 \quad (1)$$

Where Y is the actual milk yield (litres/day of 4% fat corrected milk), P is the potential milk yield when energy intake is unlimited (litres/day), **r** is the ratio of milk produced from the n^{th} MJ of net energy to milk produced from the $(n - 1)^{th}$ MJ of net energy, **x** is the average net energy (NE) intake above maintenance (MJ net energy/day) and P x 0.1 is the milk production of a cow fed a maintenance ration. It is assumed that, if a cow is fed only a maintenance ration, she will mobilise body tissue and produce approximately 10% of her potential milk yield (Hulme *et al.*, 1986).

Figure 4.2 shows the average daily milk yield over the whole lactation predicted with Equation 1, for cows of different potential milk yield and fed at different levels of NE intake above maintenance. As shown in Figure 4.2, cows with higher potential milk yield will partition more energy towards milk synthesis than cows with lower potential milk yield, when both have the same NE intake above maintenance.

4.2.1.1. Potential milk production

In order to predict actual milk yield (Y) using Equation 1, a value for potential milk yield (P) is necessary for different stages of lactation. Several types of functions have been proposed to model milk production throughout the lactation of dairy cows (Wilmink, 1987; Wood, 1980). The exponential model based on a non-linear parametric curve proposed by Wilmink (1987) was used in this model to predict potential milk yield. Wilmink's Equation has the following formulation:

$$P_t = a + be^{-0.05t} + ct \quad (2)$$

Where P_t is the daily yield of milk in the t^{th} day of lactation. Parameters **a**, **b** and **c** determine the overall shape of the curve. Parameter **a** determines the initial production and the maximum level of milk produced, parameters **b** and **c** determine the shape of the curve and how the curve changes as lactation progresses. The values for parameters **a**, **b** and **c,** used in the current model, were extracted from the results of a recent study investigating the effects of strain of Holstein-Friesian cows, feeding system and parity on lactation curves of dairy cows in Ireland (Horan *et al.*, 2005).

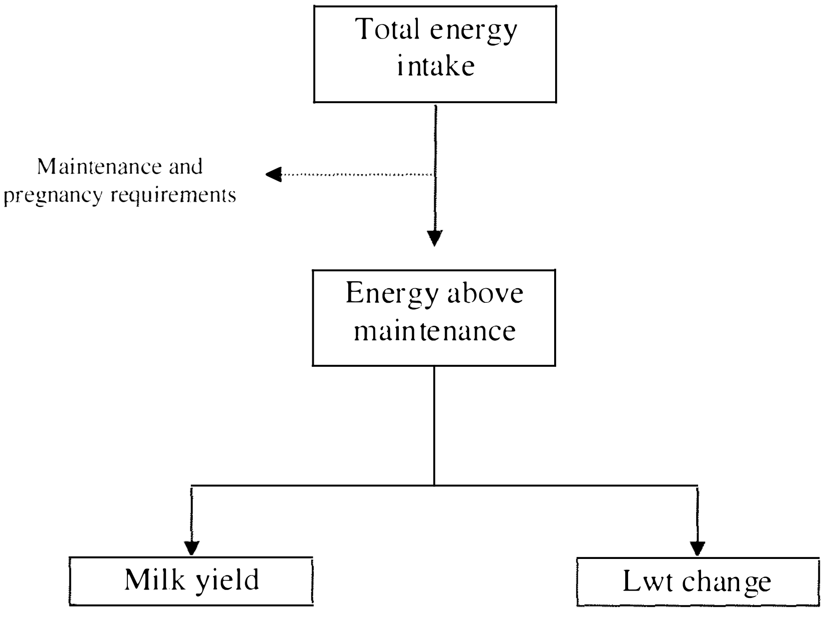

Figure 4.1: Diagrammatic representation of the model used to simulate flow of energy within the dairy cow, adapted from Larcombe (1989). Actual milk yield is a function of the amount of energy above maintenance. The energy involved in live weight change is calculated as the difference between the energy above maintenance and the energy partitioned towards milksolids production.

Parameters used for Equation 2 were those corresponding to the treatment group with the 'high productivity' strain of cows and the 'high concentrates' feeding system in the study of Horan *et al.* (2005). This strain of cows has a high proportion of American genetics, which is relatively similar to the type of cow used in Argentina (Argentine Holstein). The values for the parameters **a**, **b** and **c,** describing the curve of milk production of this strain of cows in the study by Horan *et al.* (2005), were 41.2, -22.9 and -0.0889, respectively.

Since they describe a curve of milk production in a situation close to the potential, but still actual, the value of the parameter **a** (which defines the intercept) was arbitrarily increased by 5% in the present model, in order to reflect a curve more similar to the 'potential milk yield'. The only effect of this change is an increase in milk yield all across the lactation, whilst the shape of the curve remains unchanged. Then, the parameters used in this model were 43.26, -22.9 and -0.0889 for **a**, **b** and **c** respectively.

The curves reported in the study by Horan *et al.* (2005) and the one with an increase of 5% in parameter **a** are both shown in Figure 4.3. The accumulated potential milk yield in 305 days for the 5% increased curve is 8,599 litres milk/cow (4% milkfat corrected).

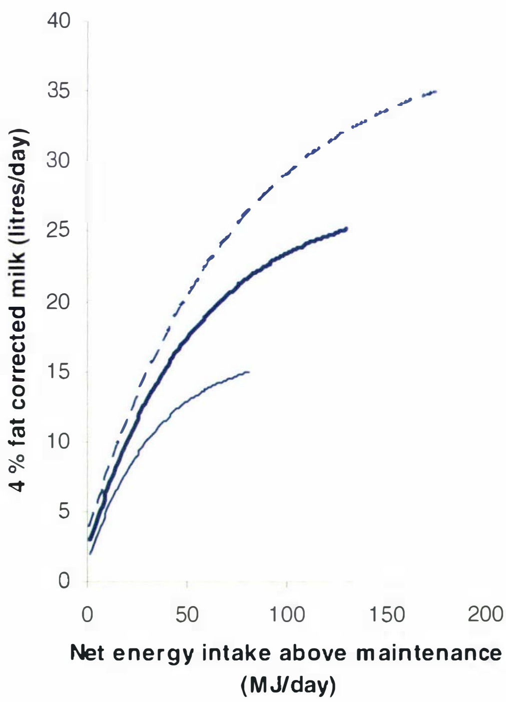

Figure 4.2: Relationship between daily net energy intake above maintenance and daily milk production. The curves are derived from Equation 1, for cows with a theoretical potential milk production of 15 (—), 25 (**—**), and 35 (- - -) litres/day (4% milkfat corrected milk). Adapted from Hulme *et al.* (1986).

4.2.1.2. Effect of body condition score on potential milk yield

The milk yield which a cow can achieve is influenced by its BCS. In the present model, the potential milk yield, calculated with Wilmink's lactation curve (Equation 2), is decreased by 7% for every unit by which the BCS of the cow is less than 6 (scale BCS 1-8). This is based on the findings of Grainger *et al.* (1982), following the methodology proposed by Hulme *et al.* (1986). Thus, if two cows, identical in all respects except BCS were fed the same ration, the cow with the high BCS would mobilise more tissue (or gain less) than the cow with the low BCS.

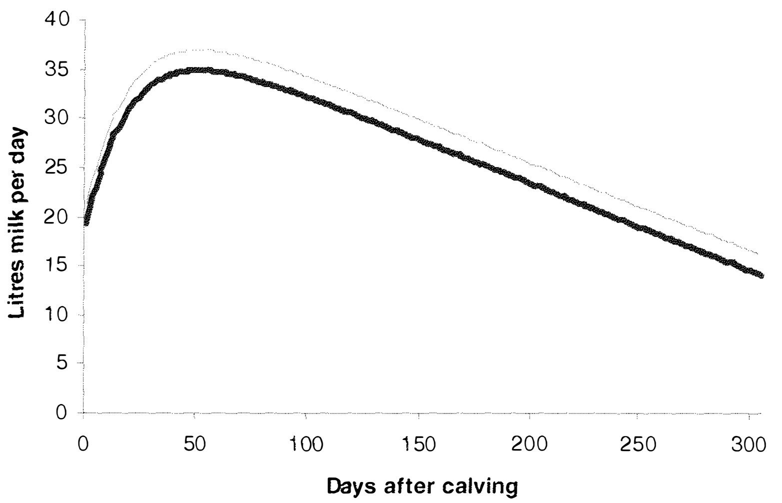

Figure 4.3: Prediction of potential milk yield in litres of milk per day (4% milkfat corrected) according to Equation 2, (**—**) values of parameters **a**, **b** and **c** as calculated from the data of Horan *et al.* (2005). (—) Parameter **a** increased by 5% from the calculated value.

4.2.1.3. Actual milk yield

The potential milk yield calculated with Equation 2, adjusted by BCS, is used in Equation 1 as the P value to calculate actual milk production.

4.2.1.4. Milkfat correction

The previous sections deal with the energy requirements for production of milk containing 4% fat. The ratio of Equation 3 is used to adjust the energy required per litre of milk produced with fat concentrations different from 4 % (Hulme *et al.*, 1986):

$$(1.509 + 0.406 \times \% \text{ fat})/(1.509 + 0.406 \times 4) \quad (3)$$

Equation 3 is based on energy requirements for production of milk containing 4% fat, proposed by ARC (1980):

$$\text{MJ NE/litre of milk} = 1.509 + 0.406 \times \% \text{ fat} \quad (4)$$

4.2.2. Prediction of change in live weight and body condition score

For the calculation of metabolisable energy (ME) associated with Lwt change (MELwt), Hulme *et al.* (1986) proposed that:

$$\text{MELwt} = \text{ME intake} - (\text{ME}_m + \text{ME}_p + \text{ME}_l) \quad (5)$$

Where ME_m is the ME for maintenance, ME_p is the ME for pregnancy and ME_l is the ME for milk synthesis.

When MELwt is negative (Equation 5), the predicted Lwt loss (kg/day) is calculated as follows:

$$\text{Lwt loss} = (\text{MELwt} \times K_l \times 1/0.84) / \text{NELwt} \quad (6)$$

Where 0.84 is the coefficient accounting for the efficiency of utilisation of body energy for milk synthesis ARC (1980), K_l is the coefficient accounting for the efficiency of utilisation of ME for lactation (see Equation 17) and NELwt is the net energy per kilogram Lwt change, which is calculated as:

$$NELwt = 10.1 + (2.47 \times BCS) \tag{7}$$

When MELwt is positive (Equation 5), Lwt gain (kg/day) is calculated as follows:

$$Lwt\ gain = (MELwt \times K_g)/NELwt \tag{8}$$

Where K_g is the coefficient accounting for the efficiency of utilisation of ME for Lwt gain. The K_g values for lactating and dry cows are shown in Equations 9 and 10, respectively.

$$K_g\ (\text{lactating cows}) = 0.6 \tag{9}$$

$$K_g\ (\text{dry cows}) = (M/D \times 0.042) + 0.006 \tag{10}$$

Where M/D is the energy density of the feed, in MJ of ME per kg DM.

The Australian system of scoring body condition was used in this model (Earle, 1976), in which condition score range from 1 to 8. Relationships amongst international body condition scoring systems including the Australian system were detailed by Roche *et al.* (2004).

Condition score is predicted in the model as a result of Lwt change. The relationship between Lwt change and BCS is based on the standard reference weight (SRW), as proposed by SCA (1990). In concept, the standard reference weight is approximately the Lwt that would be achieved by that animal, when skeletal development is complete and the empty body contains 250 g fat/kg, which is approximately a BCS of 5 for dairy cattle. For dairy cattle, with a BCS scale of 1-8, Lwt change per unit BCS may be calculated as 0.08 x SRW (SCA, 1990). Thus, for a cow 550 kg Lwt, 1 unit BCS is equivalent to 44 kg Lwt (0.08 x 550).

4.3. Calculation of energy requirements

The energy requirements in the model are based on the recommendations of SCA (1990), unless specified to the contrary.

4.3.1. Calculation of energy required for maintenance

$$ME_m\ (MJ/d) = \frac{K.S.M\ (0.28 \times Lwt^{0.75} \times e^{(-0.03A)}}{K_m} + 0.1 \times ME_l + \frac{Egraze}{K_m} \qquad (11)$$

Where K, S and M are constants with values of 1.4, 1.0 and 1.0 respectively, A is the cow's age in years, K_m is the efficiency of use of ME for maintenance (Equation 12), ME_l is the amount of dietary ME for milk synthesis, Egraze is the energy expenditure at pasture (Equation 13). The term 0.1 x ME_l indicates the acceptance that maintenance requirements are not fixed, but vary according to the level of milk yield.

The efficiency of use of energy for maintenance is calculated as:

$$K_m = 0.02 \times M/D + 0.5 \qquad (12)$$

Where M/D is the ME content per kg feed DM expressed in MJ.

The energy expenditure at pasture is calculated as:

$$Egraze = [(0.006 \times DMI \times (0.9-D)) + (0.05 \times T / (GF+3))] \times Lwt \qquad (13)$$

Where D is the digestibility of DM (decimal), T is 1, 1.5 or 2 respectively for level, undulating and hilly terrain and GF is the availability of green forage (tonnes DM/ha). The effect of energy expenditure in stressful climates was not included in this model.

4.3.2. Calculation of energy required for pregnancy

Metabolisable energy required for pregnancy (ME_p) is calculated with the following equation:

$$ME_p = \frac{(e^{349.222-349.164e^{-0.0000576t}})\,0.0201\,e^{-0.0000576t}}{k_p} \qquad (14)$$

Where **t** is the time (days) after conception, and $K_p = 0.133$, which describes the gross efficiency of use of ME for all the energy costs of gestation. Predictions are based on a 281 days gestation period and calf weight of 40 kg.

4.3.3. Calculation of energy required for milk synthesis

Requirements for milk synthesis are calculated according to the recommendations of AFRC (1990). The net energy concentration per litre of milk (NE_L) is calculated with Equation 15 as follows:

$$NE_L\,(\text{MJ/litre}) = (0.376 \times \%\ \text{milkfat}) + (0.209 \times \%\ \text{milkprotein}) + 0.976 \qquad (15)$$

Then, NE_L is converted into ME concentration per litre of milk with Equation 16 as follows:

$$\text{ME lactation (MJ/ litre)} = NE_L / K_l \qquad (16)$$

$$\text{Where } K_l = (\text{M/D} \times 0.02) + 0.4 \qquad (17)$$

Finally, ME required for lactation at day **t** is calculated with Equation 18:

$$\text{ME lactation (MJ/day)} = \text{ME per litre} \times \text{litres per day} \qquad (18)$$

4.4. Practical use of the model

Figures 4.4 and 4.5 illustrates milk yield (4% fat corrected) and Lwt change, calculated for an Argentine Holstein cow (550 kg Lwt) consuming either 14, 16, or 18 kg DM per day, across the lactation. The ME concentration per kg DM assumed in this example was 10.5 MJ/kg DM. Therefore, ME intakes per day were 147, 168 and 189 MJ ME per cow. Cows were assumed to be pregnant from the 90^{th} day after calving.

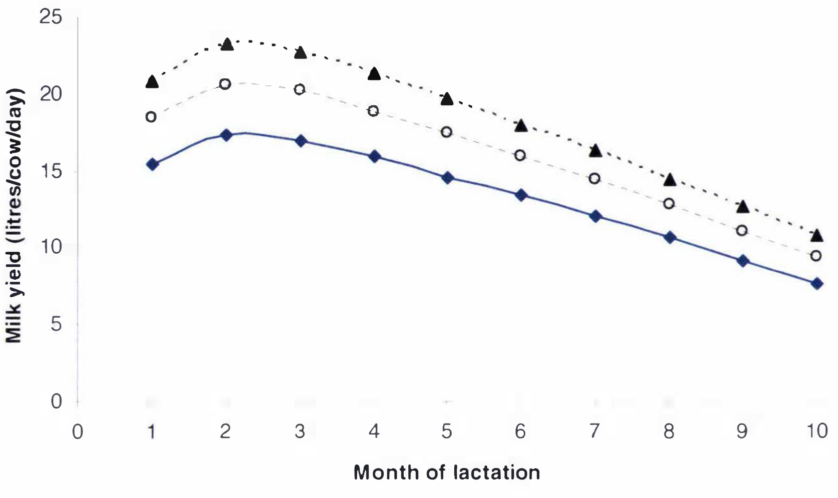

Figure 4.4: Predictions of milk yield (4% fat corrected) by the current model, for a cow consuming 14 kg (—◆—), 16 kg (- -○- -) and 18 kg (- -▲- -) dry matter per day across the lactation. Example for cows of 550 kg Lwt, consuming feed with 10.5 MJ ME per kg dry matter.

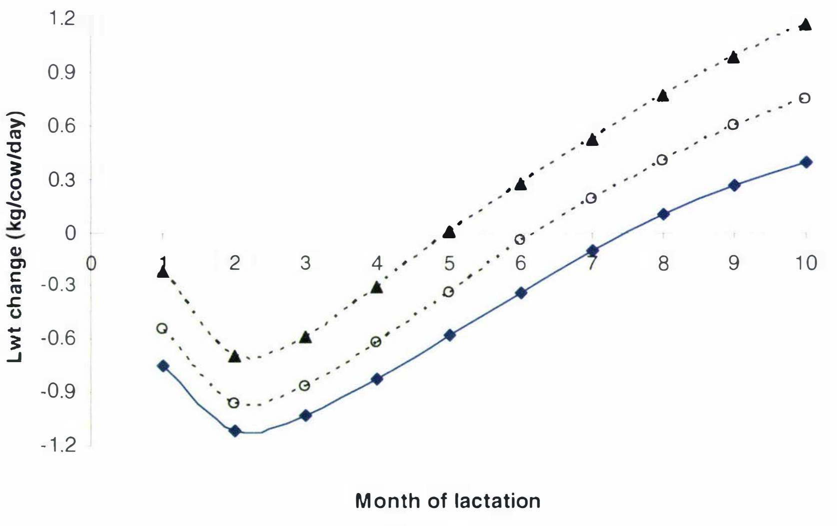

Figure 4.5: Predictions of Lwt change by the current model, for a cow consuming 14 kg (—◆—), 16 kg (- -○- -) and 18 kg (- -▲- -) dry matter per day across the lactation. Example for cows of 550 kg Lwt, consuming feed with 10.5 MJ ME per kg dry matter.

4.5. Conclusions

This is the first model specifically designed to predict milk yield and Lwt change for Argentine Holstein cows. The model bases its predictions on a potential curve of milk production and the intake of energy above maintenance. This model is a useful tool for further modelling studies of the productivity and profitability of grazing dairy systems in Argentina.

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Chapter 5

Modelling the effects of stocking rate and supplementation on the productivity and profitability of Argentine dairy systems

Abstract

Dairy production in Argentina is based on grazed pastures, with the inclusion of supplements as a secondary source of feed. Stocking rate (SR) is one of the factors with the most influence on the productivity and profitability of grazing dairy systems. The traditional definition of stocking rate, expressed as number of cows per hectare, could be improved if it is expressed as kg live weight per tonne of DM offered (comparative SR). The effects of comparative SR and its interaction with supplementation, on the productivity and profitability of the whole-farm, have not been studied in Argentina. The objective of the present study was to quantify the effects of comparative SR and the inclusion of supplementary feeds (concentrates) on farm productivity and profitability, for a representative Argentine dairy farm, based on a simulation model. In contrast to previous developed simulation studies in Argentina, pasture utilisation and milksolids production are not predetermined but are simulated, enabling them to change with changes in SR and supplementation.

A whole-farm simulation model called the Argentine Dairy System Model (ADSM) was developed. A productive model is articulated with an economic model, which enables the prediction of pasture dry matter intake (DMI), milk solids (MS) production per cow, live weight (Lwt) change per cow, economic farm surplus (EFS) and return on assets (ROA). This is a mathematical, deterministic and mechanistic whole-farm model developed on an Excel spreadsheet. All calculations were made on a monthly basis. Simulations were made over a 12-month period. The herd was broken down by month of calving and simulations of the herd performance were based on groups of cows calving in the middle of each month. The cow type used was the Argentine Holstein (550 kg Lwt and 6.8% milksolids content).

Twenty-two dairy systems were modelled, created by combinations of SR and imported concentrates. The comparative SR ranged from 50 to 123 kg Lwt/t DM. Predicted MS production per hectare were compared with actual observed MS production per hectare from eight Argentine dairy farms. The accuracy of the model predictions was satisfactory, with a mean prediction error of 9.7% of the actual mean MS production.

The model predicted that, at a low comparative SR of 60 kg Lwt/t DM (relatively common in Argentina), almost half of the pasture produced was wasted (53% pasture utilisation). Pasture utilisations of 70% or greater were achieved only in systems with

comparative SR of 80 kg Lwt/t DM or greater. Total DMI per cow per year decreased linearly as comparative SR increased. Annual intake per cow decreased from 6.0 to 4.3 t DM/cow as comparative SR increased from 60 to 110 kg Lwt/t DM. The minimum milk response to concentrates (41g MS/kg concentrate) occurred when cows consumed 6.3 t DM/cow/year. The maximum milk response (101 g MS/kg concentrate) occurred when cows consumed 4.2 t DM/cow/year. Substitution of pasture per concentrate was minimum (0.08) for cows consuming 4.2 t DM/cow/year and maximum (0.76) for cows consuming 6.3 t DM/cow/year. In the remaining systems, milk response and substitution rate ranged between these extremes. The EFS ($/ha) increased as comparative SR increased, reaching a maximum at 90 kg Lwt/t DM. Further increases in comparative SR decreased EFS. However, the optimum ROA occurred at a slightly lower comparative SR than EFS (approximately at 80 kg Lwt/t DM). At the milk payout and concentrates price used in this study, it would be profitable to increase the amount of imported feed up to 3.6 t DM per hectare (which is much higher than the average in Argentina), provided that comparative SR is simultaneously increased, in order to achieve pasture utilisation of 70% or higher. A dairy system with 8.6 t DM/ha/year produced on-farm, importing 3.6 t DM concentrates per year and stocked at 81 kg Lwt/t DM (1.8 cows/ha), would be able to utilise 71% of pasture and produce 626 kg MS/ha/year.

Results from this study suggest that the relatively low MS production per hectare, that is characteristics of Argentine dairy systems, can be improved through an increase in both the comparative SR and the amount of imported feeds. The optimum comparative SR, from the point of view of the profitability and sustainability of the system, appeared to be around 80 kg Lwt/t DM. For farms producing 8.6 t DM on-farm, the optimum comparative SR is equivalent to 1.6, 1.8, and 2.0 cows per hectare for systems importing 1.2, 2.4, and 3.6 t DM concentrates per hectare per year, respectively.

5.1. Introduction

Dairy production in Argentina is based on grazed pastures (mainly lucerne), with the inclusion of supplements as a secondary source of feed (Castillo and Gallardo, 1998). Cows graze and calve all year round, but calving is generally concentrated in autumn and spring (Garcia, 1997). The cost of pasture, conserved forages and concentrates, relative to milk price, determines that dairy production in Argentine must be based on pastures in order to be profitable (Molinuevo, 2001). However, the inclusion of supplementary feeds can be profitable, depending on the size of milk responses to the supplements and the price received for milk, relative to the cost of supplements. A survey of 966 Argentine dairy farms indicated that the average cow's diet is made up of approximately 67 % grazed pasture or crops, 11% silage and hay and 22 % concentrates (Gambuzzi *et al.*, 2003).

The output of milksolids (MS) production per hectare from a grazing dairy system reflects the product of three major efficiencies: the efficiency of pasture production (tonnes dry matter per hectare), the efficiency of pasture utilisation (proportion of pasture grown actually consumed by grazing animals) and the efficiency of conversion of pasture consumed into milksolids (Hodgson, 1995; Holmes *et al.*, 2002). Stocking rate (SR), expressed as cows per hectare, is the management practice with the greatest influence on all three of these efficiencies. The adjustment of stocking rate (SR) enables feed demand to be balanced with feed supply, on an annual basis (Bryant *et al.*, 2003).

Pasture utilisation and MS production per cow and per hectare are related to SR. As SR is increased, pasture intake and MS production per cow decreases, whilst pasture utilisation and MS production per hectare increases (Penno, 1999; Macdonald *et al.*, 2001). Therefore, SR markedly affects the productivity and profitability of grazing dairy systems (Penno, 1999). Strategically used, supplements may give farmers the confidence to increase SR, thus allowing the benefits of high SR to be captured, whilst still being able to overcome its adverse effects by maintaining reasonably high feed intakes and MS production per cow (Macdonald, 1999).

The average SR in Argentine dairy farms is approximately 1.15 cows/ha (Gambuzzi *et al.*, 2003), which is lower than the 2.8 cows/ha in New Zealand (LIC, 2005), 2.5 in Australia and 1.9 in Ireland (Dillon *et al.*, 2005), which are some of the most efficient dairy systems worldwide. However, it is technically possible to increase SR up to 2 cows per hectare in Argentina (Garcia, 1997). The SR in Argentine dairy farms was found to be correlated with milk fat production per hectare: R^2=0.82 (Garcia, 1997) and with milk production per hectare: R^2=0.54 (Gambuzzi *et al.*, 2003).

The lower SRs used in Argentina are partially explained by lower pasture production per hectare (approximately 6 to 9 t DM/ha) and lower pasture quality (9.9 MJ ME per kg dry matter of lucerne pastures, Gaggiotti *et al.*, 2002), compared with those obtained in the countries mentioned above. However, SR is also lower because of the management decisions made by farmers and advisors. This policy of using low SR is reflected by the low pasture utilisation achieved, which is usually lower than 65% (Romero *et al.*, 1998). This is lower than that obtained in the grazing dairy systems of New Zealand, Australia and Ireland. It is likely that the perceived need to achieve high milk yield per cow discourages Argentine dairy farmers from higher SRs.

Stocking rate, expressed as cows per hectare, is a simplification of the relationship between feed demand and feed supply. Live weight (Lwt) would provide a better measure of the potential feed demand of the cow, rather than just the number of cows. Similarly, the total amount of feed provided is a better way to quantify feed supply, rather than just the area farmed. This suggests that a ratio of total herd Lwt to total dry matter (DM) feed supply is a better measure of the SR ratio and this could be expressed as: kg Lwt/t DM total feed supply (Penno, 1999), which is an expression known as comparative SR.

The effects of comparative SR and its interaction with supplementation on the productivity and profitability of the whole-farm have not been studied in Argentina. Some studies simulated the productivity and profitability of dairy systems with different SR (Comeron, 2003; Comeron and Schilder, 1997; Schneider *et al.*, 2003), but with relatively similar comparative SRs. In addition, these studies assumed predetermined values of pasture utilisation and MS production and explored a maximum of six alternatives. Indeed, the isolated effect of SR has not been studied. Those simulation studies predicted that increasing SR, by using Jersey instead of Holstein cows, increased productivity and profitability per hectare (Comeron, 2003). Similarly, Schneider *et al.* (2001) suggested that more cows per hectare, resulting from more pasture production and more imported feed per hectare, would increase productivity and profitability. Additionally, Comeron and Schilder (1997) simulated three alternatives that had the same productivity per hectare, but different SR and different milk yield per cow. More feed was imported in the system with lower SR and higher cow milk yield. The results of this study indicated that the system which had the higher SR and the lower production per cow was the most profitable.

The objective of the present study was to quantify the effects of comparative SR and the inclusion of supplementary feeds (concentrates) on farm productivity and profitability, for a representative Argentine dairy farm, based on a simulation model developed for this purpose. In contrast to previous developed simulation studies in Argentina, pasture utilisation and MS production are not predetermined but are simulated, by integrating the models developed in Chapters 3 and 4. Emphasis is placed on the interactions between stocking rate, pasture utilisation, MS production per cow and per hectare and substitution of pasture by supplements.

5.2. Materials and Methods

A whole-farm simulation model called the Argentine Dairy System Model (ADSM) was developed for this study. The ADSM comprises a productive model articulated with an economic model, which enables the prediction of pasture DM intake (DMI), MS production and live weight (Lwt) change per cow, economic farm surplus (EFS) and return on assets (ROA) for Argentine dairy farms. This is a mathematical, deterministic and mechanistic whole-farm model, developed in Excel.

5.2.1. Productive model

This model simulates two basic biological processes: feed (and energy) intake and energy partitioning within the cow, either to milk synthesis or to Lwt change. The productive model resulted from the integration of the model developed in Chapter 3 (for prediction of DMI) and the model developed in Chapter 4 (for prediction of MS yield and Lwt change), using metabolisable energy (ME) as the common exchangeable unit.

This model bases its calculations on DMI and ME provided by the feeds. For the sake of simplicity, this model assumes that protein is not a limiting factor, based on the fact that energy is usually the first limiting nutrient for high producing dairy cows grazing temperate pastures (Macdonald *et al.*, 1998).

All calculations were made on a monthly basis. Values expressed on a daily basis represent the average of the month. Simulations were made over a 12-month period. The model is designed to simulate herds that calved all year-around. The herd was broken down by the month of calving and simulations of the herd performance were based on 12 groups of cows, each calving in the middle of each moth.

A general overview of the structure of the model used to predict DMI and energy intake of the herd is shown in Figure 5.1. The two main components of the system are feed demand and feed supply. The latter includes DM produced on-farm (pastures and crops) and feed imported (concentrates). The balance between feed demand and feed supply defines the amount of pasture harvested. Total DMI is the result of the summation of pasture DMI (predicted) and supplements DMI (input). The total ME intake is calculated from total DMI and the ME concentration of pastures and supplements.

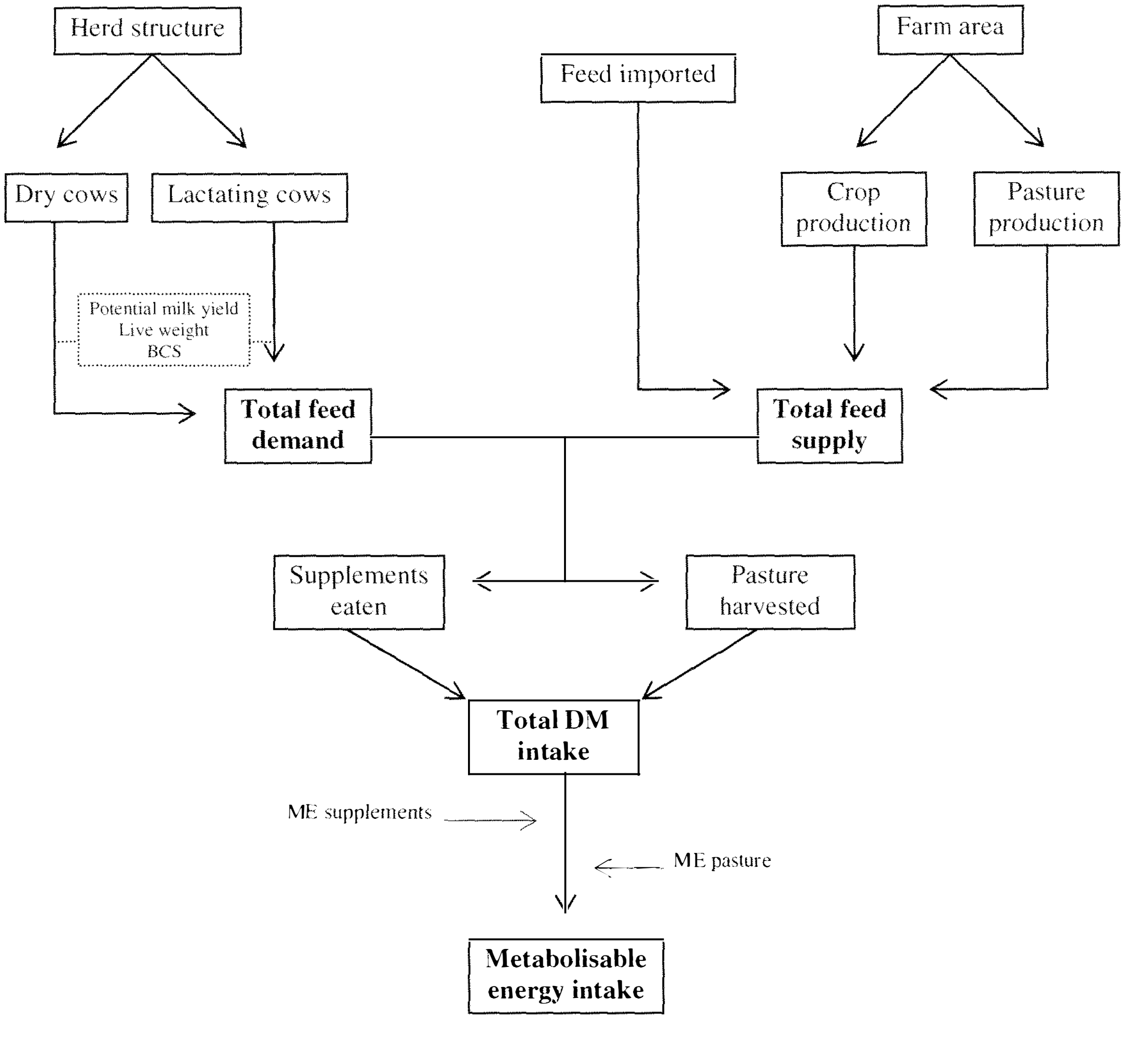

Figure 5.1: Schematic representation of the prediction of dry matter intake and metabolisable energy (ME) intake by the herd.

5.2.1.1. Inputs necessary to run the productive model

The following data is required to run the productive model and to simulate DMI, MS production and cow Lwt change:

- Farm area and land use
- Pasture and crops production per hectare per month
- Pasture and crops quality (NDF and ME) per month
- Quantity and quality (NDF and ME) of imported concentrates per month
- Herd composition (numbers of lactating and dry cows per month)
- Number of cows calved in each month
- Cow's Lwt at calving
- Average % milkfat and % milkprotein
- Body condition score at calving

5.2.1.2. Management decisions

Once the inputs have been entered, the proportion of the grazing area destined for the lactating and dry cows must be defined on a monthly basis. Other management decisions are the area of pasture to be closed for hay and the distribution of conserved forages and concentrates per month of the year and per group of cows (cows are grouped according to month of lactation).

5.2.1.3. Components of the productive model

Pastures

The characteristics of pastures are defined through its DM production per month, its concentration of neutral detergent fibre (NDF) and its ME concentration. The model is able to run with perennial pastures and winter crops for grazing. Cows are assumed to be fed every month with the pasture produced within this month.

Summer crops

Summer crops can be used either for silage or hay. The characteristics of each crop are defined through its total DM production and its quality (NDF and ME). Summer crops are considered to occupy the land for a period of six months. It is assumed that 25% of the DM produced from summer crops is wasted in the processes of conservation and feeding conserved forages (Schneider *et al.*, 2001).

Imported feed

The productive model considers that the only imported feeds are concentrates, because conserved forages are produced on-farm. This is similar to what occurs in Argentine dairy systems. It is assumed that utilisation of concentrates is 95 %.

Cows

The type of cow can be defined through its Lwt, potential milk yield curve and concentrations of milkfat and milkprotein. The equation defining the potential lactation curve used in this model was described in Chapter 3. Milk yield and Lwt change are modelled for an average group of cows for each month of calving, rather than for individual cows.

No allowances are made for cow's age in the present model (a mixed age herd is assumed). An all year round calving system is assumed. The performance of the herd is based on groups of cows calving in the middle of each month.

5.2.1.4. Prediction of dry matter and energy consumed by the herd

Predictions of pasture DMI for the individual cow were described in Chapter 3. Prediction of DMI is calculated separately for the lactating and the dry herds, considering the grazing area allocated to every herd. Average pasture DMI is calculated for each group of cows in the same month of lactation (as an individual cow). Therefore, 12 values for actual pasture DMIs are obtained for each month of the year (see example in Table 5.1).

The total pasture DMI is then calculated, taking into account the number of cows in each month of lactation. Total DMI is calculated as the summation of DMI of supplements (given as input) and DMI of pasture (predicted). Total ME intake is calculated as follows:

$$\text{Total ME intake} = (\text{pasture DMI} \times \text{ME pasture}) + (\text{supplement DMI} \times \text{ME supplement}) \quad (1)$$

Table 5.1: Actual pasture DMI over the year for each group of cows calving in the same month. Example for 550 kg live weight cows fed only pasture. Values expressed in kg DM/cow/day (average for the month).

Month after calving	J	F	M	A	M	J	J	A	S	O	N	D
1	14.6	14.2	14.6	14.0	14.0	13.8	14.0	14.0	15.6	15.7	16.8	16.8
2	16.2	15.8	16.2	15.6	15.6	15.4	15.6	15.6	17.2	17.3	18.4	18.4
3	17.6	17.2	17.6	17.0	17.0	16.8	17.0	17.0	18.6	18.7	19.8	19.8
4	17.2	16.8	17.2	16.6	16.6	16.4	16.6	16.6	18.2	18.3	19.4	19.4
5	17.0	16.6	17.0	16.4	16.3	16.2	16.3	16.3	18.0	18.1	19.2	19.2
6	16.8	16.4	16.8	16.2	16.1	16.0	16.1	16.1	17.8	17.9	19.0	19.0
7	16.6	16.3	16.6	16.1	16.0	15.9	16.0	16.0	17.5	17.6	18.6	18.6
8	16.0	15.7	16.0	15.5	15.4	15.3	15.4	15.4	17.0	17.2	18.2	18.2
9	15.6	15.3	15.6	15.1	15.0	14.9	15.0	15.0	16.6	16.7	17.7	17.7
10	15.4	15.1	15.4	14.9	14.8	14.7	14.8	14.8	16.4	16.5	17.5	17.5
DRY1	10.9	10.8	10.9	10.7	10.7	10.7	10.7	10.7	11.3	11.3	11.6	11.7
DRY2	10.9	10.8	10.9	10.7	10.7	10.7	10.7	10.7	11.3	11.3	11.6	11.7

5.2.2. Economic model

An economic model, called TAMBO 2000 (Cursack *et al.*, 2003a), was linked to the productive model described above. The integration of the productive model with the economic model TAMBO 2000 is called the Argentine Dairy System Model in this study. TAMBO 2000 is a deterministic budgeting model, developed in an Excel spreadsheet, for the economic analysis of Argentine farms. The model can be run either for dairy farms or for farms integrating dairy, beef and crop production. A detailed description of the model can be found in Cursack *et al.* (2003b).

The key output indicators of TAMBO 2000 are net income and return on assets (ROA). When all the land is owned, net income is equivalent to economic farm surplus (EFS), which was used as one of the main output indicators in this study. Table 5.2 shows a detailed structure for the calculation of EFS, which is a measure of the operating profits of a farming enterprise (Shadbolt and Martin, 2005). Return on assets was calculated as shown in Equation 2.

$$\text{ROA} = (\text{EFS - lease charges}) / \text{Total assets} \qquad (2)$$

Table 5.2: Detailed structure for the calculation of economic farm surplus (EFS), showing an example for a farm with 8.6 t DM produced on-farm (average of pasture and crops), stocked at 1.2 cows per hectare and with 1.2 t DM concentrates imported per hectare per year. Production was 340 kg MS/cow and 409 kg MS/ha. The price per kg MS was $US 2.35.

Income	$US/hectare	$US/litre[1]
Milksolids	952	0.160
Net stock income	81	0.014
+/- Change in stock number		
Gross farm income	1,033	0.174
Expenses		
Wages	133	0.022
Animal health	47	0.008
Breeding/herd testing	20	0.003
Shed expenses	11	0.002
Electricity	14	0.002
Freight	6	0.001
Feed produced on farm[2]	70	0.012
Conserved forages	45	0.008
Grazing-off heifers	40	0.007
Feed imported	119	0.020
Fertiliser	22	0.004
Calves' concentrate	2	0.000
Replacement	-	-
Repairs and maintenance	8	0.001
Vehicles	13	0.002
Administration	30	0.005
Advisors	6	0.001
Standing charges[3]	34	0.006
Depreciation	68	0.011
Operating expenses	688	0.115
EFS (Gross farm income – operating expenses)	345	0.059

[1]6.8% MS per litre of milk

[2]includes seeds, weed, pest and planting costs of pastures and grazing crops

[3]Taxes, insurances and rates

The economic model TAMBO 2000 was easily linked to the productive model, because both are based on Excel spreadsheets. The following data from the productive model was used as input in TAMBO 2000: number of cows, land use, kilograms of concentrate purchased, hay and silage production per year, volume of milk produced, MS production and pasture production.

5.2.2.1. Inputs necessary to run the economic model

The economic model, TAMBO 2000, requires the following data as inputs:

- Detailed list of assets (amount, value and expected useful life when applicable) including buildings, machinery and land
- Land use (area of pasture and crops)
- Detailed list of farm working expenses (see Table 5.2)
- Livestock number and changes during the year (stock, purchase and sales, mortality)
- Milk production, milk composition and milk price
- Price of stock sold
- Labour adjustment

5.2.2.2 Validation data

Actual data from eight Argentine dairy farms and simulated data from ADSM were compared, in order to determine the reliability of the model to predict MS production per hectare. The kilograms of MS produced per hectare is an indicator which integrates the main productive parameters of ADSM, i.e., DMI per cow, MS production per cow and stocking rate. Actual data to validate the model were obtained from one research dairy farm (Tambo Roca, INTA Rafaela) and seven commercial dairy farms located in Buenos Aires province (CREA farmers). The 'CREA farmers' are a group of top farmers of Argentina, who keep productive and economic records of their annual farm performance. The main characteristics of the dairy farms, depicted in Figure 5.2, are illustrated in Table 1 of Appendix A (farm 1 to 8). Additionally, actual data from 18 Argentine dairy farms, including comparative SR and annual pasture utilisation, were compared with ADSM predictions for a dairy farm with 8.6 t DM produced/year and 1.2

t DM imported/year (Figure 5.2). Actual data were obtained from those farms used in Figure 5.2, plus 10 commercial dairy farms, also located in Buenos Aires province (CREA farmers). The main characteristics of the 18 dairy farms are shown in Table 1 of Appendix A.

5.3. Case farm

A case farm of 100 hectares was set up with the objective of studying the effects of comparative SR and imported concentrates on the productivity and profitability of the system. The delimitation of a representative Argentine dairy farm is beyond the scope of this study, which did not try to reproduce a 'representative' dairy farm for the case farm used in this study, but instead set up a simple farm to allow the effects of SR and supplementation to be isolated and studied. However, when available, data reported as 'representative' for an Argentine dairy farm were used from Ostrowski and Deblitz (2003) and Gambuzzi *et al.* (2003).

5.3.1. Productive data

Land use, pasture and crops production (and quality) assumed for the case farm are shown in Table 5.3, whilst the calving pattern is shown in Table 5.4. The conserved forages and concentrates available for the year were distributed to meet, as far as possible, the requirements of the cows over the whole year.

Table 5.3: Land use, pasture and crops production (and quality) of the 100 hectares case farm used in the current study.

Crop or pasture	Area (has)	DM production (kg DM/ha/year)	MEconcentration (MJ ME/kg DM)	NDF (%)
Lucerne	65	8,000	10.1	44
Winter oat	30	5,000	10.3	52
Setaria (hay)	20	4,500	8.8	67
Maize (silage)	10	10,000	9.2	53
Unproductive	5	0	-	-
Total /average	100	8,600	-	-

NOTE: DM productions are within the expected range for Argentine dairy farms. Percentage of NDF and ME concentration of pasture and crops are the average of forage analysis undertaken in the Department of Animal Production Laboratory of INTA Rafaela, Argentina (Gaggiotti *et al.*, 2002).

The current study assumed that only one type of cow is used, the Argentine Holstein, which has a high proportion of American genotype (Molinuevo, 2001), an average Lwt of approximately 550 kg, 3.6% milkfat and 3.2% milkprotein (Comeron, 2003). The herd is assumed to spend 78% of the year lactating and 22% dry. The equation and parameters used for the lactation curve were described in Chapter 3. The distribution of pasture produced is shown in Table 2 of Appendix A.

Table 5.4: Calving pattern used in the case farm.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% calving	3	6	15	14	11	4	4	9	14	10	6	4

5.3.2. Economic data

The economic analysis was based on average values of marketable products and average costs of Argentine dairy farms. Economic performance was measured as EFS per hectare and ROA per hectare. Economic farm surplus is an index similar to net income, if there is no debt and all land is owned (as is the situation in the current case farm).

Incomes

The payment for milk produced was based on high quality milk with 6.8% MS, which under the current system of payment in Argentina, results in $US 0.16 per litre of milk (approximately $US 2.35 per kg MS). Beef income was derived from sale of male calves, surplus female calves and culled cows.

Expenses

Average farm costs were taken from Vega (2005) and Márgenes Agropecuarios (2005). Average expenses for the case farm, with SR of 1.2 cows per hectare and 1.2 t DM as imported concentrates per hectare per year, are shown in Table 5.2.

5.3.3. Assumptions

- It was assumed that all land was owned and no debt was considered.
- Twenty-five percent of replacement heifers were introduced as in-calf 2-year-old heifers to replace culled (voluntary and involuntary) and dead cows. The average

percentage of culled cows was 20% (Ostrowski and Deblitz, 2003). All male and surplus female calves were assumed to be sold at one month of age.

- Heifers were assumed to be grazed away from the farm from two-months of age until two-months before calving date. Body condition score (BCS) at calving was assumed to be 4.5 units (scale 1-8). All pasture was used by grazing (no pasture area closed for hay).
- As SR increased, it was assumed that expenses in animal health, breeding and herd testing, shed expenses, electricity, freight and grazing-off increased proportionally to cow numbers. However, expenses for wages, administration and advisors were assumed to vary in proportion to the volume of milk produced per year (which is usually the case in Argentine dairy farms). Expenses for repairs and maintenance, pasture and crops production, conserved forages and standing charges were assumed to be constant as SR increased. The use of fertiliser increased in proportion to cow numbers, in order to compensate for the higher nutrient extraction as SR increased and consequently, pasture utilisation increased.
- It was assumed that the capital invested in milking machinery, feeding machinery and cowshed increased proportional to cow numbers. The investment on the remainder of the machinery, land improvements and buildings was assumed to be the same, irrespective of the SR.
- 1.00 $US = 3.05 $AR = 1.43 $NZ (exchange rates from February 2006).

5.3.4. Statistical analysis

Predicted MS productions (P) were compared against actual observed MS productions (A) using the mean-square prediction error (MSPE) defined as:

$$\text{MSPE} = \frac{1}{n}\sum(A - P)^2$$

where n is the number of pairs of values of A and P being compared. The fitness of the model was evaluated by the mean prediction error (MPE), calculated as the square root of MSPE divided by the mean actual MS production. The accuracy of the prediction was considered satisfactory when MPE was lower than 10% of mean actual MS production, relatively good for MPE between 10 and 20% and unsatisfactory for MPE greater than 20% (Fuentes Pila *et al.*, 1996). Predicted MS productions were regressed against actual MS productions to determine coefficient of determination (R^2).

5.3.5. Model simulations

Twenty two dairy systems were modelled with ADSM, by combining eight levels of SR and three levels of concentrates imported into the farm (excluding the two extreme systems with the highest and lowest comparative SR). Thus, different comparative SRs were obtained, with different proportions of feeds imported and produced on-farm (Table 5.5).

Although some of the comparative SR of the systems included in this study were 'not sensible' for a commercial dairy farm, they were included to study the full range of changes in DMI and MS production as functions of comparative SR. Productive outputs of the model are shown in table 5.6, whilst economic outputs are shown in Table 5.7.

Table 5.5: Comparative SR (kg Lwt/t DM total feed supply) of the systems simulated with ADSM, for 8.6 t DM produced on-farm and cows of 550 kg Lwt.

	Stocking rate (cows/ha)							
Imported feed (t DM/ha/year)	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
1.2	56	67	79	90	101	112	123	
2.4	50	60	70	80	90	100	110	120
3.6		54	63	72	81	90	99	108

5.4. Results

5.4.1. Model validation

Figure 5.2 shows that ADSM predicted MS production with reasonable accuracy for the eight dairy farms tested, which had detailed farm data. However, an average under-prediction of 7.3% was observed. The fitness of the model was satisfactory: MPE of 9.1 % of the mean actual MS production for data plotted in Figure 5.2.

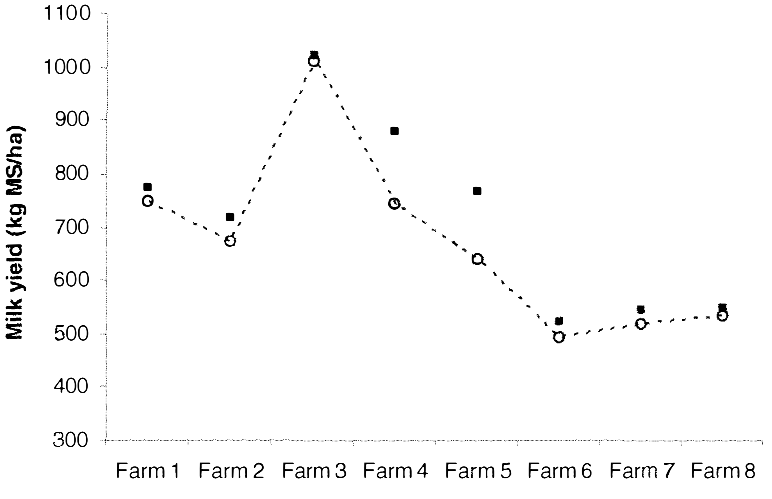

Figure 5.2: Milk yield (kg MS/ha) observed (▪) of eight Argentine dairy farms and predicted with the model (- -○- -).

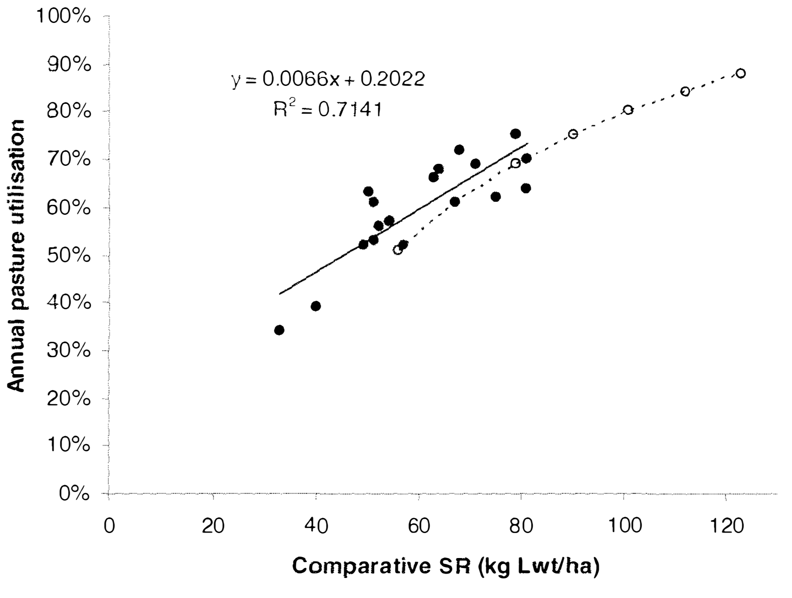

Figure 5.3: Annual pasture utilisation (pasture eaten/pasture grown x 100) as a function of comparative SR observed in 18 Argentine dairy farms (•) with average pasture production of 9.9 t DM/ha, and modelled with ADSM (- -•- -) for a dairy farm with 8.6 t DM produced on-farm and 1.2 t DM of concentrate imported per hectare per year. Regression line (——) for data observed in Argentine dairy farms.

Annual pasture utilisation was positively correlated with comparative SR for data observed in the Argentine dairy farms (R^2=0.71) (Figure 5.3). Annual pasture utilisation increased 6.6% for every increase of comparative SR of 10 kg Lwt/t DM, according to the equation of Figure 5.3. The curve predicting pasture utilisation for the modelled systems shows a similar trend with data observed in the Argentine dairy farms analysed. ADSM predicted slightly lower values of pasture utilisation than actual data, for the same comparative SR.

5.4.2. Pasture utilisations

A curvilinear relationship was found between comparative SR and annual pasture utilisation for the systems modelled. At a low SR of 60 kg Lwt/t DM (relatively common in Argentina), almost half of pasture produced was wasted (53% pasture utilisation). Pasture utilisation increased up to 76% as SR increased up to 90 kg Lwt/t DM and up to 85% for SR of 110 kg Lwt/t DM. Annual pasture utilisation over 70% would imply an important increase of efficiency for the current Argentine dairy system. Pasture utilisations of 70% or greater were achieved only in systems with comparative SR of 80 kg Lwt/t DM or greater, according to ADSM predictions (Figure 5.4, Table 5.5 and 5.6).

At a common value for comparative SR, pasture utilisation was hardly affected by the inclusion of concentrates (Figure 5.4a), but pasture utilisation decreased with more concentrate per hectare at a common value of cows per hectare (Figure 5.4b).

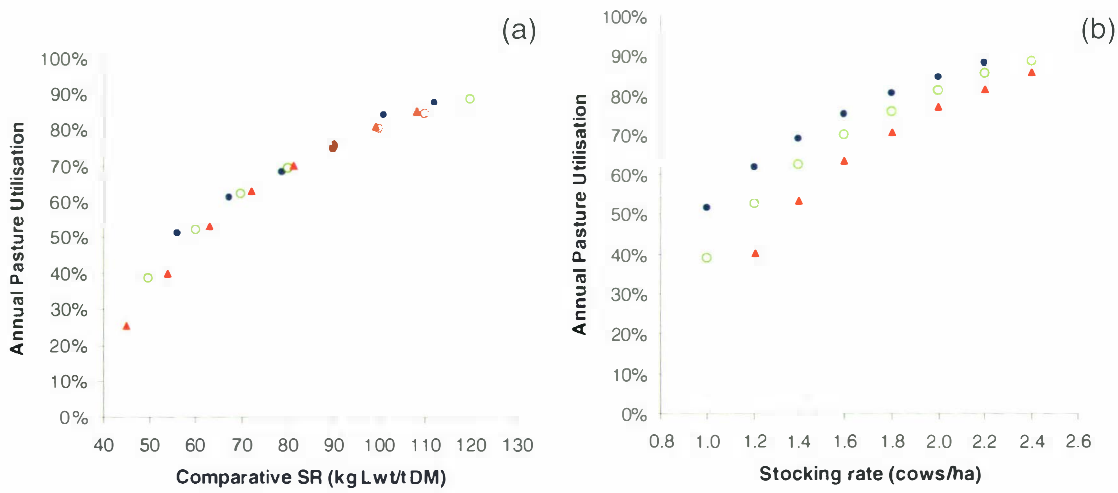

Figure 5.4: Annual pasture utilisation (pasture eaten/pasture grown x 100) as a function of comparative SR (a), and as a function of SR (b), for 8.6 t DM produced on-farm and 1.2 (•), 2.4 (○) and 3.6 (▲) t DM of concentrate imported per hectare per year.

5.4.3. Dry matter intake

Total DMI per cow per year decreased linearly as comparative SR increased. Annual intake per cow decreased from 6.0 to 4.3 t DM/cow as SR increased from 60 to 110 kg Lwt/t DM (Table 5.6 and Figure 5.5a). For the case farm studied, total DMI per cow should decrease from 6.0 to 5.2 t DM/year, if it is to achieve an annual pasture utilisation of 70%.

5.4.4. Milk yield

The maximum milk yield per cow (432 kg MS) was achieved at the lowest comparative SR for the system which imported 3.6 t DM per hectare. However, annual pasture utilisation was very low in this system (40%). The maximum milk yield per hectare (kg MS) was achieved with comparative SRs of 101, 100 and 99 kg Lwt/t DM for systems with 1.2, 2.4 and 3.6 t DM concentrates imported per hectare, respectively (Table 5.6 and Figure 5.6b). Milk yield per cow was reduced by 138 kg MS (34%) as comparative SR changed from the lowest to the comparative SR which maximised MS production per hectare (average of three levels of feed imported). Systems which maximised milk yield per hectare reduced cow's Lwt by 61, 47 and 35 kg when importing 1.2, 2.4 and 3.6 t DM, respectively (Table 5.6). Figure 5.7 shows data for total DMI and milk yield expressed as functions of the traditional ratio of SR (cows/ha).

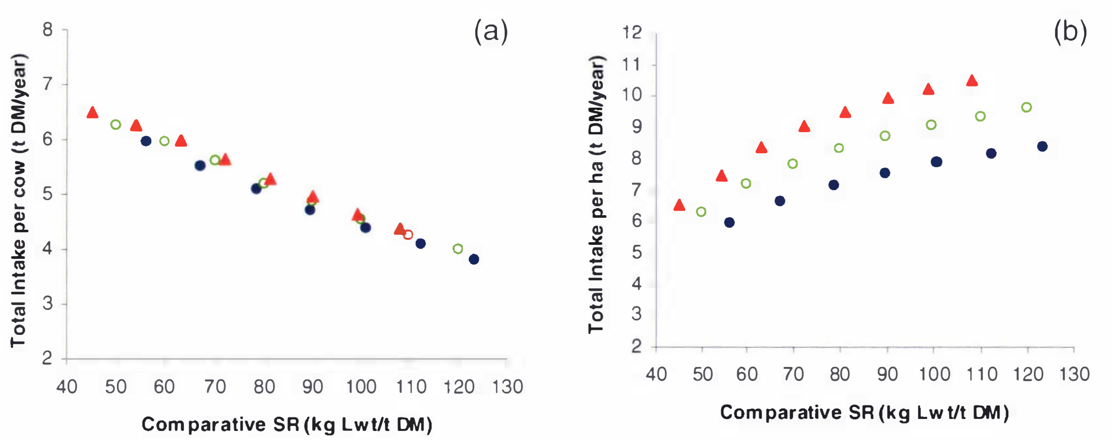

Figure 5.5: Total DMI per cow (a) and per hectare (b) as functions of comparative SR (kg Lwt/t DM total feed supply) for 550 kg Lwt cows, 8.6 t DM produced on-farm, for 1.2 (•), 2.4 ( ) and 3.6 (▲) t DM of concentrate imported per hectare per year.

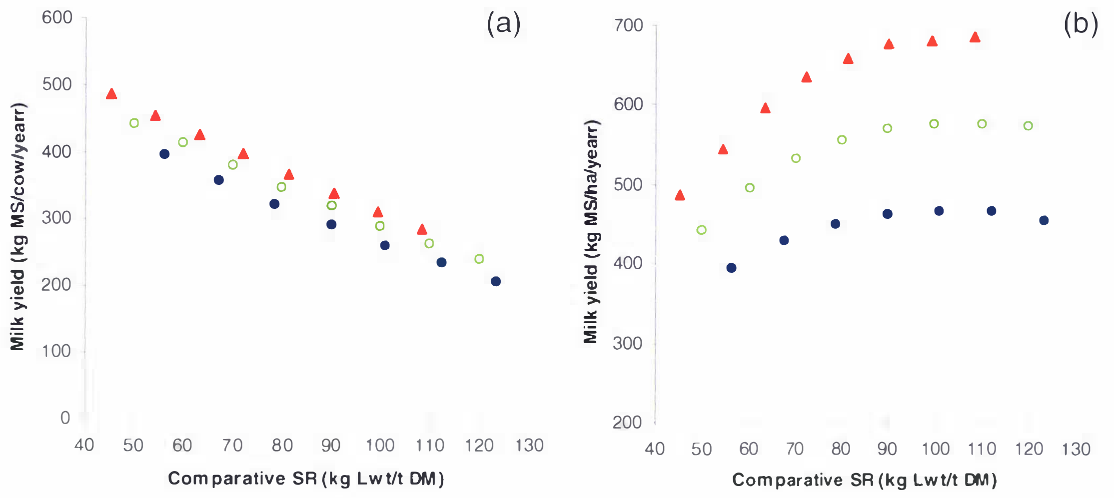

Figure 5.6: Milk yield (kg MS) per cow (a) and per hectare (b) as functions of comparative SR (kg Lwt/t DM) for 550 kg Lwt cows, 8.6 t DM produced on-farm and 1.2 (•), 2.4 ( ) and 3.6 (▲) t DM of concentrate imported per hectare per year. The average metabolisable energy of the diet were 10.2, 10.4 and 10.6 MJ/kg DM, respectively.

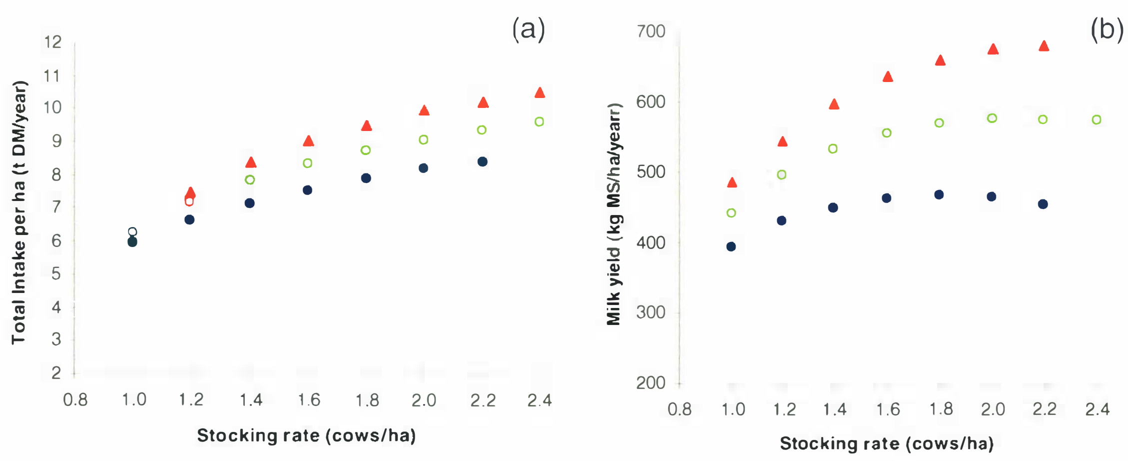

Figure 5.7: Total dry matter intake (a) and milk yield in kg MS/ha (b) as functions of comparative SR for 550 kg Lwt cows, 8.6 t DM produced on-farm and 1.2 (•), 2.4 ( ) and 3.6 (▲) t DM of concentrate imported per hectare per year. The average metabolisable energy of the diet were 10.2, 10.4 and 10.6 MJ ME, respectively.

Table 5.6: Per cow and per hectare performance for the 22 systems modelled with ADSM for 8.6 t DM produced on-farm and cows of 550 kg Lwt.

	Imported feed (t DM/ha/year)	Stocking rate (cows/ha)							
		1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
Total intake	1.2	6.0	5.5	5.1	4.7	4.4	4.1	3.8	
(t DM/cow/year)	2.4	6.3	6.0	5.6	5.2	4.9	4.6	4.3	4.0
	3.6		6.3	6.0	5.7	5.3	5.0	4.7	4.4
Milk yield /cow	1.2	5558	5058	4538	4087	3671	3275	2906	
(litres/year)	2.4	6217	5834	5371	4912	4468	4077	3695	3357
	3.6		6404	6018	5623	5178	4790	4375	4044
MS yield /cow	1.2	375	340	305	275	247	220	195	
(kg MS/cow/year)	2.4	420	393	362	330	300	273	248	225
	3.6		432	406	378	348	321	294	268
MS yield per ha	1.2	375	409	428	439	444	440	430	
(kg MS/ha/year)	2.4	420	472	506	528	540	547	545	540
	3.6		518	568	605	626	643	646	644
Lwt change	1.2	44	12	-15	-41	-61	-80	-93	
(kg/cow/year)	2.4	75	50	24	-4	-27	-47	-64	-83
	3.6		77	57	32	6	-15	-35	-54
ME maint. x 100	1.2	49	51	53	56	58	61	64	
Total ME	2.4	46	48	50	52	54	56	58	60
	3.6		46	47	49	51	53	55	56
Feed conversion	1.2	63	61	60	58	56	54	51	
efficiency	2.4	67	65	64	63	62	60	58	56
(kg MS/t DM eaten)	3.6		69	68	67	66	64	63	62
Annual pasture	1.2	52	62	69	75	81	85	88	
utilisation (%)	2.4	39	53	63	70	76	81	85	88
	3.6		40	54	63	71	77	82	86

5.4.5. Feed conversion efficiency

Feed conversion efficiency (FCE) can be defined as the kilograms of MS produced per cow for every tonne of DM eaten per cow (Holmes *et al.*, 2002). FCE was reduced as comparative SR increased in the present modelling study. The maximum FCE was obtained with the highest level of imported feed, the highest MS yield per cow and the lowest comparative SR (69 kg MS/t DM consumed) for the cow type used in this study (relatively high potential for milk yield). The minimum FCE of 51 kg MS/t DM consumed was obtained with the lowest level of imported feed, the lowest MS yield per cow and the highest comparative SR (Table 5.6). Requirements for maintenance and pregnancy represented a low proportion of total energy intake (46%) for cows at the lowest SR. In contrast, cows with the lowest DMI, at the highest SR, used a greater proportion (64%) of the total energy consumed to meet maintenance and pregnancy requirements (Table 5.6).

5.4.6. Milk responses to imported feed and substitution rates

The minimum milk response (41 g MS/kg concentrate) occurred when cows consumed 6.3 t DM/cow/year. Maximum milk response (101 g MS/kg concentrate) occurred when cows consumed 4.2 t DM/cow/year.

The substitution rate is defined as: kilograms of pasture dry matter intake reduction per kilogram supplement consumed. Substitution of pasture per concentrate was minimum (0.08) for cows consuming 4.2 t DM and maximum (0.76) for cows consuming 6.3 t DM. In the remaining systems, milk response and substitution rate ranged between these extremes.

5.4.7. Economic farm surplus

Economic farm surplus increased as comparative SR increased, reaching a maximum at 90 kg Lwt/t DM. Further increases in comparative SR decreased EFS (Table 5.7 and Figure 5.8). At the price of concentrates and milk payout used in this study (0.09 $US/ kg concentrate and 0.16 $US/ litre milk), increasing the amount of imported feed up to 3.6 t DM/ha resulted in increased EFS, except at low comparative SRs. The maximum superiority was achieved at comparative SRs which maximised EFS/ha, with 33% higher EFS/ha for the system importing 3.6 t DM/ha than for that with 1.2 t DM/ha imported (Figure 5.8).

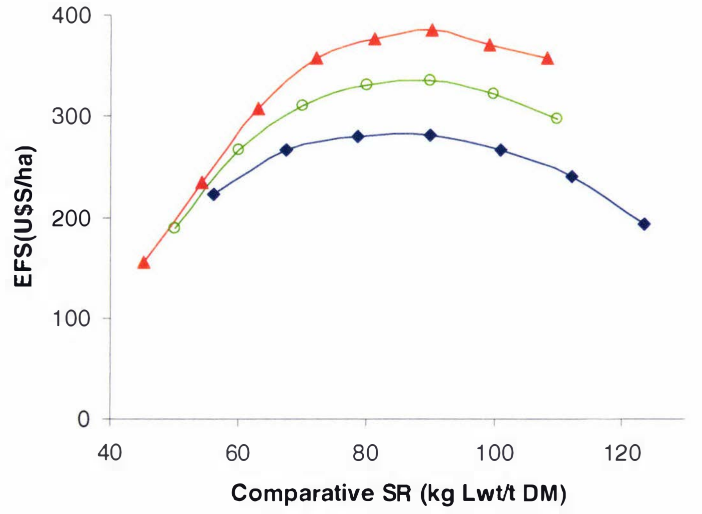

Figure 5.8: Economic farm surplus (EFS) per hectare as a function of comparative SR (kg Lwt/t DM) for 550 kg Lwt cows, 8.6 t DM produced on-farm and 1.2 (•), 2.4 ( ) and 3.6 (▲) t DM of concentrate imported per hectare per year.

Table 5.7: Economic indicators for the systems modelled with ADSM, for a farm of 100 hectare, 8.6 t DM produced on-farm, cows of 550 kg Lwt, 0.16 $US milk payout per litre and 0.09 $US per kg concentrate.

	Imported feed (t DM/ha/year)	Stocking rate (cows/ha)							
		1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
Total income ($US/ha)	1.2	940	1033	1088	1128	1149	1150	1135	
	2.4	1046	1182	1275	1339	1379	1407	1413	1412
	3.6		1291	1420	1521	1583	1635	1653	1676
Capital invested (thousands of $US/ farm)	1.2	408	420	432	444	457	469	482	
	2.4	409	421	433	446	458	471	483	496
	3.6		422	435	447	459	472	485	498
Economic farm surplus ($US/ ha)	1.2	297	345	361	365	353	324	282	
	2.4	265	348	396	420	423	416	392	361
	3.6		319	396	451	473	486	470	459
Return on assets (%)	1.2	7.3	8.2	8.3	8.2	7.7	6.9	5.9	
	2.4	6.5	8.3	9.1	9.4	9.2	8.8	8.1	7.3
	3.6		7.6	9.1	10.1	10.3	10.3	9.7	9.2

5.4.8. Return on assets

Return on assets was calculated as the ratio of EFS to the total assets. Systems modelled with ADSM showed trends in ROA similar to those observed for EFS. However, the maximum ROA occurred at a slightly lower comparative SRs (approximately at 80 kg Lwt/t DM) than the maximum EFS. Additionally, at low comparative SR, systems with low imported DM resulted in similar ROA to systems with high imported DM (Figure 5.9). At comparative SRs between 80 and 90 kg Lwt/t DM, the difference in ROA between systems importing 3.6 and 2.4 t DM were small and then it increased as SR increased (Figure 5.9).

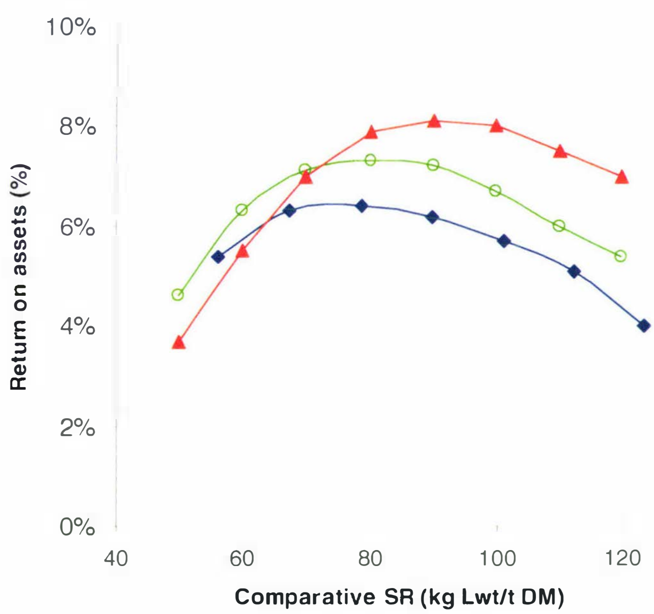

Figure 5.9: Return on assets (ROA) per hectare as a function of comparative SR (kg Lwt/t DM) for 550 kg Lwt cows, 8.6 t DM produced on-farm and 1.2 (-•-), 2.4 ( ) and 3.6 (-▲-) t DM of concentrate imported per hectare per year.

5.4.9. Sensitivity analysis for economic farm surplus

A sensitivity analysis was conducted, in order to study the changes in EFS as milk payout or concentrate price increased or decreased by 10% (Table 5.9).

The maximum EFS was found at the same comparative SR (90 kg Lwt/t DM), irrespective of changes in milk payout or concentrate price. At this comparative SR, changing the milk price by ±10%, either increased or decreased EFS by 24%, 26% and 27% for the low, medium and high level of imported feed, respectively (Table 5.8). Changing the price paid for concentrates by ±10 %, either increased or decreased EFS by 3%, 5% and 7% for the low, medium and high level of imported feed, respectively (Table 5.8).

Table 5.8: Sensitivity analysis showing economic farm surplus ($US/ha) resulting from changes in ±10% of either milk payout or concentrate price. The original milk payout and concentrate prices were $US 0.16 and $US 0.09, respectively.

	Imported feed (t DM/ha/year)	Stocking rate (cows/ha)							
		1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
+ 10 % milk payout	1.2	372	426	446	452	441	412	367	
(0.176 $US/ litre)	2.4	349	443	497	526	531	526	501	468
	3.6		423	510	572	598	615	600	589
- 10 % milk payout	1.2	222	262	275	277	265	237	197	
(0.144 $US/ litre)	2.4	181	253	294	314	315	307	283	253
	3.6		215	282	329	347	357	341	329
+ 10% concentrate	1.2	286	333	350	354	342	313	271	
price (0.099 $US/ kg)	2.4	243	326	374	398	401	395	370	339
	3.6		287	364	419	440	453	438	427
- 10% concentrate	1.2	307	355	372	375	364	335	293	
price (0.081 $US/ kg)	2.4	286	369	417	441	444	438	413	382
	3.6		351	428	483	505	518	502	491

5.5. Discussion

A representative survey of 966 dairy farms, in the main dairy production areas of Argentina, reported that the average dairy farm has approximately 1.15 cows/ha (equivalent to approximately 60 to 70 kg Lwt/t DM) with 1.2 t DM concentrate imported per cow (Gambuzzi *et al.*, 2003), which is approximately 1.4 t DM/ha. As a result, low pasture utilisation of 60-65% or less (Guaita and Gallardo, 1995), low milk yield per hectare of 334 kg MS/ha (Gambuzzi *et al.*, 2003) and poor economic performance are obtained. This is relatively similar to the system with 1.2 cows/ha and 1.2 t DM imported per hectare modelled in the current study, which produced 409 kg MS/ha with 62% pasture utilisation (Table 5.6). However, as discussed below, the productivity and profitability of Argentine dairy farms could be increased by increasing the comparative SR and the amount of imported feed.

5.5.1. Model validation

Although ADSM predictions are close to actual data for pasture utilisation and MS production per hectare, it must be recognized that actual data for pasture production and utilisation in the Argentine farms used for validation is a general estimation made by farmers and advisors, based on non-systematic pasture measurements. Nevertheless, this is some of the best data available in Argentina.

5.5.2. Pasture utilisation

A curvilinear relationship was found between comparative SR (kg Lwt/t DM) and annual pasture utilisation for the systems modelled. The effects of comparative SR on pasture utilisation were mediated through the effects of comparative SR on herbage allowance (herbage allowance decreased as SR increased). Pasture utilisations predicted with ADSM were relatively similar to those found by Macdonald *et al.* (2001), in a trial with pasture (ryegrass-clover) as sole feed in New Zealand (Figure 5.10). However the model predicted lower pasture utilisation at low SRs and higher pasture utilisation at high SRs than those found by Macdonald *et al.* (2001). Predictions with ADSM included concentrates in total DM offered, whilst the Macdonald *et al.* (2001) experiment did not include concentrates.

A survey of 100 dairy farms in Argentina revealed that pasture utilisation ranged from 35% to 60% (Guaita and Gallardo, 1995). This is in agreement with the low SR used in those dairy farms (0.75 cows/ha). However, dairy research farms of INTA Rafaela achieved values of 75% of pasture utilisation, with approximately 80 kg Lwt/t DM (2 cows/ha), in agreement with the predictions of the ADSM, in which pasture utilisation of 70% or greater were only achieved in systems with comparative SR of 80 kg Lwt/t DM or greater. However, in the current study, factors other than SR and level of supplementation were assumed to remain constant. Nevertheless, variables such as pasture quality and the ability of the farmer to manage grazing will markedly influence the efficiency of pasture utilisation in practice.

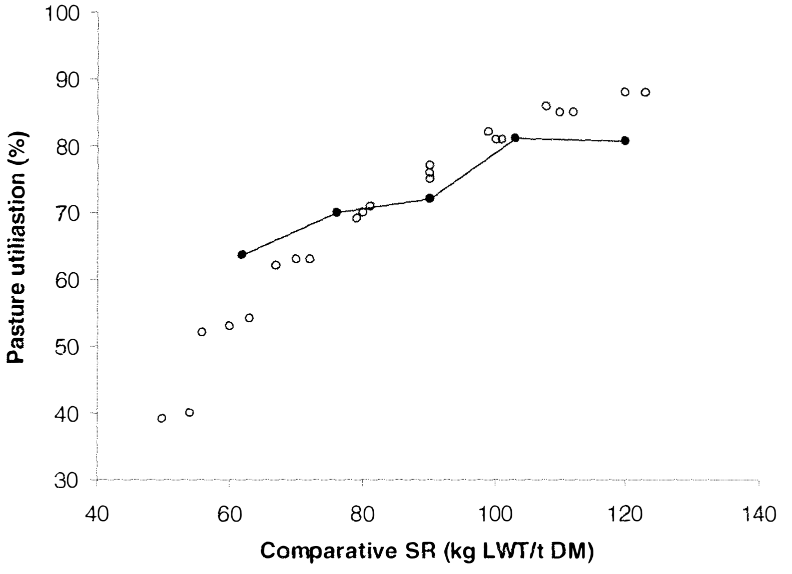

Figure 5.10: Annual pasture utilisation (pasture eaten/pasture grown x 100) as a function of comparative SR (kg Lwt/t DM) observed in the experiment of Macdonald *et al.* (2001) for systems with only pasture in New Zealand (•) and modelled with ADSM (○) for dairy systems with 8.6 t DM produced on-farm and 1.2, 2.4 and 3.6 t DM of concentrate imported per hectare per year.

5.5.3. Dry matter intake

In the present study, DMI per cow decreased linearly as comparative SR increased (Figure 5.5b), in agreement with the studies of Macdonald *et al.* (2001) and Penno (1999). As comparative SR increased, the effect of the increase in pasture utilisation was more important than the effect of the decrease in individual DMI, resulting in increasing DMI per hectare (Figure 5.5b).

5.5.4. Milk yield, economic farm surplus and return on assets

Schneider *et al.* (2001) simulated the effects of the amount of pasture produced on-farm (7.8, 9.8 and 12.7 t DM/ha/year) and the percentage of pasture utilisation (two arbitrary values: 55% and 70%) for Argentine dairy systems. Thus, six alternatives were evaluated (Table 5.9). Increases in pasture production were proposed as a result of using the technology available and best practices (fertiliser, improved cultivars, grazing management, weeds and insects control). Stocking rate was increased to allow the same amount of feed per cow per year and 0.7 t DM was imported per cow for all the systems. Productivity (kg milk yield per hectare) increased by 28% per each increase of 2 or 3 t DM/ha in pasture production and by 14% as pasture utilisation increased from 55 to 70% (Table 5.10).

Similarly, the systems modelled with ADSM predicted that, as pasture utilisation increased from 55 to 70%, productivity (kg milk yield per hectare) increased by 12% (Table 5.7) as an average of the three levels of imported feed. Overall, the results from the study of Schneider *et al.* (2001) for productivity and net income are relatively similar to those reported in the present study (Table 5.6 and 5.7).

Table 5.9: Simulation study predicting productivity and profitability for Argentine dairy farms. Three levels of DM produced on-farm and two levels of pasture utilisation, with 0.7 t DM imported as concentrate/cow/year (Schneider *et al.* 2001). Comparative SR ranged from 65 to 74 kg Lwt/ t DM. Milk payout of $US 0.15 per litre (cost per kg concentrate was not reported).

DM produced on-farm (t /ha/year)	Pasture utilisation (%)	Stocking rate (cows/ha)	Milk yield (kg milk/ha/yr)	Net income ($US/ha/year)
7.8	55	1.00	4,928	131
	75	1.13	5,694	182
9.8	55	1.28	6,296	202
	75	1.46	7,172	261
12.7	55	1.66	8,158	296
	75	1.88	9,253	370

Comeron and Schilder (1997) simulated three dairy systems (A, B and C) with differences in SR, supplementation and milk yield per cow (Table 5.10). The objective of this study was to analyse the productivity and profitability of the intensification of milk production in Argentine dairy farms and to find out whether it is more profitable to achieve a high productivity (9,050 kg milk/ha/year) with high SR (and low milk yield per cow) or with high milk yield per cow (low SR). Pasture produced on-farm was approximately 12 t DM/ha/year. The results of the study suggested that the highest net income (and ROA) per hectare was produced by the 'System A', with the lowest milk yield per cow and the highest SR. In the study of Comeron and Schilder (1997), pasture utilisations were not predicted, but assumed. Pasture utilisation assumed for 'system A' (75%) agrees with the predictions of ADSM. However, ADSM would predict lower pasture utilisation than those assumed for 'system B' and 'system C'.

Table 5.10: Simulation study evaluating three alternatives of intensification designed to produce the same amount of milk per hectare, varying SR and production per cow, for Argentine dairy farms. Pasture produced on farm approximately 12 t DM/ha/year and cow's Lwt of 550 kg (Comeron and Schilder, 1997).

	System A	System B	System C
Stocking rate (cows/ha)	2.0	1.6	1.2
Pasture utilisation[1]	75%	70%	60%
Concentrate (kg/cow/day)	3.0	4.4	7.0
Milk production (litres/cow/day)	16.0	20.0	26.4
Milk production (litres/ha/year)	9,050	9,050	9,050
Net income ($US/ha/year)	455	438	281
Return on assets (%)	10.3	9.8	6.1

[1]Values assumed in this study.

For New Zealand conditions, Macdonald *et al.* (2001) reported that cows fed only pasture would maximise EFS at a comparative SR of 90 kg LW/t DM. At lower comparative SR, the effect of low pasture utilisation on system performance was more important than the benefit of higher MS production per cow, in terms of economic benefit. At the other extreme, at higher SRs, the benefit of higher pasture utilisation was not large enough to compensate for the diminished FCE of the cows. In a review of New Zealand studies, Penno (1999) suggested that SRs of 84 and 85 kg Lwt/t DM would maximise EFS, for Jersey and Holstein-Friesian cows, respectively.

Results of the current study showed that EFS was maximised at 90 kg Lwt/t DM, irrespective of the amount of feed imported. Milk yields per cow at maximum EFS were 4,538, 4,912 and 5,178 litres of milk per cow for systems which imported 1.2, 2.4 and 3.6 t DM per hectare, respectively. Increases in the amount of imported concentrates increased the amount (and content) of ME consumed per cow, and therefore the milk yield per cow. Although EFS was maximised at 90 kg Lwt/t DM with Argentine

Holstein cows in the current study, it should be noticed that at this SR cows lost 41, 27 and 15 kg of Lwt per year. This is obviously not sustainable and could have negative effects on the reproductive performance of cows in the long-term. This effect was not accounted for in the economic analysis of the present study.

Gallardo and Castillo (1998) reported higher levels of productivity for two intensive dairy research units: UPLI 1 (40% spring and 60% autumn calving) and UPLI 2 (100% spring calving) of INTA Rafaela, Argentina. Those farms achieved 940 kg MS/ha per year (500 kg milkfat), with SR of 2.2 cows per ha (550 kg Lwt/cow), high DM produced on-farm (more than 12 t DM/ha/year, high quality pastures) and high amounts of imported concentrates (2.4 t DM/cow/year, specially formulated to balance the basal diet). This level of productivity per hectare is higher than the most productive alternative evaluated with ADSM in this study (646 kg MS/ha), though with a lower feed supply (8.6 t DM produced on-farm) and lower amount of imported concentrates (1.6 t DM/cow/year) (Table 5.6).

ROA increased as comparative SR increased for all systems modelled, reaching a maximum at 80 kg Lwt/t DM, irrespective of the level of feed imported. Therefore, maximum ROA occurred at lower comparative SR than was the case for EFS. However, systems which imported 3.6 t DM/ha still maintained the maximum ROA at 90 kg Lwt/t DM. At low comparative SR, systems with low imported DM resulted in ROA which were similar to those for systems with high imported DM (Figure 5.9). This is because the same comparative SR was obtained with more cows (more capital) for systems which imported more feed (Table 5.7). However, as comparative SR increased, the system with higher imported DM resulted in higher ROA and showed higher difference with other systems, as comparative SR progressed.

In conclusion, the optimum comparative SR, in terms of both economic and sustainable physical performance for the Argentine Holstein cows, seems to be around 80 kg Lwt/t DM total feed supply.

5.5.5. Feed Conversion efficiency

The feed conversion efficiencies (FCE) obtained in the current study for Argentine dairy systems ranged from 51 to 69 kg MS/t DM eaten (Table 5.6), which are lower than those reported for New Zealand dairy systems. The FCE resulting from the study of Macdonald *et al.* (2001) in New Zealand ranged from 73 to 86 kg MS/t DM eaten for cows fed sole pasture with high energy concentration (11.3 to 11.6 MJ ME/kg DM). Penno (1999) summarised five New Zealand experiments and reported that FCE ranged from 57 to 77 kg MS/t DM total feed supply. The lower FCE in Argentine dairy systems may be due to the higher Lwt of cows, the lower MS concentration of milk and the lower pasture quality in Argentina, in comparison to New Zealand.

The Lwt of the cow can affect its FCE, defined as the quantity of MS produced per kilogram of DMI, through the amount of feed required for maintenance. At a common MS yield, 25% decrease in Lwt causes efficiency to improve by 10 to 12% (Holmes *et al.*, 1993). In New Zealand, for example, the production of 280 kg MS can be expected from a 450 kg Lwt cow (eating 3.7 t DM), or from a 550 kg Lwt cow eating 4.1 t DM. This results in 75 kg MS/t DM eaten for the lighter cow and 69 kg MS/ t DM for the heavier cow (Holmes *et al.*, 2002).

Another reason which explains higher FCE in New Zealand dairy cows may be the higher MS concentration per litre of milk, which is 8.57% (LIC, 2005) in comparison with the 6.8% MS concentration per litre of milk of Argentine Holstein cows (Comeron, 2003). Thus, one kilogram of MS is energetically more expensive for Argentine dairy cows, due to the higher relative cost involved in the synthesis of lactose, which is relatively constant per litre of milk. Milk lactose content is essentially a constant 4.85% of milk and varies only slightly with breed (NRC, 2001). Therefore, one kilogram of MS from milk with 8.57% MS, as in New Zealand, is equivalent to 11.7 kg of milk and would demand the synthesis of 66.2 g lactose per kg MS (11.7 kg x 4.85%). Whereas, one kilogram of MS from milk with 6.8% MS, as in Argentina, is equivalent to 14.7 kg of milk and would demand the synthesis of 71.3 g lactose per kg MS (14.7 kg x 4.85%).

A third factor that may reduce the FCE in Argentine dairy systems is the lower average quality of pastures and conserved forages when they are compared with New Zealand pastures and conserved forages. Indeed, the quality of pastures in New Zealand may be similar or even higher than the quality of the total diet composed of pastures plus conserved forages plus concentrates of Argentine dairy farms. The average cow's diet in Argentina is made up of 67 % pasture, 11 % silage and hay and 22 % Concentrates (Gambuzzi *et al.*, 2003). Average values of feed quality are: 9.9 MJ ME per kg DM pasture (44 % NDF), 8.6 MJ ME per kg DM pasture hay (57 % NDF) and 9.2 MJ ME per kg maize silage, with 53 % NDF (Gaggiotti *et al.*, 2002). This would be equivalent to an average 10.3 MJ/kg DM for the whole diet (with 12 MJ/kg DM concentrate), which is lower than the average of 11.3-11.7 MJ/kg DM reported by Macdonald *et al.* (2001) in New Zealand.

5.5.6. Cow type and feeding environment

A higher ME concentration occurs in the diet of New Zealand cows, than that which is found in Argentina cows, despite the higher proportion of concentrates used in Argentina. Judging by the average MS production per cow in Argentina, which is 1.02 kg MS per day averaged across the whole lactation (Gambuzzi *et al.*, 2003), the 'feeding environment' of Argentine dairy systems is probably no better than the 'feeding environment' of the pastoral dairy system in New Zealand. Certainly, the quality and availability of feed in Argentine dairy systems is much lower than that of the feeding systems in the North Hemisphere, with its total mixed rations offered ad-libitum, for which big cows with a high genetic potential for milk production have been selected. However, as stated above, Argentine Holstein cows have a high proportion of North American genetics, even though the Argentine feeding environment is not as good as that in the North Hemisphere.

The reasons detailed above, explain the lower FCE of Argentine dairy systems in comparison to New Zealand dairy systems and suggest that a lighter cow, with a higher concentration of MS per litre of milk would be more efficient and consequently, more suitable for Argentine dairy systems. In New Zealand, Kolver *et al.* (2002) compared New Zealand Holstein with North American Holstein cows, both fed generously at grazing (an allowance greater than 60 kg DM/cow/day) with high quality pastures (11.7 MJ ME/kg). They found that New Zealand Holsteins produced similar MS (465 kg/cow) to the American Holstein cows (459 kg MS/cow). Furthermore, NZ Holsteins gained 44 kg Lwt per lactation and showed 7% empty rate, whilst American Holstein cows lost 20 kg Lwt and showed 62% empty rate. Therefore, the cow most suitable for Argentine dairy systems might be closer to the New Zealand cow type than to the North American cow type. However, the type of cow most suitable to maximise profitability will also depend on whether the system of milk payout is based on MS or milk volume.

The effects of mating strategies and payment systems on the farm profit ($/ha) of an Argentine dairy herd were evaluated by Lopez-Villalobos *et al.* (2001). The mating strategies were: upgrading to Holstein, upgrading to Holstein-Friesian, upgrading to Jersey and rotational crossbreeding Holstein-Friesian x Jersey using imported semen. Upgrading the herd to Holstein resulted in the heaviest cows with the highest production per cow of milk, fat and protein, the highest feed requirements per cow, the lowest stocking rate, the lowest production of fat and protein per hectare and the highest production of milk per hectare. Upgrading to Jersey resulted in the lightest cows with the lowest production per cow of milk, fat and protein, the lowest feed requirements per cow and consequently, the highest stocking rate, the highest production of fat per hectare and intermediate production of protein per hectare and the lowest production of milk per hectare. Rotational Holstein-Friesian x Jersey crossbreeding resulted in similar production of fat and protein per hectare to that of upgrading to Jersey although this was achieved with a lower stocking rate.

Upgrading to Holstein resulted in the highest profit ($322/ha), if milk was paid on milk volume. Upgrading to Jersey resulted in the highest profit ($311/ha), if milk was paid on fat yield. Rotational crossbreeding resulted in the highest profit for all other payment systems. Based on these results, the authors suggested that rotational crossbreeding systems could increase the profitability of Argentine dairy herds under the market conditions assumed in the analysis.

5.5.7. Substitution rate and milksolids response to feed imported

Milk responses to concentrate between 41 and 101 g MS/kg DM consumed were obtained for the systems modelled with ADSM in the current study, which is in agreement with experimental results of supplemented grazing dairy cows. The greatest milksolids responses to concentrate were obtained at restricted feeding levels (4.2 t DM/cow/year), whilst the lowest responses were obtained at generous feeding levels (6.3 t DM/cow/year).

Kellaway and Porta (1993) reviewed the use of supplementary feeds in Australia and concluded that when pasture was restricted, offering energy concentrates was likely to result in an immediate effect of 0.5 kg milk/kg concentrate fed (about 42 g MS/kg DM). They also estimated that carry-over effects resulted in an additional 0.5 kg milk/kg concentrate fed. Penno (2001) summarised whole-lactation studies that have been made in grazing dairy systems and found an average milk response to supplements of 78 g MS/kg DM. Bargo *et al.* (2003) reviewed studies of high yielding grazing cows supplemented with concentrates and found that milk production increased linearly as the amount of concentrate increased from 1.2 to 10 kg DM/cow/day, with an overall milk response of 1 kg milk/kg concentrate (approximately equivalent to 60 to 85 g MS/kg DM).

A short-term study conducted in Argentina with grazing dairy cows reported milk responses of 0.9 kg milk/kg concentrate (Gagliostro *et al.*, 1996). Castillo and Gallardo (1998) summarised experiments of cows grazing alfalfa in Argentina and reported responses between 0.44 and 0.98 kg milk/kg concentrate (approximately between 30 and 67 g MS/kg DM). Therefore, the model predictions between 41 to 101 g MS/kg DM concentrate, covered the full range of experimentally measured values and appeared to be realistic.

5.5.8. Sensitivity analysis

The sensitivity analyses showed that EFS was more sensitive to changes in milk payout, than to changes in concentrate price. However, the maximum EFS was found at a common comparative SR (90 kg Lwt /t DM), irrespective of changes in milk payout or concentrate price. Therefore, a significant stability was observed in the relative operating profits of the different systems. At this comparative SR, changing milk price by ±10%, either increased or decreased EFS by 24%, 26% and 27% for the low, medium and high level of imported feed, respectively (Table 5.8). Changing the price paid for concentrate by ±10%, either increased or decreased EFS by 3%, 5% and 7% for the low, medium and high level of imported feed, respectively (Table 5.8).

A sensitivity analysis, conducted on dairy research units of INTA Rafaela, showed that changing the milk payout by 10% either increased or decreased net income by 28%. Similarly, changing the concentrate price by 10% either increased or decreased net income by 9.8% (Romero *et al.*, 1998). The model results agree satisfactorily with data from that study.

5.5.9. Cows per hectare to maximise return on assets

In the present study, systems evaluated with ADSM study were based on a farm with 8.6 t DM produced on-farm per year. The comparative SR which gave the maximum ROA per hectare was 80 kg Lwt/t DM for the three levels of imported feed. However, when expressed in cows per hectare (Argentine Holstein cows of 550 kg Lwt), the SR which maximised EFS were 1.4, 1.6 and 1.8 cows per hectare for the low, medium and high level of imported feed, respectively. A further set of simulations were done with the objective of predicting the number of cows per hectare which would maximise ROA for systems producing either 6.6 or 10.6 t DM per hectare. Results are shown in Table 5.11.

Table 5.11: Predicted stocking rates (cows/ha) required to maximise return on assets in a simulated Argentine dairy herd, for three levels of DM produced on-farm per hectare per year and three levels of imported DM. Results modelled with ADSM for Argentine Holstein cows (550 kg wt), milk payout of 0.16 $US per litre and concentrate cost of 0.09 $US per kg.t), milk payout of 0.16 $US per litre and concentrate cost of 0.09 $US per kg.

DM produced on-farm (t DM/ha/year)	Concentrate imported (t DM/ha/year)		
	1.2	2.4	3.6
6.6	1.1	1.3	1.5
8.6	1.4	1.6	1.8
10.6	1.7	1.9	2.1

5.6. Conclusions

This is the first study in which the effects of comparative SR, in isolation and in combination with imported feeds on farm productivity and profitability, have been explored for Argentine dairy systems. In validation tests, the productive model was within the acceptable limits. This suggests (but does not prove) that the model predicts pasture DMI, MS production and Lwt change of real systems with reasonable realism.

From the performance of the systems modelled in this study, it can be concluded that the relatively low pasture utilisation and low MS production per hectare, that are characteristics of Argentine dairy systems, can be improved through an increase in the comparative SR and the amount of imported feed per hectare. The optimum comparative SR, from the point of view of the profitability and sustainability of the system, appears to be around 80 kg Lwt/t DM, which is relatively similar to the optimum SR found in the pastoral dairy systems of New Zealand. Increasing the amount of imported feed up to 3.6 t DM/ha/year would be profitable at the current payout of milk and concentrates price, provided that SR is simultaneously increased up to 80 kg Lwt/t DM. It is possible that increasing imported feed more than 3.6 t DM/ha would still be profitable.

The results of this study suggest that cows with lower Lwt and higher MS concentration would be more efficient in converting feed into MS, than the current Argentine Holstein cow, in Argentine dairy systems. However, the type of cow needed to maximise profitability will depend on the payment system for milk.

Overall, the results of this study illustrated the relationship among comparative stocking rate, amount of feed imported, pasture utilisation, MS production per cow and MS production per hectare. These results provide a framework to understand different systems of dairy production in Argentina.

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Chapter 6

General Discussion

6.1. Introduction

The present study has integrated the main parts of the whole-farm dairy system through a simulation modelling approach, which allowed the effects of comparative stocking rate and supplementation on the whole-farm to be explored. Although simulation models are increasingly used in animal research (Bywater and Cacho, 1994; Jensen *et al.*, 2005), there are no previous whole-farm models predicting pasture intake, milk yield and profitability for Argentine dairy farms.

The lack of whole-farm models for Argentine dairy systems is possibly due to the fact that the dairy industry in Argentina is focused on production per cow, rather than on production per hectare, which is typical in Northern Hemisphere countries. This is despite the fact that dairy production in Argentina is based on grazed pastures. Therefore, this study provides a different, more holistic, approach than that commonly applied to dairy production studies of Argentina. It would be expensive to research the systems modelled in this study. However, the results of the present study may help to identify the systems which need to be researched experimentally, thereby reducing the size of the field experiment required.

A review of the effects of SR and supplementation on farm productivity and profitability provided the scope for this study in Chapter 2. A method to predict pasture dry matter (DM) intake per cow and per hectare at grazing was developed in Chapter 3. A complementary model was developed in Chapter 4, to predict the partitioning of energy within the cow, which enabled the prediction of milksolids (MS) production and live weight (Lwt) change. Finally, the productivity and profitability of Argentine dairy farms were studied in Chapter 5, by integrating the models developed in Chapter 3 and 4 with a pre-existent economic model. The comparative SR and supplementation levels (imported feed) which maximise profitability were predicted. Since this is a modelling study, its results do not prove, but only suggest, possible ways of improving the profitability of Argentine dairy farms.

The conflict between productivity per cow and per hectare was approached in this study, with a focus on the effects of comparative SR and supplementation. This chapter will present a brief discussion that integrates the main points arising from this thesis.

6.2. Limitations of simulation models used in this thesis

A simple but original model was developed in Chapter 3, for the prediction of pasture dry matter intake (DMI) and the harvesting efficiency of grazing dairy cows in Argentina. That model enables the prediction of pasture intake with relatively few and simple data, namely: pasture allowance, supplements intake, cow Lwt, stage of lactation, pasture NDF concentration, ME concentration of pasture and supplements and the cow's energy demand.

In validation tests, using data from cows grazing lucerne in Argentina, the model was within the accepted limits. However, those data were limited in terms of amount and accuracy. Therefore, a detailed set of data, from a trial with three strains of Holstein-Friesian cows grazing ryegrass-clover pastures in Ireland and with 849 individual measurements of intake, was also used to validate the model. Again the model predictions were within acceptable limits.

The model developed in Chapter 4 allows the prediction of energy partitioning towards either milk yield or Lwt gain. However, this model was not validated, because of the lack of data comprising energy intake, milk production and Lwt change for Argentine Holstein cows. Nevertheless, the productive predictions of the whole-farm model developed in this study (Argentine Dairy System Model; ADSM), which included the model developed in Chapter 4, was validated against data from a group of Argentine dairy farms.

Although ADSM predictions were close to actual data for MS production per hectare, it must be recognised that the actual data for pasture production and utilisation in Argentine dairy farms, used for validation, is a general estimation made by farmers and advisors, based on non-systematic pasture measurements. Nevertheless, this is some of the best data available in Argentina.

6.3. Stocking rate

Many whole-farm experiments have been carried in out in Southern Hemisphere countries, such as Australia and New Zealand, which base their dairy production on pasture. Data reviewed in the present study suggests that SR is a factor with great influence on dairy farm profitability in Argentina, as it is in Australia and New Zealand. These three countries have in common the fact that land is the main resource used in dairy farms, their dairy farms are based on grazed pastures and the price of milk is relatively low. These characteristics make it necessary to maximise MS production per hectare, which is markedly influenced by SR.

It is interesting to note, that some decades ago, the reluctance to increase SR (at the expense of production per cow) was also experienced in New Zealand. In the 1960s, the SR in New Zealand was much lower (approximately 1.5 cows/ha) than the current SR (2.8 cows/ha) (LIC, 2005). To illustrate that reluctance, the words of a prominent New Zealand researcher who advocated the benefits of higher SR in dairy farms at that time can be quoted: *"More coals of fire have been heaped upon my head for my views on stocking rate...... I have been accused of advocating overstocking as a national policy...I have been described as the most dangerous enemy our grassland has ever had...However, I remain unrepentant. I do so because I am firmly convinced that no more powerful force for good and evil exists than control of the stocking rate in grassland farming"* (McMeekan, 1961). Some decades latter, the efficient dairy industry of New Zealand, based on high SR, has widely recognized the valuable concepts of C.P. McMeekan.

The main benefit of a high SR is that it ensures high utilisation of pasture, which is the cheapest feed resource. Pasture utilisation is low in Argentina, as a consequence of low SR.

Although pasture production and quality are higher in New Zealand than in Argentina, in the latter country, cheap, high quality supplements are available to feed cows, which makes it possible to increase SR in Argentina. If the experience of the last decades in the New Zealand dairy industry is acknowledged, will the Argentine dairy industry face the same reluctance, to accept the idea that the profitability of dairy systems can potentially be increased, by increasing SR?

6.4. Imported supplements

This study evaluated the effect of feeding imported concentrates on the productivity and profitability of the farm. Results highlighted that high milk responses (total long-term responses of approximately 70g MS/kg DM concentrate) can be obtained at a comparative SR of about 80 kg Lwt/ t DM.

The ratio: value of 1 litre of milk to the cost of 1 kilogram dry matter can be used to judge the convenience of using feeds to produce milk, assuming an average response of approximately 1 litre of milk produced per 1 kilogram extra concentrate fed (Holmes, 2003). In New Zealand, for example, this ratio is approximately 0.6 for concentrates and 1.0 for cereal grains. In order to keep high SRs without deteriorating productivity per cow, some supplements are being imported into the majority of New Zealand dairy farms. In Argentina, the ratios are approximately 1.7 for concentrates and more than 2.0 for cereal grains. However, the amount of imported feed is still low (1.2 t DM/ha). Results of the present study suggested that the profitability of dairy systems may be increased by increasing the amount of imported concentrates up to 3.6 t DM/ha, provided that SR is simultaneously increased.

Additionally, increasing the amount of feed imported into the farm can indirectly increase pasture growth, provided that the SR is simultaneously increased. This occurs, because imported feed is equivalent, to some extent, to importing nutrients into the system. A high proportion of nutrients from imported feed and consumed by the animals can end up in the paddocks (through dung and urine) and this in turn, can increase pasture production, if it is spread properly.

6.5. Productivity and profitability of Argentine dairy systems

Although this thesis explored the effects of comparative SR and supplementation, it is recognized that pasture production (which was assumed in the present study) is a factor which has enormous influence on the productivity and profitability of grazing dairy systems.

In some dairy farms, it is possible that MS production per hectare is limited by pasture growth, rather than by the comparative SR. Efforts to improve pasture production should precede, or be simultaneous to, those optimising comparative SR and supplementation. However, the benefits of higher pasture production will only be expressed in systems with adequate comparative SR. Otherwise, excessive amounts of pasture offered can result in excessively high pasture wastage and this, in turn, will tend to deteriorate the quality of the pasture and the performance of the cows.

The present study suggests that the low average pasture utilisation of Argentine dairy farms could be increased by increasing comparative SR. Model predictions indicated that MS production per hectare would be maximised at a comparative SR of approximately 100 kg Lwt/t DM, economic farm surplus (EFS) at 90 kg Lwt/t DM and return on assets (ROA) at 80 kg Lwt/t DM. Additionally, the model predicted that cows stocked at a comparative SR of about 80 kg Lwt/t DM will neither increase nor decrease Lwt over a complete season (lactating and dry periods). These results suggest that the optimum comparative SR, in terms of both economic and sustainable physical performance for the Argentine Holstein cows, seems to be around 80 kg Lwt/t DM. Annual pasture utilisations were 70%, 76% and 81% for comparative SRs of 80, 90 and 100 kg Lwt /t DM, respectively.

Therefore, the results of the present study suggest that pasture utilisations higher than 70% should not be targeted by systems with Argentine Holstein cows which aim to maximise their profitability and sustainability, at the milk price and costs used in this study. However, in the current study, factors other than SR and level of supplementation were assumed to remain constant. Variables such as pasture quality and the ability of the farmer to manage grazing will, in practice, strongly influence the efficiency of pasture utilisation. Therefore, skilful farmers could achieve higher pasture utilisations, than those predicted in this study (at the same comparative SRs), and consequently they could achieve higher MS production per cow and per hectare.

As comparative SR increases, DMI per cow decreases and there is a point at which the reduction in the efficiency of production per animal is more important than the increase in efficiency of pasture utilisation. In the present study, this point occurred at a SR of approximately 100 kg Lwt/t DM, which is the comparative SR that maximised MS/ha. The benefits of harvesting more pasture per hectare, at higher SRs, were off-set by the loss of feed conversion efficiency by the cows. This happened because an increasing proportion of the energy consumed was partitioned towards maintenance costs as comparative SR increased (and DMI per cow decreased).

The relatively low MS production per hectare of Argentine dairy farms could be increased by increasing both the amount of imported concentrates and the comparative SR. To take advantage of the beneficial effects of high comparative SR, a controlled feed budget should be put into practice by the farmer, in order to ensure both high pasture utilisation and acceptable DMI by the cows.

6.6. Future implications

The accuracy of predictions of the model developed in this thesis could be improved in the future if a whole-farm field experiment is designed taking into account the variables included in the model. Results of the present study would provide the basic framework to design a whole-farm field experiment.

The effect of the breed and type of cow and the combined effects of SR and cow type need to be studied in both modelling and field research, because it is possible that the current Argentine Holstein cow is not the most suitable genetic group for the feeding and financial environment of Argentine dairy farms.

6.7. Conclusions

Pasture utilisation and MS production per hectare are low in Argentine dairy systems, when compared with other countries in which dairy production is based on pasture. The relatively low SR used in Argentine dairy farms seems to be one of the main reasons which can explain the low MS production per hectare.

Model predictions indicated that MS production per hectare can be increased by increasing both the comparative SR and the amount of imported concentrates in Argentine dairy farms. The optimum comparative SR (to maximise ROA) seems to be around 80 kg Lwt/t DM total feed supply. Changing either the price of milk or the cost of concentrates by ±10% did not alter the relative profitability of the different systems.

Low efficiency of feed conversion into milk has been reported in Argentine experiments with grazing dairy cows and in the present study. The feed conversion efficiency in Argentine dairy systems, which is lower than in New Zealand, may be partially explained by the higher Lwt of cows and the lower MS concentration of milk. Therefore, cows with lower Lwt and higher MS concentration would be more efficient in converting feed into MS, than the current Argentine Holstein cow, used in Argentine dairy systems. However, the type of cow to maximise profitability will depend on the system of milk payout.

The benefits of increasing comparative SR, up to the apparent optimum, will only be obtained if a feed budget is put into practice, in order to control and balance the requirements of the herd and the amount of pasture and other feeds offered and consumed throughout the year.

Overall, the results of this thesis provide a framework to understand different systems of dairy production in Argentina.

6.8. References

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Appendix A

Appendix A

Table 1: Main characteristics of the Argentine dairy farms used to validate the productive model in Chapter 5

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8	Farm 9	Farm 10	Farm 11	Farm 12	Farm 13	Farm 14	Farm 15	Farm 16	Farm 17	Farm 18
Year of data	03-04	04-05	03-04	04-05	2004	1999	1999	1999	03-04	03-04	03-04	03-04	03-04	03-04	03-04	03-04	03-04	03-04
Farm area (hectares)	345	417	671	827	111	464	386	276	221	198	205	372	258	250	474	291	330	196
DM produced on-farm (t DM/ ha)	7.4	8.3	7.4	8.5	9.3	7.5	6.9	7.3	11	11	9.5	11	13	10	14	10	14	13
Supplement imported (t DM/ ha)	4.8	4.3	7.6	4.3	2.4	2.4	2.6	2.4	2.7	3.5	3.9	2.5	3.3	2.6	3.1	3.5	1.4	3.4
Productivity (Kg MS/ ha)	772	718	1022	878	767	520	545	549	607	668	495	540	680	398	545	573	312	535
Productivity (Kg MS/ cow)	422	399	426	411	470	306	287	305	393	410	356	344	447	321	433	372	321	353
Pasture utilisation (%)	61	69	69	72	75	62	70	64	61	63	52	68	56	57	39	66	34	52
Cow's Lwt	475	475	440	410	570	437	406	443	450	450	550	550	550	550	550	550	530	530
Stocking rate (cows/ha)	1.8	1.8	2.4	2.1	1.6	1.7	1.9	1.8	1.5	1.6	1.4	1.6	1.5	1.2	1.3	1.5	1.0	1.5
Stocking rate (kg Lwt / t DM)	67	71	71	68	79	75	81	81	51	50	57	64	52	54	40	63	33	49
Milking cows/Total cows (%)	84	80	82	83	84	74	80	81	75	77	81	65	79	72	87	79	69	80

Table 2: Distribution of pasture DM production over the year (used in Chapter 5 for simulations with ADSM).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% per month	7	6	9	8	6	5	4	7	10	13	13	12