THE RESPONSE BY GRAZING DAIRY COWS TO SUPPLEMENTARY FEEDS

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This thesis is dedicated to my Grandparents

William James and Nancie Julia Penno

ABSTRACT

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Many experiments have measured the responses of grazing dairy cows to various forms of supplementary feed, but few have studied the reasons for the large differences in responses between experiments. Two short-term, and one long-term supplementary feeding trials were designed to help understand the reasons for wide variation in responses that have been reported, and to develop a biophysical framework to improve the prediction of the response by grazing cows to supplementary feeds.

Two grazing trials (trial 1 in year 1; trial 2 in year 2) were conducted with groups of cows in early, mid and late lactation in spring, summer, autumn and winter, in a partially complete Latin Square arrangement. At each stage of lactation, and in each season of the year, cows were offered either a restricted pasture allowance (25 to 35 kg DM/cow/day), or the restricted pasture allowance plus supplements offered at 50 MJME/cow/day in trial 1 and 80 MJME/cow/day in trial 2. The supplements were either rolled maize grain (MG) or a mixture of feeds formulated to nutritionally balance the diet (BR). Supplemented cows at each stage of lactation and during each season of the year were compared to their respective control groups, which received only the restricted pasture allowance.

In both trials 1 and 2, offering MG and BR supplements resulted in large increases in DMI. At a restricted metabolisable energy (ME) allowance, offering supplementary feeds increased ME intake by 0.65 MJME/MJME offered. This highly significant linear relationship was consistent across the different seasons and did not diminish at higher ME allowance. Between stages of lactation, substitution rates (SR) ranged from 0.1 to 0.3 ($\pm$0.1) during trial 1, and 0.1 to 0.5 ($\pm$0.1) during trial 2, however differences were not closely associated with either stage of lactation, season of the year or type of supplement offered. The pasture dry matter intake of the unsupplemented cows (PDMI) was closely associated with SR, with SR increasing from 0.0 to 0.6 kg as the PDMI increased from 1.5 to 3.5% of liveweight.

In trial 1, the immediate responses ranged from 2.0 to 5.6g milksolids (MS)/MJME and from 0.3 to 11.1g liveweight/MJME. In trial 2, the immediate responses ranged from 0.3 to 3.3g MS/MJME and from 1.9 to 6.4g liveweight/MJME. The immediate MS responses were consistently smaller during spring than in other seasons of the year. The carryover responses (measured during the four weeks following supplementary feeding) were about 0.5 times the immediate effects in both trials 1 and 2. In trial 1 there was no difference ($P>0.10$) between the total milksolids responses (immediate plus carryover responses) of early and mid lactation cows, whereas in trial 2 mid lactation cows demonstrated larger ($P<0.05$) total milksolids responses than early lactation cows. In trial 1 the total milksolids responses measured in spring, summer autumn and winter were 6.4, 6.9, 3.6 and 7.5 (±1.17) g MS/MJME, respectively. During trial 2 the total milksolids responses measured in spring, summer autumn and winter were –0.1, 3.4, 3.6 and 4.7 (±0.74) g MS/MJME, respectively. There was no difference in the total milksolids response resulting from MG or BR in trial 1, whereas during trial 2 the milksolids response from MG and BR were 1.9 and 3.9 (±0.52) g MS/MJME, respectively.

Stage of lactation and season of the year accounted for little of the variation in the magnitude of the marginal milksolids response from feeding supplementary feeds. The factor that was of greatest importance was the relative feed deficit (RFD) measured by the reduction in milksolids yield (kg MS/cow/day) of the respective control groups that had occurred when the feeding treatments had been imposed. Total marginal milksolids responses were greatest when severe feed restrictions, relative to the current feed demand, resulted in large reductions in milksolids yield of the control groups. Total marginal milksolids response increased ($P<0.01$) by 0.9g MS/MJME offered as supplement per 0.1 kg MS/cow/day RFD. Total marginal milksolids responses also declined ($P<0.01$) by 0.2g MS/MJME offered as supplement as pasture allowance increased by 10 MJME/cow/day.

In the long-term trial, five spring-calving pasture-based farmlet systems were compared with the objective of measuring the long-term effects of offering large quantities of three types of supplementary feed within dairying systems. Four of five farmlets (5.67 ha) were stocked with 25 high genetic merit Friesian cows (4.41 cows/ha) and one farmlet was stocked with 19 cows (3.35 cows/ha) calving between 12 July and 31 August in each year, for three complete years. Herds on the higher stocked (HS) farmlets were offered either no supplementary feed from off farm sources (Control), or supplementary feeds of rolled maize grain (MG), or whole maize crop silage (WCS), or a nutritionally balancing ration (BR). The herd grazing the lower stocked farmlet (LS) was offered supplementary feed of pasture silage that had been conserved on that farmlet from surplus spring pasture.

The high stocking rate and early calving date of the supplemented herds resulted in low pasture allowances at most times of the year, requiring the use of 1.1 to 1.7 t DM/cow/year as supplementary feed. While some pasture substitution may have occurred, there was no difference between the annual pasture dry matter intake (DMI) of the supplemented and control herds. Feeding treatments of MG, WCS, BR and LS increased annual milksolids (MS) yield from 269 (Control herd) to 400, 363, 408 and 361 (±15.8) kg/cow, respectively. Differences in total dry matter and metabolisable energy intake per cow explained most of the differences in MS yield per cow between the five farmlets. Marginal responses from the MG, WCS, BR, and LS treatments averaged 7.3, 7.6, 7.8, and 6.6g MS/MJME over the three years of the experiment. Cows in the HS supplementary feeding herds and the LS herd calved in fatter condition and maintained higher DMI in early spring, and had shorter post partum anoestrous interval and a lower incidence of anoestrous than those in the HS control herd.

A model based on the data derived from the two short-term trials used RDF, pasture allowance, supplement intake and stage of lactation to predict much of the variability between some published short-term experiments, and closely agreed with the milksolids responses measured during the long-term trial.

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TABLE OF CONTENTS

TABLE OF CONTENTS

CHAPTER 6: EXTRA FEED FOR GRAZING DAIRY COWS: A COMPARISON OF MAIZE GRAIN, MAIZE SILAGE, A NUTRITIONALLY BALANCING RATION AND EXTRA PASTURE

LIST OF APPENDICES

LIST OF TABLES

CHAPTER 2

CHAPTER 3

LIST OF FIGURES

CHAPTER 2

CHAPTER 3

CHAPTER 4

CHAPTER 5

CHAPTER 6

LIST OF ABBREVIATIONS

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AA	Amino acids
ADF	Acid detergent fibre
ADFIP	Acid detergent fibre insoluble protein
AP	*Ad libitum* pasture
ARDOM	Apparently rumen digested organic matter
ATP	Adenosine triphosphate
BOH	Beta hydroxy butyrate
BR	Nutritionally balancing ration
CNCPS	Cornell Net Carbohydrate and Protein System
CP	Crude protein
DIM	Days in milk
DM	Dry matter
DMI	Dry matter intake
DOMD	Digestible organic matter in dry matter
eNDF	Effective neutral detergent fibre
FCM	Fat corrected milk (4%)
HS	High stocking rate
LCFA	Long chain fatty acids
LS	Low stocking rate
ME	Metabolisable energy
MEA	Metabolisable energy allowance
MEI	Metabolisable energy intake
MF	Milkfat
MG	Maize grain
MP	Milk protein
MR	Milk yield response
MS	Milksolids
MY	Milk yield
NDF	Neutral detergent fibre

NDFIP	Neutral detergent fibre insoluble protein
NEFA	Non-esterified fatty acids
NPN	Non protein nitrogen
OM	Organic matter
OMD	Organic matter digestibility
PDMI	Pasture dry matter intake of unsupplemented cows
r.s.d.	Residual standard deviation
RDP	Rumen degradable protein
REML	Residual maximum likelihood
RFD	Relative feed deficit
s.e.d.	Standard error of the difference
SOLCHO	Soluble carbohydrate
SR	Substitution rate
UDP	Rumen undegradable protein
VFA	Volatile fatty acids
WCS	Whole crop silage (Maize silage)

CHAPTER ONE

INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 Background

Pasture has been almost the only feed offered to New Zealand dairy cows for over 100 years. New Zealand's international position as the lowest cost producer of milk in the developed world is underpinned by the suitability of our temperate climate and recent soils to grow large amounts of pasture and enable grazing throughout the year. Researchers and farmers have learnt to increase pasture production by draining land, improving soil fertility and by establishing and maintaining the most productive pasture species. Increasing stocking rates so that the total annual feed requirements of the herd are similar to the amount of pasture grown each year has increased milk production per hectare. More recently, grazing techniques have been developed that allow farmers to manage the inevitable periods of pasture surplus and deficit with farms and herds that are constantly increasing in size.

While the New Zealand dairy industry has been built on grazed pasture as a low cost feed base, sole reliance on grazing also presents a major constraint to dairy production, particularly milk production per cow. Most herds are calved in spring and dried off in autumn to closely match the annual pattern of the feed requirements of the herd to the pattern of pasture production. Cows begin calving early enough to ensure that peak requirements match peak pasture production. However, this often results in cows being fed poorly immediately after calving. Pasture growth usually peaks in late spring, before declining through early summer to autumn when moisture stress limits growth. At high stocking rates, feed intake per cow declines with decreasing pasture growth, and in turn, milk yield and body condition also decline. Eventually, the body condition score of the herd and the reserves of pasture on the farm are depleted to the extent that the herd must be dried off with sufficient time for the required reserves of body condition and pasture mass to be replenished before the subsequent calving. Thus, while the traditional seasonal-calving pasture-based dairying system can result in high levels of pasture utilisation and milk yields per hectare of land, the resultant restricted feeding levels and short lactations can also severely constrain milksolids production per cow.

For many years researchers and farmers have experimented with offering supplementary feed to grazing cows in an attempt to improve feed intake and milk yield during periods of slow pasture growth. Unfortunately, these experiments have yielded mixed results for farmers and researchers alike. Increases in animal production resulting from supplementary feeding have usually been much lower than the theoretically possible responses and have generally been extremely variable. As late as the early 1990's, advice on supplementary feeding in New Zealand was restricted to a few general (and often conflicting) rules of thumb. Rules of thumb such as; supplements should be offered in spring when cows are most efficient, supplements should not be used during a summer dry spell, supplements should only be offered to cows that are severely underfed on pasture alone, and that feeding supplements to grazing dairy cows was generally uneconomic anyway.

Driven by higher milksolids prices and a desire for improved performance per cow, farmers continued to experiment, despite the advice. Over the past decade farmers have increasingly used supplements to improve total milk production per cow, per hectare and from the farm as a whole. Concurrently, farmlet trials in New Zealand and Victoria have demonstrated that milk yield responses to supplements within the whole farm system have sometimes been larger than those previously measured during short-term experiments. Some of the largest responses were reported in the summer and autumn rather than in spring. However, these trials were generally not designed to discover the reasons for the large variation in responses reported from both farmlet trials and farmer experience.

1.2 Overall aim and objectives

Farmers need information that will allow them to predict the likely long-term milk response, in any given situation, in order to make economically sound supplementary feeding decisions. While the literature contains many reports on individual supplementary feeding experiments and some reviews that have compiled the findings of these experiments, there has been little attempt to develop a unifying biophysical framework within which the body of literature and farmer experience can be interpreted. Consequently, the overall aim of this thesis was to develop such a conceptual framework to help understand supplementary feeding of grazing dairy cows. It was considered that the quantitative and qualitative nutritional requirements of the cows, the energy and nutrient supply from pasture, and the energy and nutrient supply from the supplement, were the key elements for such a framework. Within seasonal pasture-based dairying systems, the nutritional requirements of the herd are closely related to stage of lactation, and energy and nutrient supply are closely associated with season of the year. Therefore, the specific objectives of the research reported in this thesis were:

1) to determine the effect of stage of lactation (as separate from season of the year) on the milk yield response of grazing dairy cows to supplementary feed.

2) to determine the effect of season of the year (as separate from stage of lactation) on the milk yield response of grazing dairy cows to supplementary feed.

3) to determine the importance of providing the specific mixture of nutrients deemed to be limiting milk yield.

4) to determine the long-term response of a spring-calving pasture-based farm system to large amounts of three different forms of supplementary feed.

1.3 Thesis structure

This thesis is presented in seven chapters. This introduction is followed by a review of the literature (Chapter 2), in which a conceptual model describing the response of grazing dairy cows to supplementary feeds begins to be developed. The following two chapters report results from a series of trials which measured the short- and medium-term responses of dairy cows in early, mid and late lactation grazing restricted amounts of pasture, to various supplementary feeding treatments. Chapter 3 reports feed intake responses, and Chapter 4 milksolids yield and liveweight gain responses. Data generated in these experiments are then used in Chapter 5 to numerically develop the conceptual model proposed in Chapter 2. The long-term effects (three complete seasons) of supplementary feeding on the whole farm system are reported in Chapter 6, allowing a comparison with the short-term responses previously reported. Chapter 7 advances the proposed conceptual model, and discusses how it might be further developed and applied to help farmers make improved supplementary feeding decisions.

CHAPTER TWO

LITERATURE REVIEW: THE RESPONSE OF GRAZING DAIRY COWS TO SUPPLEMENTARY FEEDS

CHAPTER 2: LITERATURE REVIEW: THE RESPONSE OF GRAZING DAIRY COWS TO SUPPLEMENTARY FEEDS

2.1 Introduction

Fresh pasture provides a low cost feed source for ruminant production. Nutrient availability, ingestion, and the utilisation of ingested nutrients for milk synthesis determine productivity of pastoral dairying systems. Attaining high levels of efficiency requires synchrony between the demand for nutrients by the grazing dairy cow and the supply of readily ingestable feed, which when digested will yield an appropriate mix of energy and nutrients. Reliance on pasture as the sole diet of dairy cows often results in discrepancies between nutrient supply and demand. In practice these imbalances often result in sub-optimal daily milk production, loss of body reserves, short lactation lengths and subsequently low annual milk yield per cow.

From an economic viewpoint, feeds other than pasture should only be used if the value of any increased milk production exceeds the costs of providing the additional feed. Therefore, to make sound supplementary feeding decisions, farmers must be able to predict the response of the herd. Unfortunately, while the quantities of energy and protein required by dairy cattle to support predetermined levels of milk production and the amounts of energy and protein various feeds will yield are well understood (NRC, 1989; INRA, 1988; Fox *et al.,* 1992; AFRC, 1993), these systems are not able to accurately predict animal responses to changes in availability of feed (AFRC, 1998).

Oldham and Emmans (1988) defined responses as the consequences of a cow interacting with its food and environment. Possible manifestations of the cow's response to a change in nutrition are changes in:

- Voluntary feed intake
- Yield of milk and milk constituents
- Body mass and composition or the rate of change of body state
- Reproductive performance
- Animal health

Numerous researchers have reported the results of short-term experiments where various feeds have been offered to grazing dairy cows in an attempt to increase milk yield. Experiments investigating supplementary feeding of dairy cattle on temperate pasture have been reviewed many times in an attempt to provide predictive information regarding the response of grazing dairy cows to supplementary feeds (Leaver *et al.,* 1968; Journet and Demarquilly, 1979; Leaver, 1985; Mayne, 1991; Kellaway and Porta, 1993; Stockdale *et al.,* 1997). Responses reported in these reviews are typically 0.3 to 0.5 kg milk/kg supplement offered. These reviews also emphasise the large range in responses that have been reported, often from nil to 2 kg milk/kg DM of supplementary feed.

Responses can be described as either marginal or absolute. Marginal responses are the changes in output resulting from defined changes in input. Absolute responses describe total output at a defined total level of input. The ability to predict absolute response allows the calculation of marginal responses, however, the reverse is not necessarily true (Fisher *et al.,* 1973). Most experiments, and subsequently reviews, have attempted to define only the marginal responses to supplementary feeds. Unfortunately, most experiments have been designed to simply measure marginal responses to different feeds offered under a wide range of conditions. The approach has resulted in a large range in reported marginal responses, with little quantitative rationale to allow dairy farmers to make accurate predictions of the absolute responses that might be expected from offering a given mix of feed comprising grazed pasture and supplement.

Describing the absolute response of grazing dairy cows to supplementary feeds is complex, but is much more useful to the farmer when making supplementary feeding decisions. Cows do not respond to supplementary feeds as such, but rather to the energy and protein yielding nutrients provided by the total diet to which the supplement contributes. Therefore, prediction of absolute response requires an understanding of the state of the cow, her nutritional requirements, and the availability, characteristics and subsequent intake of energy and protein yielding feeds.

Oldham and Emmans (1988) discussed a conceptual framework for considering the absolute responses of dairy cows to the availability of defined feeds (Figure 2.1). The aim of this review is to apply this framework to grazing dairy cows offered supplements, in order to enable performance to be predicted. Such a framework will facilitate the interpretation of recent research that has investigated supplementary feeding of dairy cows grazing pasture. Implicit in this approach is the assumption that the cow cannot be considered in isolation from her environment.

2.2 Pasture as a nutrient source for grazing dairy cows

2.2.1 Energy and protein yielding nutrients supplied by pasture

2.2.1.1 Yield and chemical composition of New Zealand dairy pastures

Temperate pastures comprise various populations of grass, legume and weed species, which are tolerant of periodic defoliation of leaf and stem material by grazing animals. Perennial species that produce high yields of leafy material are cultivated to maximise the potential grazable quantities of energy and protein yielding nutrients. Ryegrass/clover associations dominate New Zealand cultivated pasture. Radcliffe *et al.* (1987) estimated potential annual net accumulation of dairy pasture dry-matter (DM) of 15 to 19 t /ha/year, although yields of 21.5t DM/ha/year have been reported when ryegrass dominant pastures were heavily fertilised with nitrogen (McGrath *et al.,* 1998).

Nutritive value of pasture for ruminant production has been reviewed by Minson (1990) and Sheaffer *et al.* (1998), while Moller (1997) published a survey of

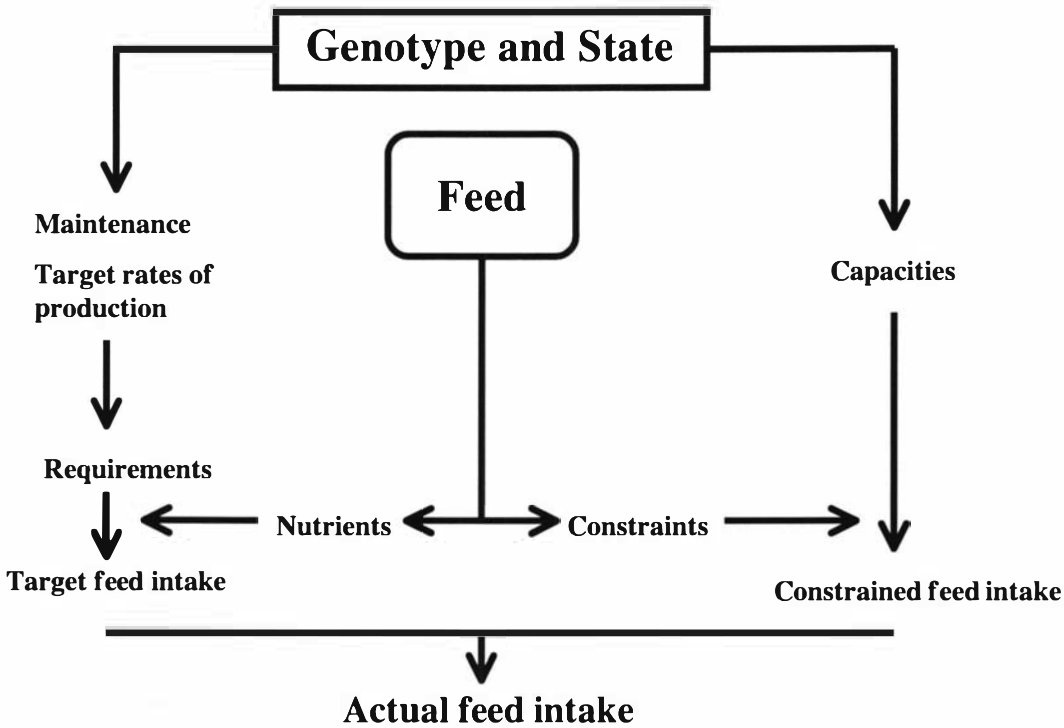


Figure 2.1: A scheme for linking animal, feed, and environmental characteristics to animal performance and feed intake.

the chemical composition of pastures collected from four New Zealand dairy farms for a complete season (Table 2.1).

2.2.1.2 Carbohydrates in pasture

Energy and protein yielding components of pasture can be broadly categorised into cell contents and cell wall. Cell contents of pasture provide organic acids, soluble carbohydrates, proteins, lipids and minerals, and are highly digestible (83 to 100%). Cell walls comprise various proportions of cellulose, hemicellulose, lignin and pectin depending on the structure and functionality of the cell.

Cell wall carbohydrates provide the predominant source of energy yielding nutrients for ruminants grazing pasture. However, the digestibility of cell wall components varies considerably (Minson, 1990). Cellulose and hemicellulose of young leafy pasture is approximately 95% digestible whereas lignin is only about 25% digestible (Waghorn and Barry, 1987). Lignification of the cell wall increases as plants mature, reducing the digestibility of the cell wall by protecting cellulose and hemicellulose from microbial degradation. The proportion of cell contents in forage DM declines from 60% in young leafy forage to 40% in perennial ryegrass at seed set and is associated with a decline in total DM digestibility from 86 to 62% (Waghorn and Barry, 1987).

2.2.1.3 Protein in pasture

Pastures typically have a crude protein (CP) content of between 6 and 20% (Minson, 1990). Legumes have a higher CP content than grasses and temperate grasses have a higher CP content than tropical grasses. High quality temperate dairy pastures in New Zealand, with varying proportions of grasses and legumes fall within the range of 18 to 30% CP (Table 2.1). A large proportion of the protein in fresh pasture is contained in the leaves. Therefore, the concentration of CP in the DM declines as the pasture matures and the proportion of stem material in the sward increases.

Approximately 40% of pasture proteins are in the form of ribulose-1, 5-biphosphate carboxylase (Rubisco) which is the CO_2 fixing enzyme found in the leaf chloroplast (Mangan, 1982). Cytoplasmic and chloroplastic proteins comprise

Table 2.1: Seasonal variation in the mean (± SEM) digestible organic matter in dry matter (DOMD), acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein, soluble carbohydrate (SOLCHO), pectin, phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) concentration (g/100g DM) of pastures sampled to grazing height from four commercial dairy farms (from Moller, 1997).

Season	**Winter**	**Spring**	**Summer**	**Autumn**
DOMD	74.3 ± 0.4	73.7 ± 0.5	74.5 ± 0.8	73.5 ± 0.4
ADF	26.7 ± 0.2	28.8 ± 0.3	29.0 ± 0.6	28.1 ± 0.2
NDF	36.4 ± 0.7	38.6 ± 0.8	38.5 ± 1.3	38.3 ± 0.7
Crude Protein	24.6 ± 0.4	23.2 ± 0.5	23.8 ± 1.0	23.4 ± 0.5
SOLCHO	10.9 ± 0.3	10.4 ± 0.4	11.1 ± 0.5	10.6 ± 0.3
Pectin	2.05 ± 0.07	2.04 ± 0.10	1.81 ± 0.07	1.93 ± 0.06
P	0.37 ± 0.004	0.35 ± 0.005	0.33 ± 0.010	0.37 ± 0.004
K	2.65 ± 0.07	2.85 ± 0.08	2.72 ± 0.14	2.79 ± 0.05
Ca	0.70 ± 0.01	0.78 ± 0.02	0.73 ± 0.03	0.70 ± 0.01
Mg	0.20 ± 0.002	0.20 ± 0.002	0.20 ± 0.003	0.20 ± 0.002

approximately 25%, and proteins from chloroplasts, and nuclear and mitochondrial membranes comprise approximately 35% of total pasture proteins (Thomson, 1982). Soluble non-protein nitrogen (NPN) accounts for between 14 to 34% of CP and comprises peptides, nitrate, and non-essential amino acids (Van Soest, 1994). Rubisco and NPN are rapidly degraded in the rumen, with cytoplasmic and chloroplastic proteins being degraded more slowly (Thomson, 1982). Proteins in the cell wall components of pasture plants are less soluble, particularly those associated with hemicellulose and lignin which are considered indigestible and may comprise 4 to 15% of total CP (Van Soest, 1994).

2.2.1.4 Rumen fermentation of ingested feed

The digestive physiology of ruminants is distinguished by the development of the rumino-reticulum (rumen). The rumen contains bacteria, protozoa and fungi capable of hydrolysing cellulose, hemicellulose and other substances resistant to enzymatic digestion by the host animal (Minson, 1990). Hydrolysis is a slow process, therefore the rumen is a large organ with a small outlet. The rumen and contents accounts for 10 to 20% of a ruminants liveweight.

2.2.1.4.1 Energy substrates derived from fermentation

The rumen is responsible for approximately 55 to 65% of apparent organic matter (OM) disappearance from the digestive tract (Waghorn and Barry, 1987). Volatile fatty acids (VFA) are formed as the end products of microbial fermentation. During microbial fermentation, energy is conserved as adenosine triphosphate (ATP) and subsequently used for maintenance and growth of the microbial population. Volatile fatty acids, waste products of microbial fermentation, provide the primary source of energy for the host animal and account for approximately 75 to 88% of the energy absorbed from the rumen, caecum and colon (AFRC, 1998).

Dietary carbohydrates form the predominant fermentation substrates, with cellulose, starch, pectin and soluble sugars degraded to hexose, and hemicellulose and some pectin degraded to pentose, before being converted to VFA via pyruvate. Most soluble carbohydrates, starch, and pectins are rapidly and completely degraded in the rumen, with the exception of starch from maize grain. As much as 35% of starch from maize grain can escape rumen fermentation (AFRC, 1998), but this is almost totally digested and absorbed in the small intestine as glucose. Dietary protein can also be a source of VFA particularly in diets such as fresh pasture, which contain relatively large amounts of rumen degradable protein (France and Siddons, 1993). The proteins are hydrolysed to amino acids, which are then deaminated before conversion to VFA.

Forage diets typically result in a mixture of VFA containing 65 to 75% acetate, 15 to 25% propionate, and 8 to 15% butyrate (Mackle *et al.*, 1996; AFRC, 1998). As the amount of starch and soluble carbohydrate in the diet increases, the proportion of propionate formed usually increases at the expense of acetate (Murphy *et al.*, 1982; Sutton, 1985). These changes in the relative proportions of VFA are the result of shifts in microbial metabolism and species (Russell and Hespell, 1981).

2.2.1.4.2 Protein substrates derived from fermentation

During ingestion and rumination most cell walls are ruptured, exposing the protein from cell contents to rapid microbial degradation. Rumen microbes hydrolyse proteins to amino acids (AA), which are then either directly incorporated into microbial protein or further degraded to form ammonia (NH_3). The ammonia is either incorporated into microbial protein, or is absorbed before being either recycled or excreted after conversion to urea. In fresh pasture diets, approximately 70% of protein is degraded in the rumen (Waghorn and Barry, 1987), with the remainder escaping to the small intestine whence it is absorbed. Degradation of protein is reduced by any factor that slows the processes of microbial degradation or reduces the time spent in the rumen by the forage (Minson, 1990).

Microbes utilise ammonia, amino acids and energy derived from the hydrolysis of plant carbohydrates to grow and multiply, hence forming microbial protein. Microbes washed from the rumen form the predominant source of protein available to the cow. The availability of nitrogenous and energy yielding compounds control the rate of production of microbial protein. The efficiency of microbial CP synthesis ranges from 98 to 308g/kg apparently rumen digested organic matter (ARDOM). In an extensive review, Minson (1990) showed that the mean efficiencies of microbial protein synthesis from fresh forage, dried forage and ensiled forages were 206, 177, and 152 g/kg ARDOM, respectively. The higher efficiency of microbial protein production from fresh forage has been attributed to the higher VFA yield from each kg DM apparently digested in the rumen (Walker *et al.*, 1975). For the same reason, it could also be expected that forages of higher digestibility result in greater efficiency of microbial protein production than low digestibility forages. For optimum efficiency of microbial protein production forages should contain about 17g CP/100g DM, and forages containing less than 100g CP/kg DM usually result in low efficiency (McMeniman and Armstrong, 1977).

The total CP flowing to the small intestine is the sum of the undegraded plant protein, microbial protein, and any endogenous protein sloughed from the walls of the rumen. When fresh forage contains more than 13g CP/100g DM, less non-ammonia CP leaves the rumen than enters it, the difference being adsorbed as ammonia. Of the non-ammonia CP entering the small intestine, about 80% is true protein and the remainder is predominantly nucleic acids. The net absorption efficiency is 0.7, therefore the yield of AA has been estimated as 560g/kg non-ammonia CP entering the small intestine (Minson, 1990). Undigested CP enters the large intestine and is either deaminated and fermented to VFA, or is excreted in the faeces.

Despite the many changes that occur to the CP during the process of ruminal fermentation and absorption, CP in the forage can still provide a reasonable estimate of AA yield to the cow (Minson, 1990).

2.2.2 The cow

2.2.2.1 Nutrient demand

In order to understand the energy and nutrient demand of the cows, it has been proposed that their purpose is to achieve predetermined "targets" for maintaining body integrity and function, establishing and maintaining pregnancy, secreting milk and milk constituents and attaining and maintaining target levels of body fat and protein mass (Emmans and Fisher, 1986). Target dry matter intake (DMI) is determined by the quantity of energy required to meet the cows' maintenance and productive targets and the metabolisable energy (ME) yield of the DM.

Blaxter (1959) suggested that the response of a cow to additional feeding is relative to her potential milk yield, as defined by her performance when fed to a recognised standard. Thus, it is impossible to predict the response to a change in nutrient supply unless the initial state of the cow is known relative to her target performance. Therefore, when predicting responses to changes in nutrition, as much consideration must be given to the state of the cow as to the diet (Oldham and Emmans, 1989). The cow must have the ability to respond to extra feed by first eating it, in addition to the feed already eaten, and secondly to use the resultant increased energy and nutrient supply to increase the desired aspect of productivity.

When the long-term availability of feed nutrients is not limiting, output will be determined by the genetic merit of the cow, which provides an estimate of her upper bounds of performance. Performance can be described in terms of mature size, rate of maturing, body composition at maturity and the upper limits to the rates of secretion of milk and its constituents (Oldham and Emmans, 1989). The capacities of the cow to ingest bulky feeds and mobilise body tissue are also important, because these traits enable the productive traits to be expressed.

2.2.2.2 Priorities for nutrients from competing functions

When feed nutrients are limiting, as is the case most of the time on pasture-based diets, accurate prediction of response requires knowledge of the use of nutrients by competing animal functions. Of primary interest is the partitioning of fat precursors between body fat and milkfat; partitioning of amino acids between tissue protein and milk protein; and partitioning of glucogenic precursors between milk lactose and milk protein production (Oldham and Emmans, 1989).

As a general rule, the animal gives highest priority to maintenance of body integrity, and lowest to maintaining body reserves (AFRC, 1998). However, as reserves of body tissue become increasingly depleted, maintenance of body reserves becomes increasingly important. The AFRC (1998) suggested the following hierarchy of metabolic processes:

1) The cow gives highest priority to functions essential to maintenance of life and metabolic activity.

2) The cows will maintain a minimum body protein and fat mass, with body protein being of greatest importance.

3) Once pregnancy has been established, the cow will maintain nutrient supply to the foetus at the expense of milk production.

4) The cow will aim to produce milk at levels determined by her genetic potential, with the pattern of production of milk, milkfat, protein and lactose being related to the stage of lactation, age and parity of the cow.

5) The cow has an upper limit to body protein mass at a given stage of maturity.

6) The cow will aim to achieve a desired level of body fat mass, relative to protein mass, stage of maturity and stage of lactation.

Two regulatory mechanisms, homeostasis and homeorhesis, control the partitioning of nutrients between the tissues of demand (Bauman and Currie, 1980). Homeostasis maintains equilibrium of the physiological state of the animal. In a nutritional sense, homeostasis regulates the storage and mobilisation of nutrients to cope with fluctuating supply associated with meal times or with changing levels of nutrition over time.

Homeorhesis is the orchestrated co-ordination of the metabolism of body tissues to support a particular physiological state. When the dairy cow initiates lactation, homeorhetic controls are responsible for the large changes that occur to the general partitioning of nutrients, and metabolic rates of body tissues, to meet the nutrient demands of the mammary gland. At the onset of lactation, these demands are so great that Bauman and Currie (1980) suggested "the high producing cow should be considered an appendage to the udder, not the other way around". Homeorhetic control results in increased lipolysis and decreased lipogenesis in the adipose tissue, increased glycogenesis and glucogenesis in the liver, and decreased use of glucose and increased use of fatty acids as energy sources for the general tissues to meet the heavy energetic demand of the mammary gland. In addition, as much as 27% of the body protein mass can be mobilised to supply AA for milk protein and catabolism for glucogenesis (Bauman and Currie, 1980).

Glucose and insulin are the predominant homeostatic controls of lipid metabolism in adpipose tissue. As plasma glucose levels rise, the release of insulin stimulates lipogenesis in the adipose tissue. However, during early lactation the adipose tissue is unaffected by glucose levels (Metz and van den Bergh, 1977), while the adipose tissue is more responsive to homeostatic signals to mobilise body fat. It is thought that these controls are mediated by a decrease in the numbers of insulin receptors in the adipose tissue (Bauman and Currie, 1980). By late lactation, these trends have reversed. The adipose tissues, with increased concentrations of insulin receptors, are more responsive to lipogenesis and less receptive to lipolysis signals. Hence, a combination of homeostatic and homeorhesis regulation is responsible for the cow mobilising large amounts of body tissue in early lactation so that energy output can exceed energy intake.

Differences in genetic merit are largely determined by differences in the individuals propensity to partition nutrients to milk yield rather than body tissue (Veerkamp *et al.*, 1994). Animals of high genetic merit have greater voluntary feed intake, and use more of their own body reserves in early lactation (Bryant and Trigg, 1981; Holmes, 1995; McGilloway and Mayne, 1996). High milk yields are strongly correlated with large losses of body reserves in early lactation. While increases in feed intake are observed with increasing genetic merit, they are small relative to the large differences in milk yield (Veerkamp *et al.,* 1994). Patterson *et al.* (1995) described a 160 day study where high genetic merit cows demonstrated 30% greater milk yield, but only 6% greater feed intake than low merit cows. While this discrepancy was partially explained by higher gross efficiency of the high merit cows, since the proportion of feed eaten required for maintenance and pregnancy was reduced, high genetic merit was associated with greater losses of body reserves during lactation (Patterson *et al.*, 1995). Body fat and protein reserves mobilised by high genetic merit cows in early lactation must be replaced in late lactation and during the dry period. The processes of depositing dietary energy as body reserves, and then mobilising them for milk production later, are only slightly less efficient than the direct use of dietary energy for milk production (Moe *et al.,* 1971). Therefore, the increase in efficiency achieved by using energy from mobilised body reserves to effectively increase "intake" and dilute the energetic costs of maintenance, far outweigh the loss in efficiency associated with deposition and mobilisation of body reserves.

2.2.2.3 Use of nutrients derived from the diet

Feeding standards generally describe the "nutrient" requirements of ruminants in terms of energy and protein (NRC, 1989; INRA, 1988; AFRC, 1993). These simplifications are usually sufficient for the purpose of providing a diet that meets the energy and protein requirements of a group of animals at known levels of performance (Broster and Thomas, 1981; Oldham, 1995). Nevertheless, they remain inadequate for the purpose of predicting performance resulting from a change in nutritional status of the group or individual, or indeed for the purpose of explaining the specific outcomes of subtle dietary changes (Beever and Oldham, 1986; MacRae *et al.*, 1988; AFRC, 1998). In addition to the effects of homeostasis and homeorhesis on the partitioning of nutrients, the relative supply of specific energy and protein-yielding nutrients can also affect the partitioning of nutrients between competing metabolic processes. The literature contains many examples of different types of feed which, although isoenergetic, influence the relative yield of milk components (e.g. Sutton, 1989) or alter the partitioning of feed energy between milk yield and body tissue accretion (e.g. Sutton, 1985).

Oldham and Emmans (1989) simplified a schematic representation of the flow of absorbed feed nutrients derived from fermentation to body tissues and milk components, originally proposed by Baldwin *et al.* (1987) (Figure 2.2: taken from Figure 9, Oldham and Emmans, 1989).

Maintenance of metabolic processes and body integrity requires energy and protein predominantly derived from VFA and AA. As part of maintenance energy requirement, dairy cows also have an obligatory need for approximately 250 g/d of glucose (Girdler *et al.*, 1984). The predominant substrates for glucose synthesis are propionic acid, glycerol and AA (Huntington, 1984). These glucogenic substrates

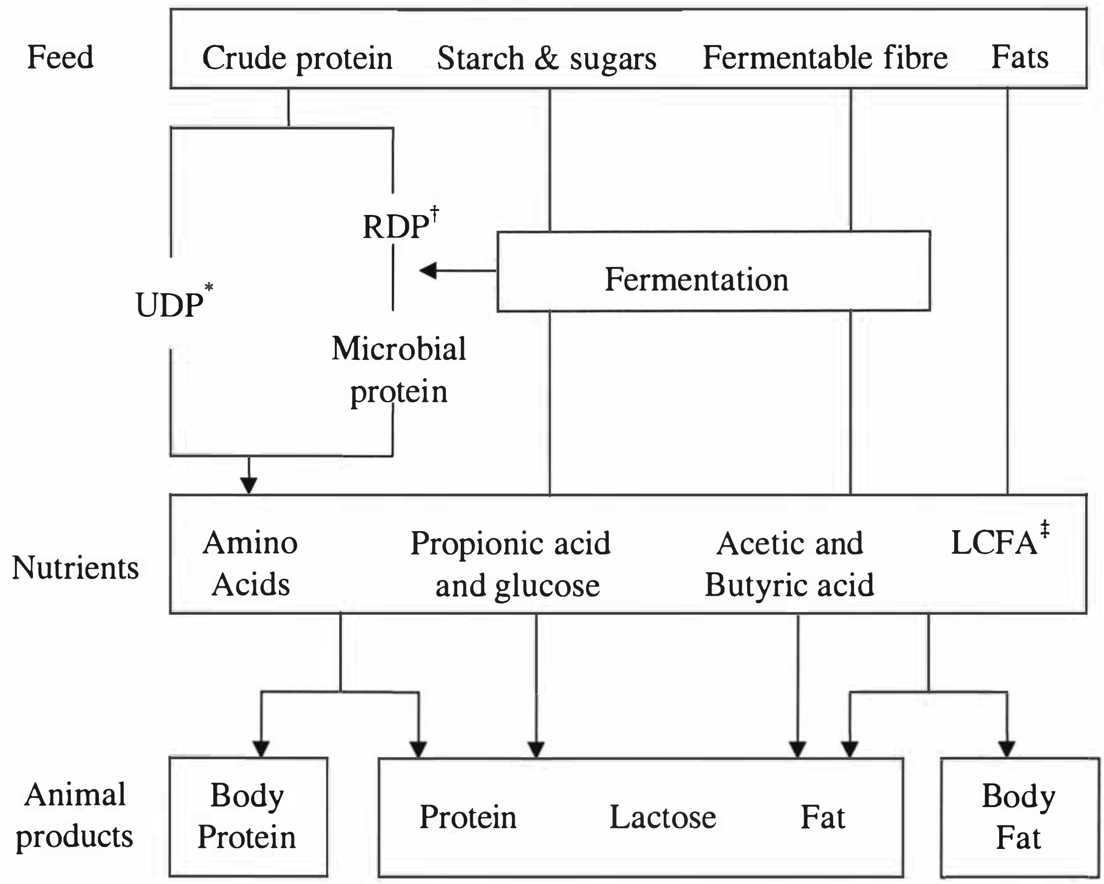


Figure 2.2: A simplified view of links between feed chemistry, end products of digestion (nutrients), and the production of milk and body constituents.
*Rumen undegradable protein
†Rumen degradable protein
‡Long-chain fatty acids

will be partitioned to glucogenesis for maintenance in preference to competing metabolic functions because maintenance is the cow's first priority for nutrient use.

Once pregnancy has been established, the foetus, gravid uterus and foetal membranes have a high priority for the restricted range of substrates required for their development. The predominant sources of energy and protein are glucose, acetate and lactate (AFRC, 1998). Glucose, lactate and acetate provide the fuel for oxidative metabolism, and AA and glucose provide the predominant source of nutrients for growth (Bauman and Currie, 1980). Glucose generally supplies 50 to 70% of total substrates oxidised by the foetus and lactate provides 20 – 25%. The remaining energy requirements are provided by amino acids, presumably by catabolism to glucose in the foetus or placenta (Bauman and Currie, 1980). When the cow is under nutritional stress, the catabolism of AA increases to provide as much as 70% of the total energetic requirements (AFRC, 1998). These amino acids are partitioned to the foetus at the expense of milk synthesis and accumulation of body protein mass (Oldham and Emmans, 1989).

Initially, foetal nutrient requirements are low with the foetus attaining only 40% of its birth weight after 7 months of gestation. However, during the final 2 months of gestation the daily glucose and amino acid requirements of the rapidly developing foetus are equivalent to that required to produce 3 to 6 kg of milk (Bauman and Currie, 1980). Fortunately this period generally occurs after the cow has been dried off, because the demands represent a 75% increase above basal energetic requirements.

Glucose is the predominant precursor for lactose synthesis (Kuhn, 1983) which in turn determines milk volume (Sutton, 1989). Therefore, the availability of storage trigyceride, glycerol and propionic acid has a dominant effect on milk yield. If these precursors are available in sufficient quantities, after the nutrient requirements of maintenance and pregnancy have been satisfied, the cow will try to meet her genetic potential for milk yield (Oldham and Emmans, 1989). Likewise, the genetic potential for milk protein synthesis will be met only if sufficient AA and energy-yielding substrates are available after maintenance and foetal requirements have been met. Approximately 50% of the fatty acids secreted in milk are synthesised in the mammary gland with the remainder being generated from blood plasma triglycerides (Sutton, 1984). Short-chain fatty acids (C_4 to C_{10}) are synthesised from acetate (80%) and beta-hydroxybutyrate (20%). The long-chain fatty acids ($\geq C_{18}$) are derived from blood triglycerides, and intermediary chain length fatty acids can be derived from either source. Because the long-chain fatty acids are not metabolised in the gland, the composition of the fatty acids absorbed from the gastrointestinal tract and mobilised from body fat mass can directly affect the fatty acid composition of milk (Smith, 1988).

Only after all other nutrient demands have been satisfied will AA, VFA and LCFA be used to enable the animal to attain target body protein and fat masses. Remaining AA are first used to replenish body protein reserves, then catabolised to provide glucose and acetic acid for the synthesis of storage triglycerides to replenish body fat reserves. Likewise, any remaining glucose, VFA and LCFA are also used for the synthesis of storage triglycerides to replenish body fat reserves (Oldham and Emmans, 1989). Within this framework, there is no surplus energy, because once all requirements have been met, there would be no further nutrient demand and nutrient intake would be limited (Figure 2.1).

Given the ability of the cow to use different metabolic pathways to satisfy demand for specific nutrients (Figure 2.2), total nutrient supply has a dominant effect on animal performance. It is for this reason that total ME requirements can be predicted with high levels of accuracy (Oldham and Emmans, 1988), despite the fact ME ignores the specific products of digestion, thereby failing to accurately predict the partitioning of energy between milk production and body reserves (Broster and Thomas, 1981). Nevertheless, because the requirements for maintenance and pregnancy are met first, milk production and body reserves are particularly sensitive to marginal changes in ME intake. By necessity, the energy and nitrogen balance of animals must be maintained in the long-term. If energy intake cannot be increased, animal performance must be reduced once body reserves are exhausted (Broster *et al.*, 1993).

2.2.3 Feed intake

2.2.3.1 General model of feed intake

Oldham and Emmans (1988) suggested that animals control intake of energy and protein yielding nutrients in an attempt to satisfy target rates of performance determined by genotype and current state. Physiological demand drives increases in DMI until the nutrients required to achieve target performance are satisfied, or until physical or chemical constraints of the feed limit DMI (Figure 2.1). However, there is a lag between increased energy requirement and the subsequent increase in feed intake. This lag is demonstrated in early lactation when the rate of increase in DMI of dairy cows is insufficient to meet the increasing energetic requirements of lactation. A period of negative energy balance results and body reserves are mobilised to provide the energetic shortfall (Baile and Forbes, 1974). In fact the DMI of the high yielding dairy cow seldom meets the nutrient requirements of both target milk yield and attaining target levels of body fat and protein mass during lactation, even when high energy concentrate-based diets are fed indoors (Veerkamp *et al.,* 1994). The situation in further exacerbated with grazing Holstein Friesian cows, where there may be physical constraints to pasture DMI (Kolver and Muller, 1998).

2.2.3.2 Rate of eating and grazing

Cattle generally spend up to 12 hours each day eating, and can achieve DMI of 50g/minute when offered fresh silage indoors (Forbes, 1995). Grazing involves processes of searching, selecting and prehending fresh herbage from large areas. Spedding *et al.* (1966) proposed that the DMI of fresh herbage (HI) can be explained by the total time spent grazing (GT), the rate of bites taken per minute (BR), and the DMI per bite (IB) as expressed by;

$$HI = GT \times RB \times IB$$

The total time spent grazing can vary from approximately 400 to 800 minutes/day (Arnold, 1981; Rook, 1994b). Grazing time increases as herbage availability declines (Rook *et al.*, 1994b) up to a point at which the benefits from increased grazing time are outweighed by the extra effort required, after which further reductions in herbage availability reduce grazing time. Grazing time is also increased as the nutrient demand of the cow increases (Journet and Demarquilly, 1979). Biting Rate is influenced by the DMI per bite and the extent of the hunger drive, and generally ranges from 45 to 65 bites/minute, increasing as bite size declines (Chacon and Stobbs, 1976; Phillips, 1993; Patterson *et al.*, 1998). Stobbs (1973) found that grazing time rarely exceeded 600 minutes/day and the total number of bites was restricted to 36,000/day. Hodgson (1981) suggested that the total number of bites/day was restricted to approximately 40,000 implying that DMI per bite is the critical variable controlling herbage intake. Further, if the number of bites that can be taken each day is limited, the ability of cows to compensate for large variations in sward presentation by altering grazing time or biting rate is equally limited. However, at low DMI per bite, Rook *et al.* (1994b) measured grazing times of 765 minutes/day and 47,660 prehension bites/day, demonstrating some flexibility by the cow to alter the number of bites taken according to sward conditions and feed demand. The longer grazing times and larger number of bites each day observed by Rook *et al.* (1994b) may also be a reflection of higher milk yield and, therefore, higher nutrient demand than in the previous studies. Nevertheless, the importance of DMI per bite is obvious.

Recent studies with grazing cows have demonstrated that when offered ideal sward conditions, cows can achieve faster rates of DMI from grazed pasture than from pasture silage offered indoors (Patterson *et al.*, 1998). Cushan *et al.* (cited by McGilloway and Mayne, 1996) demonstrated that DMI/bite increased from 0.39 to 1.19 g DM in a linear relationship as sward height increased from 80 to 180 mm. At all sward heights, DMI per bite increased with increasing sward bulk density. At a constant sward height of 120 mm, DMI/bite increased from approximately 0.6 to 1.0 g as sward mass increased from 0.6 to 1.2 t fresh herbage/ha. This work suggested that under favourable grazing conditions, dairy cows have the potential to achieve herbage intakes of 3.5 kg DM/hour.

Many authors suggest that the processes of ingestive behaviour explain the limitations that grazing imposes on DMI (McGilloway and Mayne, 1996). However, recent research has demonstrated that cows have a greater ability to adapt grazing behaviour to changing sward conditions than previously thought (Hodgson, 1981; Rook *et al.*, 1994b). It may be that grazing behaviour is a measured response to changing conditions of the sward at observed levels of herbage intake which must be mediated via the mechanisms of grazing defined by Spedding *et al.* (1966). Nevertheless, there is no doubt the amount and presentation of herbage offered has a large affect on herbage DMI.

2.2.3.3 Diet digestibility and rumen capacity

When ruminants are eating low digestibility feeds, the rumen may reach its fill-capacity before the cows' nutrient requirements have been met. It is known that stretch receptors located on the rumen wall are connected to the central nervous system (Leek, 1986). Campling (1970) found that cows ate to a similar rumen fill when offered hay varying in digestibility from 50–70%. Conrad (1966) demonstrated that DMI varied in direct proportion to liveweight when DM digestibility was less than 64%, however, once the digestibility of ingested feed was greater than 64%, feed intake varied with liveweight to the power of 0.73. This led to the suggestion that the DMI of cows eating low digestibility feeds is limited by rumen capacity (assuming that rumen capacity is proportional to the size of the cow) but the DMI of high digestibility feed is determined by the metabolic requirements of the cow.

Rumen capacity has received considerable attention as the predominant factor limiting the DMI of ruminants eating forage diets, on the basis that larger cows can generally eat more (Campling, 1970), and rumen size is closely related to the size of the animal (Bines, 1971). In keeping with this theory, many authors have attempted to explain the known decreases in the DMI of fat and pregnant cows in terms of reduced abdominal space due to internal fat deposits (Campling, 1970) or the products of conception (Campling, 1966; Johnson *et al.*, 1966; Marsh *et al.*, 1971). Indeed, reducing the capacity of the rumen by inserting water filled balloons has been shown to have a negative linear effect on DMI (Anil *et al.*, 1993). Nevertheless, the larger cow also has a higher nutrient demand. While the effects of rumen fill are likely to limit the potential intake of low quality forages, its importance has probably been over-emphasised in the past (Forbes, 1995). When the digestibility of fresh forage is less than 70%, there is a positive relationship between digestibility and DMI, however, at higher digestibility it is unlikely that DMI is limited by rumen capacity (Meijs, 1981).

2.2.3.4 Metabolic constraints

When cows are consuming high quality diets, they eat to satisfy a target energy intake regardless of the composition of the diet (Baumgardt, 1970). Once the nutrient yield from a diet is sufficiently high to meet requirements, DMI declines as the nutrient density increases and ME intake remains constant (Bines, 1971). Therefore, when cows are consuming high quality diets, energetic intake is not controlled by rumen fill. While the existence of this "metabolic control" has been recognised for many years, the specific contribution of individual metabolites to the satiety complex is not clearly understood.

It has been suggested that the concentration of VFAs in the rumen and portal blood supply may effect DMI. Infusion experiments have suggested that VFAs have their greatest influence within the rumen. Infusing VFA directly into the rumen has a greater effect than infusing VFA to the portal blood supply (Forbes, 1995). While it would appear that ruminal infusion of acetate is the most potent DMI inhibitor among the different VFA's (de Jong, 1986), it is also present in the greatest concentration. Expressed per mole of acid, infusions of sodium propionate have a greater effect than infusions of sodium acetate (Anil *et al.*, 1993). When present in equal amounts, the high sensitivity of the satiety complex to propionate may be due to the presence of propionate receptors in the liver (Anil and Forbes, 1980). However, the situation is complicated by the claim that the predominant effect of infused VFA salts on DMI was their effect on rumen osmolality rather than on specific VFA receptors (Grovum, 1995).

A negative relationship between body fat mass and DMI is well-established (Broster and Broster, 1998). In an attempt to attain target body fat mass, thin cows eat more at a given level of feed availability than fat cows (Broster and Thomas, 1981). In the rat, lowering the insulin concentrations in the blood causes increases in intake and fat deposition (de Jong, 1986). Likewise, elevated glycogen levels in the rat, associated with weight loss, also resulted in increased meal size (de Jong, 1986).

Lower yielding cows have lower nutrient demand corresponding to lower target levels of performance, and will therefore regulate DMI at a lower level than their high yielding counterparts (McGilloway and Mayne, 1996). In cows with higher nutrient demand, VFAs are cleared from the rumen faster than in cows with lower nutrient demand. Similarly, higher demands from productive tissues remove nutrients from the blood at a faster rate. Therefore, the higher the nutrient demand, the weaker will be the negative feedback signals from osmo- and chemo-receptors in the rumen, the liver and via the central nervous system (CNS) (Forbes, 1995).

The myriad of factors influencing DMI is integrated via the central nervous system in an additive manner (Forbes, 1995). Mbanya *et al.* (1993) demonstrated that the negative effects of inserting water filled balloons into the rumen were additive with those of ruminal infusions of sodium acetate and sodium propionate. This implies that high yielding cows with reduced chemo-stimulation arising from greater metabolic demand, will also be able tolerate a greater rumen distension before the combined effect reaches the threshold at which the meal will end (Forbes, 1995). The metabolic efforts required to continue grazing are probably also integrated into the CNS control of DMI, hence providing a plausible explanation for the higher DMI observed in grazing dairy cows of higher milk yield (McGilloway and Mayne, 1996).

2.2.4 Integrating the cow, feed supply and nutrient demand

The DMI of the cow is a function of a dynamic relationship between the demand for nutrients and the supply of nutrients over time. After parturition, the dairy cow will attempt to produce her target milk yield which is determined by her genetic merit. However, even at this early stage, her nutritional history has a marked bearing on her ability to attain that target milk yield. Attaining target milk yield is reliant on sufficient body reserves being available to supply the inevitable shortfall in energy and nutrients derived from the diet in early lactation. If the negative nutrient balance is too great, milk yield will reach some new equilibrium with nutrient supply, somewhat below her genetically determined target milk yield. If the gland is not supplied with the nutrients required to function at its potential capacity, there is some inevitable loss of secretory tissue. As the gland senesces, the target milk yield for the remainder of the season is reduced (Davis *et al.*, 2000). Therefore, even after nutrient balance has been restored, the nutrient intake required to attain the new targets will be reduced for the remainder of the season.

2.3 Responses of pasture-fed cows to increases in feeding level

Leaver (1985) extensively reviewed milk production from grazed temperate pasture and concluded that the major factor determining milk yield of cows was herbage intake. The amount of pasture eaten by the grazing dairy cow represents an equilibrium between her demand for feed to attain the required energy and protein yielding nutrients to satisfy target performance, and the ease with which pasture can be ingested and digested. Caird and Holmes (1986) used multiple regression to demonstrate that total intake of grazing dairy cows was positively correlated with milk yield, liveweight, concentrate intake and herbage allowance.

2.3.1 Response to extra pasture

A strong positive relationship between pasture allowance and pasture DMI has been clearly established (Holmes, 1987). Recently, Wales *et al.* (1998) studied the effect of increasing pasture allowance on the DMI of mid lactation dairy cows grazing high and low quality pasture. On high quality ryegrass white clover pastures, DMI increased linearly as allowance increased from 15 to 40 kg DM/cow. Cows grazing lower quality pasture increased DMI from about 8 to 17 kg/cow/day as allowance increased from 20 to 70 kg DM/cow. Differences between seasons have previously been observed in the relationship between pasture allowance and pasture DMI (Holmes, 1987), and between pasture of different structural composition (Stockdale, 1985). However, many of these differences can be explained by the quality of pasture on offer, as measured by ME concentration. When the relationship between pasture ME allowance (MEA), and pasture ME intake is considered (Figure 2.3), there is a high level of agreement between recent grazing experiments in New Zealand and Australia (Suksombat *et al.,* 1994; Stockdale, 1996; Robaina *et al.*, 1998; Wales *et al.,* 1998; Wales *et al.,* 1999). Grainger and Mathews (1989) established a similar relationship, although these cows ate a higher proportion of the pasture offered, than cows in the other experiments, by grazing to extremely low post-grazing pasture masses (420 to 1310 kg DM/ha).

Maximum intake is generally not achieved until the herd is able to leave about half the herbage on offer ungrazed (Combellas and Hodgson, 1979). Further, as the

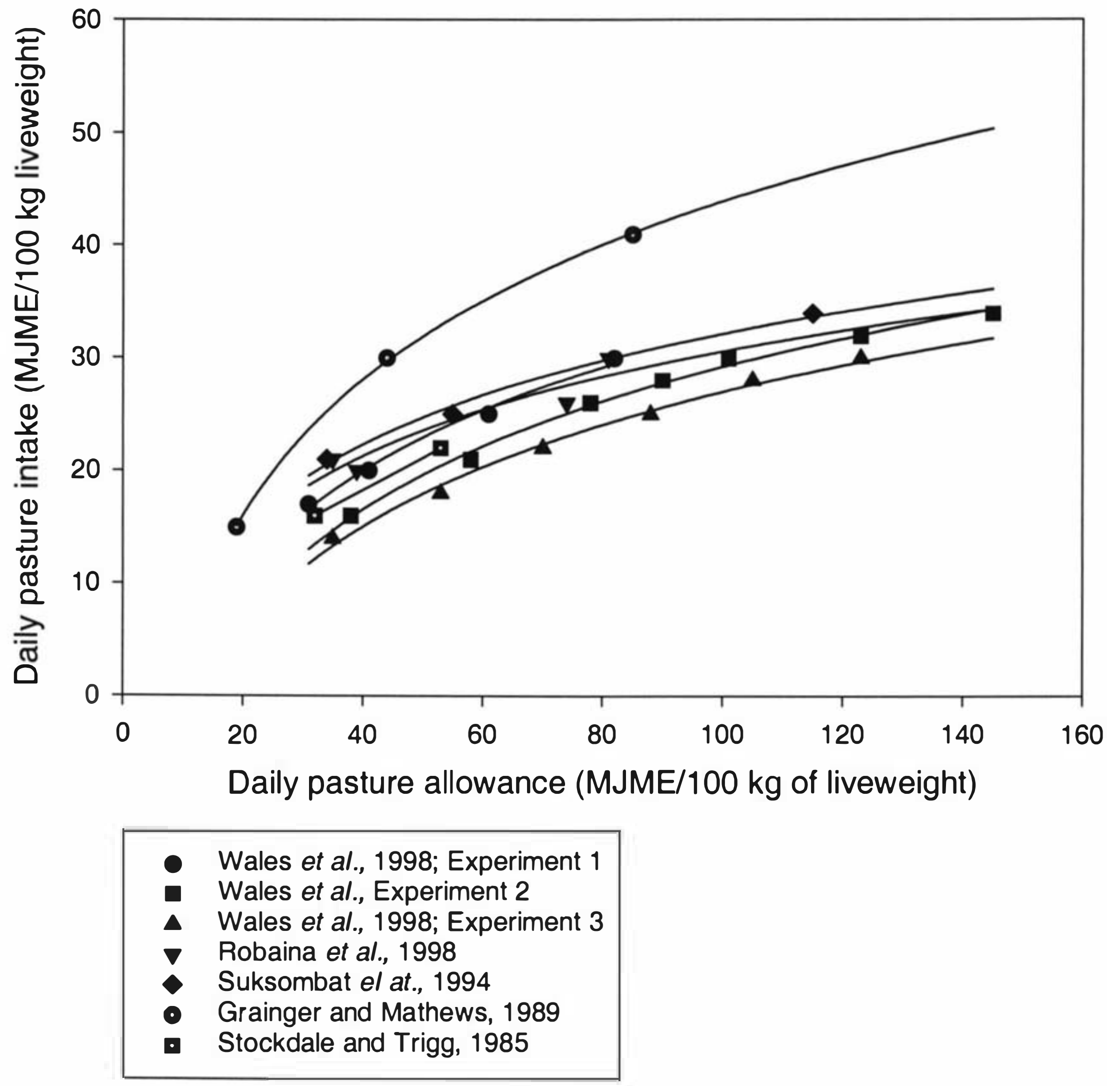


Figure 2.3: The effect of pasture ME allowance on pasture ME intake of grazing dairy cows, measured in some recent experiments.

metabolic demand of cows increases with increasing milk yield, DMI increases by approximately 0.5 kg DM/kg milk at a constant herbage allowance (Stakelum, 1993). Similarly, as lactation progresses, and milk yield declines, digestible organic matter (DOM) intake also decreases at a constant pasture allowance (Bryant, 1980). Thus, the relationship between pasture allowance and intake is affected by nutrient demand of the cow, as determined by genetic merit, stage of lactation and previous nutritional history, and by the chemical and structural composition of the pasture on offer.

2.3.2 Responses to extra feed other than pasture (supplementary feed)

Kolver and Muller (1998) demonstrated the response of high yielding early lactation dairy cows (46.3 kg milk/cow/day) to changing the diet from a total mixed ration fed in confinement to grazed high quality pasture. The pasture diet reduced dry-matter intake (DMI) from 23.4 to 19.0 kg/day, 4% fat-corrected milk (FCM) yields from 40.5 to 28.3 kg/day, and liveweight from 597 to 562 kg/cow when compared with the cows offered TMR in confinement. These large differences were the results of changes to almost all the physical and chemical properties of the diet and changes to the environment. Nevertheless, they demonstrate that high quality pasture is unable to meet the nutrient demands of high genetic merit Holstein Friesian cows, even when generous amounts of pasture are offered.

McGilloway and Mayne (1996) suggested that farmers should offer supplementary feeds to grazing dairy cows in order to overcome short-term pasture deficits, or to increase animal performance above levels achievable from pasture alone. In reality, both objectives represent an attempt to increase the performance of the animal by improving the supply of energy and protein yielding nutrients to the productive tissues. However, as previously discussed, a prerequisite to attaining a response from the grazing animal to an increase in nutrient supply is the ability to increase total nutrient intake, milk secretion, or accretion of body fat or protein mass (Oldham and Emmans, 1989). In other words, the animal must need the extra feed. In addition, the responsiveness of cows with current milk yield well below their genetic potential may be limited by any previous restrictions in nutrient supply and the adverse effects on secretory tissue.

It is generally accepted that increasing the energy intake of dairy cows results in a curvilinear increase in milk yield and an exponential increase in liveweight gain (Broster and Thomas, 1981). As discussed earlier, the partitioning of nutrients between milk production and accumulation of body protein and fat mass is dependent on genotype, nutritional history and stage of lactation. Coulon and Remound (1991) reviewed sixty-six feeding experiments to determine the effect of these parameters on the marginal increase in milk and milk protein yield resulting from increases in energy intake. In agreement with Broster and Broster (1984), the largest responses to additional energy were in early lactation, provided that the cows were initially offered less than their requirements. When energy intake exceeded theoretical requirements, early lactation responses were similar to those measured in mid lactation. Responses obtained during long-term trials were greater than those measured during short-term trials. Broster *et al.* (1993) argued that the larger response measured in full lactation experiments were the result of removing the buffering effect of changes in body reserves. According to the model of Oldham and Emmans (1989), an increase in level of nutrition can increase milk yield only up to the cows target milk yield, and surplus additional energy and nutrients will be used to replenish body reserves of fat and protein, in the short-term. However, in the long-term, stored body reserves are available for milk production. Thus, the short-term milk yield response to an increase in feeding almost invariably underestimates the total effect of the increase in feeding level on milk yield. Unfortunately, the vast majority of experiments investigating supplementary feeding of pasture-fed cows have only measured the short-term responses.

A summary of 39 short-term experiments (less than 12 weeks), published since 1979, investigating the effects of supplements offered to pasture-fed cows is contained in Table 2.2. On average, each marginal 1 kg DM (11.7 MJME) offered as supplementary feed reduced pasture intake by 0.31 kg DM and resulted in an additional 0.68 kg milk, 23 g milkfat, 25 g protein, and 124 g liveweight. The energy represented by these mean responses accounts for only about 80% of the energy provided by the supplementary feed (Table 2.3). Further, there is a high level of variability between the experiments.

Table 2.2: Some details of supplementary feeding experiments published since 1979 including; pasture allowance, stage of lactation (SOL) supplementary feed intake, milk yield (MY) of the control cows, marginal responses in milk yield (MY), milkfat (MF), milk protein (MP), and liveweight per kg of dry matter (DM) offered as supplementary feed, marginal milksolids (MS) response per mega-joule of metabolisable energy (MJME) offered as supplement, and pasture substitution rate (kg DM/kg DM).

Experimental details							Marginal response					
Reference	Season	SOL	Supplement	Allowance (kg DM/cow)	Supplement intake (kg DM/cow)	Control MY (kg/cow)	kg MY/kg DM	g MF/kg DM	g MP/kg DM	g MS/MJME	g LW/kg DM	kg DM/kgDM
Castle *et al*. (1979)	Summer	Mid	Concentrate		2.5	19	0.61	19	22	3.4		
	Summer	Mid	Concentrate		2.4	19	0.68	21	18	3.3		
	Summer	Mid	Concentrate		2.5	17.6	0.63	29	21	4.2		
	Summer	Mid	Concentrate		2.5	17.6	0.63	18	18	3.0		
Hodge & Rogers (1982)	Summer	Mid	Concentrate		3.3	6.89	0.55	20	20	3.6		
	Summer	Mid	Concentrate		6.4	6.89	0.83	30	29	5.4		
Robinson & Rogers (1983)	Summer	Mid	Concentrate		3.6	14.3	-0.58	-24	-22	-4.0		
	Summer	Mid	Concentrate		3.6	11.5	-0.58	-24	-22	-4.0		
	Summer	Mid	Concentrate		3.6	12.7	-0.58	-24	-22	-4.0		
	Summer	Mid	Concentrate		3.6	10.9	-0.58	-24	-22	-4.0		
Robinson & Rogers (1983)	Spring	Early	Concentrate		3.6	18	0.50	1	20	1.9		
	Spring	Early	Concentrate		3.5	21	0.03	-29	-3	-2.9		0.31
Moate *et al*. (1984a)			Pasture silage		3.0	11.5	0.30	15	8	2.4		0.23
			Pasture silage		6.0	11.5	0.30	-10	10	0.1		0.18
			Pasture silage		3.0	14	0.70	12	23	3.6		0.33
			Pasture silage		6.0	14	-0.02	-6	1	-0.5		0.45
	Winter	Late	Oats		4.4	5.29	0.75	15	25	3.2		
Hodge & Rogers (1984)	Spring	Early	Oats		4.4	22	-0.20	-14	-5	-1.5		
	Spring	Early	Soybean & maize meal		4.0	22	0.48	-2	16	1.0		
	Summer	Mid	Oats		4.4	11.6	0.25	11	5	1.3		
	Summer	Mid	Soybean & maize meal		4.0	11.6	0.50	10	15	1.8		
	Summer	Mid	Cottonseed & soybean meal		4.0	11.6	0.53	24	19	4.5		
Moate *et al*. (1984b)	Spring	Early	Oats		2.2	13.5	1.05	23	31	5.2		

	Spring	Early	Oats		4.4	13.5	0.73	6	30	3.5		
	Spring	Early	Lupins		4.2	13.5	0.76	14	24	3.3		
Stockdale & Trigg (1985)	Autumn	Late	Concentrate	16	1.8	7.4	1.61	72	72	12.0	514	-0.06
	Autumn	Late	Concentrate	15	3.6	7.4	0.78	42	33	6.3	239	0.00
	Autumn	Late	Concentrate	15	6.3	7.4	0.70	19	22	3.4	219	0.24
	Autumn	Late	Concentrate	26	1.8	8.6	1.22	56	28	6.9	333	0.94
	Autumn	Late	Concentrate	26	3.5	8.6	0.83	37	31	5.7	311	0.43
	Autumn	Late	Concentrate	26	6.2	8.6	0.55	24	24	4.0	121	0.31
Stakelum (1986a)	Spring	Early	Concentrate	20	3.6	17.47	0.28	11	19	2.2		0.39
Stakelum (1986b)	Summer	Mid	Concentrate	20	3.9	12.2	0.49	18	15	2.4		0.49
Dobos *et al*. (1987)	Spring	Early	Wheat		3.0	21.5	0.10	-3	-3	-0.6		
Crosse & Gleeson (1987)	Autumn	Late	Beat Pulp		2.7	8.6	1.07	37	41			
Stockdale *et al*. (1987)	Spring	Early	Concentrate		1.8	13.4	0.94	44	67	9.3	159	
	Spring	Early	Concentrate		2.7	13.4	1.78	56	59	9.6	106	
	Spring	Early	Concentrate		5.4	13.4	1.33	30	44	6.2	79	
	Spring	Early	Concentrate		9.6	13.4	1.21	4	49	4.4	126	
	Spring	Late	Concentrate		1.8	9.4	0.61	-6	17	0.9	476	
	Spring	Late	Concentrate		3.6	9.4	0.17	36	31	5.5	218	
	Spring	Late	Concentrate		6.1	9.4	0.72	-2	36	2.8	152	
	Spring	Early	Concentrate		3.6	9.8	1.64	56	58	9.3	20	
	Spring	Early	Concentrate		8.7	9.8	1.07	16	39	4.5	49	
	Spring	Late	Concentrate		2.2	6.4	1.64	27	41	5.6	390	
	Spring	Late	Concentrate		4.4	6.4	0.89	18	27	3.7	195	
	Spring	Early	Concentrate		2.2	10.4	1.00	-5	36	2.6	390	
	Spring	Early	Concentrate		4.5	10.4	1.82	56	62	9.7	95	
Ehrlich *et al*. (1993)	Spring	Mid	Whole cottonseed		2.2	12.4	-0.68	0	-13			
	Spring	Mid	Sorghum		3.0	12.4	0.23	16	11			
	Spring	Mid	Whole cottonseed		2.9	20.1	-0.07	-14	-7			
	Spring	Mid	Whole cottonseed		2.2	20.9	-0.27	-27	-23			
Stockdale & Trigg (1989)	Spring	Mid	Concentrate		2.2	10.5	1.18	18	41	4.8	357	
	Spring	Mid	Concentrate		4.5	10.5	1.87	58	60	9.7	206	
	Spring	Mid	Concentrate		2.2	13.4	2.00	36	73	8.9	195	
	Spring	Mid	Concentrate		4.5	13.4	1.13	24	44	5.6	143	
	Spring	Mid	Concentrate		2.2	16.4	1.50	50	45	7.8	130	
	Spring	Mid	Concentrate		4.5	16.4	0.58	24	24	4.0	95	
	Spring	Late	Concentrate		2.2	7.6	0.77	36	36	6.0	422	
	Spring	Late	Concentrate		4.4	7.6	0.89	30	36	5.4	211	

	Spring	Late	Concentrate		2.2	9	1.41	55	55	8.9	0	
	Spring	Late	Concentrate		4.4	9	0.75	30	34	5.2	211	
	Spring	Late	Concentrate		2.2	9.9	1.32	36	45	6.7	195	
	Spring	Late	Concentrate		4.4	9.9	0.77	14	30	3.5	114	
Grainger & Mathews (1989)	Spring	Early	Concentrate	8	3.2	15.4	0.97	10	23	3.1		-0.06
	Spring	Early	Concentrate	17	3.2	20.9	0.69	18	25	3.9		0.25
	Spring	Early	Concentrate	33	3.2	23.1	0.28	1	11	1.1		0.75
King *et al.* (1990)	Autumn	Early	Concentrate		3.3	23.4	-2.45	-3	24	1.7	-91	0.21
McLachlan *et al.* (1991)	Spring	Mid	Molasses		2.7	10.4	0.33	15	11	2.2		
	Spring	Mid	Molasses & Maize		5.1	10.4	0.49	20	18	2.9		
Suksombat *et al.* (1994)	Winter	Early	Concentrate	63	2.7	20.3	0.81	26	26	4.2	0	0.70
Wilkins *et al.* (1994)	Spring	Early	Concentrate		2.0	20.6	1.30	65	60			
	Spring	Early	Concentrate		4.0	20.6	1.23	65	43			
	Spring	Early	Concentrate		2.0	22.8	2.15	115	60			
	Spring	Early	Concentrate		4.0	22.8	0.85	55	38			
	Spring	Early	Concentrate		2.0	25.4	0.25	35	25			
	Spring	Early	Concentrate		4.0	25.4	0.23	5	13			
Rook *et al.* (1994a)	Spring	Early	Concentrate		4.0	17.2	0.90	35	30	6.3		0.43
	Spring	Early	Concentrate		4.0	21.2	0.85	38	28	6.3		0.38
	Spring	Early	Concentrate		4.0	21.5	1.15	38	43	7.7		0.08
	Spring	Mid	Concentrate		4.0	22.1	0.57	45	25	6.7		0.08
	Spring	Mid	Concentrate		4.0	21.1	0.93	65	35	9.6		0.08
Stockdale & Dellow (1995)	Spring	Early	Maize Silage	20	5.0	17.8	0.58	22	19	3.8		0.48
	Autumn	Late	Maize Silage	21	4.2	12	0.81	43	28	6.4		0.40
	Spring	Mid	Maize Silage	23	3.7	20.2	0.35	24	20	4.2		0.24
	Spring	Mid	Maize Silage	22	3.4	21.1	0.06	0	3	0.3		0.79
	Autumn	Mid	Maize Silage	20	3.8	12.9	0.55	19	19	3.8		0.16
	Autumn	Mid	Maize Silage	20	3.8	11.8	0.97	29	29	5.9		0.32
	Autumn	Late	Maize Silage	20	4.4	10.1	0.82	31	27	5.2		0.14
	Spring	Mid	Maize Silage	21	4.8	22	0.50	16	25	3.8		0.33
	Spring	Mid	Maize Silage	23	4.6	17.9	0.46	6	14	1.9		0.28
	Autumn	Late	Maize Silage	21	4.9	14.5	0.63	26	26	4.9		0.18
Murphy *et al.* (1995)	Summer	Late	SBM		1.4	14.7	0.42	18	19	2.9		
	Summer	Late	SBM		2.8	14.7	0.18	7	1	0.6		
	Summer	Late	SBM		2.8	14.7	0.36	10	12	1.7		
	Summer	Late	SBM		2.7	12.7	0.86	11	28	3.1		

	Summer	Late	SBM		2.7	12.7	0.56	-10	21	0.9		
O'Brien *et al*. (1996)	Autumn	Late	Pasture Silage		2.0	11.3	-0.05	0	-5	-0.5		
	Autumn	Late	Pasture Silage		4.0	11.3	-0.20	-15	-33	-4.4		
	Autumn	Late	Concentrate		2.0	11.3	0.80	30	35	5.4		
	Autumn	Late	Concentrate		4.0	11.3	0.65	20	28	4.0		
Reeves *et al*. (1996)	Autumn	Mid	Barley		2.6	14.2	1.58	41	59	8.0		
	Autumn	Mid	Barley		5.2	14.2	0.73	10	27	2.9		
	Autumn	Mid	72 Barley:24 Formadehyde-treated sunflower meal		2.6	12.5	2.31	88	88	12.9	-121	
	Autumn	Mid	72 Barley:24 Formadehyde-treated sunflower meal		5.2	12.5	0.94	33	36	5.0	-30	
Stockdale (1996)	Autumn	Late	Maize Silage	19	4.4	10.1	0.82	30	27	5.4	77	0.14
	Autumn	Late	Maize Silage	39	4.3	15.5	0.09	9	7	1.6	37	0.40
Neil & Thomson (1997)	Summer	Mid	Pasture silage	25	4.2	10.8	0.48	10	12	2.1	106	0.29
Thomson *et al*. (1997)	Spring	Early	Concentrate	22	3.0	17.2	1.10	43	50	7.8	100	-0.30
Stockdale (1997a)	Spring	Early	Maize Silage	21	4.8	22	0.50	16	25	3.8	15	0.33
	Spring	Early	Maize Silage + 75g Urea	21	4.8	22	0.52	34	26	5.6	69	0.42
	Spring	Early	3 Maize Silage + 2 Barley	21	4.9	22	0.41	17	19	3.2	98	0.18
	Spring	Early	3 Maize Silage + 2	21	4.9	22	0.63	31	29	5.6	65	0.41
	Spring	Early	3 Maize Silage + 1 Cottonseed meal + 1 Barley	21	4.8	22	0.73	28	29	5.2	94	0.46
	Spring	Early	Maize Silage	22	4.6	17.9	0.46	6	13	1.8	20	0.28
	Spring	Early	Maize Silage + 75g Urea	22	4.9	17.9	0.65	26	21	4.3	18	0.31
	Spring	Early	3 Maize Silage + 2 Barley	22	4.9	17.9	0.73	37	22	5.1	-14	0.51
	Spring	Early	3 Maize Silage +	22	5.0	17.9	0.84	22	24	4.3	18	0.46

			2 CSM									
	Spring	Early	3 Maize Silage + 1 CSM + 1 Barley	22	4.9	17.9	0.69	24	19	3.8	-6	0.24
Stockdale (1997b)	Autumn	Late	Maize Silage	22	5.0	6.8	1.02	49	25	6.9	-116	0.32
	Autumn	Late	Maize Silage + 75g Urea	22	5.0	6.8	1.04	50	32	7.6	46	0.26
	Autumn	Late	3 Maize Silage + 2 Barley	22	5.0	6.8	1.14	55	38	7.9	2	0.14
	Autumn	Late	3 Maize Silage + 2 CSM	22	5.0	6.8	1.20	59	35	8.7	54	0.14
	Autumn	Late	Maize Silage	22	4.9	14.5	0.63	26	26	4.8	43	0.18
	Autumn	Late	Maize Silage + 75g Urea	22	5.0	14.5	0.66	26	25	4.8	-24	0.12
	Autumn	Late	3 Maize Silage + 2 Barley	22	4.9	14.5	0.73	21	29	4.3	-39	0.12
	Autumn	Late	Concentrate	14	3.3	7.28	0.59	17	21	2.8		0.25
	Autumn	Late	Concentrate	21	3.3	9.13	0.22	2	11	1.0		0.57
Dillion *et al,* (1997)	Spring	Early	Concentrate		1.8	24.2	0.89	28	28	4.6		0.33
	Spring	Early	Concentrate		3.6	24.2	0.50	8	17	2.1		0.31
	Spring	Early	Concentrate		1.8	24	0.56	11	28	3.2		0.06
	Spring	Early	Concentrate		3.6	24	0.72	14	25	3.2		0.08
Robaina *et al.* (1998)	Autumn	Late	Barley	39	4.4	14	0.55	35	24	4.7	-7	0.59
	Autumn	Late	Barley	19	4.3	10.6	0.98	47	30	6.2	49	0.60
	Autumn	Late	Barley	26	1.8	12.9	1.56	67	52	9.5	244	0.44
	Autumn	Late	Barley	26	3.4	12.9	0.94	37	31	5.5	265	0.65
	Autumn	Late	Barley	26	6.7	12.9	0.82	34	29	5.1	94	0.58
Moate *et al,* (1998)	Summer	Mid	Barley		6.0	12.4	0.62	35	21	4.5	123	
Mean							0.68	23	25	4.1	124	0.31
Standard deviation							0.59	23	19	3.1	140	0.22
Maximum							2.31	115	88	12.9	514	0.94
Minimum							-2.45	-29	-33	-4.4	-121	-0.30

Table 2.3: Mean responses and associated energetic requirements resulting from 1 kg DM (11.7 MJ metabolisable energy; ME) offered as supplementary feed to pasture-fed dairy cows (Table 2.2).

	Response	**Energy requirement**	**Total (MJME)**
Pasture substitution	-0.3 kg DM	10.7 MJME/kg DM[a]	3.2
Milk yield	0.6 kg 4% FCM	4.8 MJME/kg 4% FCM[b]	2.9
Liveweight	0.124 kg	38.5 MJME/kg[b]	3.3
Total			9.4

[a] Mean pasture ME content published in trials contained in Table 2.2.
[b] Holmes *et al.* (1987)

2.3.3 Pasture substitution

When supplementary feeds are offered to cows grazing pasture, increases in milk yield are the result of an increase in the total yield of energy and protein yielding nutrients from the feed eaten. However, incremental increases in supplementary feed intake do not result in additive increases in total DMI (Mayne, 1991). As supplementary feeds are introduced to forage-based diets, the amount of forage eaten almost always declines. The quantitative decline in forage intake, expressed per kg DM of supplementary feed offered, is known as the substitution rate (SR).

Substitution has recently been reviewed by Bines (1985) and Thomas (1987) for forages other than pasture, and by Leaver (1985), Mayne (1991), and Kellaway and Porta (1993) when supplementary feeds were offered to pasture-fed cows. There is general agreement that the extent to which supplementary feeds substitute for forage and, therefore, increase total DMI, is the single greatest factor contributing to the variation in responses reported in the literature. Unfortunately, it is also one of the most complex factors to understand.

Bines (1985) suggested that when concentrates are added to a forage-based diet, SR increased with increasing forage quality from 0.17 when the basal diet was poor quality hay, to a maximum of 1.00 for cows eating spring grass. Thomas (1987) suggested a mean pasture silage substitution rate of 0.52 kg DM for each 1 kg DM offered as concentrates, based on a review of 43 estimates of substitution rate provided by 27 experiments. Fifteen of the experiments reviewed in Table 2.2 provided 32 estimates of substitution for grazing dairy cows offered supplements. The mean substitution rate of pasture for supplement was 0.31, however the data are characterised by a high level of variability, with a standard deviation of 0.22 and a range of –0.3 to 0.94. Given that total DMI is determined by interactions between the state of the cow and the characteristics of the feed on offer, the variability in estimates of substitution rate are not surprising given the large range in experimental conditions under which substitution rate has been measured.

2.3.3.1 Effects of pasture and supplement allowance

Substitution rate generally increases as the level of feeding relative to the nutrient requirement of the cow increases, or as the need for extra feed decreases. Meijs and Hoekstra (1984) demonstrated increasing substitution rates both as pasture allowance increased from 15 to 30 kg organic matter (OM)/cow/day, and as the level of concentrate offered increased. Increasing rates of supplementary feeding effectively depressed the effect that pasture allowance is known to have on pasture DMI (Figure 2.4). Subsequently, Stakelum (1986a, b and c), Grainger and Mathews (1989) and Robaina *et al.* (1998) have also demonstrated these effects.

Grainger and Mathews (1989) suggested that substitution rate (SR) could be accurately predicted from the pasture DMI (PDMI) of the unsupplemented group of cows by the equation: $SR = -0.445 + 0.315 (\pm 0.057) PDMI$. This would suggest that SR is largely determined by the extent to which the pasture on offer meets the nutritional requirements of the cow. A rare exception to these findings is that of Rook *et al.* (1994a) who actually demonstrated a decrease in SR as pasture availability increased. Early lactation cows continuously stocked on pastures at 4, 6 and 8 cm, substituted pasture for concentrate at 0.9, 0.5 and 0.1, respectively, when offered 4 kg DM of concentrates (Rook *et al.*, 1994a).

Debate also surrounds the relationship between the amount of supplement offered and the resultant SR. Some authors have demonstrated increasing substitution rates as the amount of supplementary feed offered increased (Le Du *et al.* 1979; Meijs and Hoekstra, 1984; Faverdin *et al*, 1991). However, Thomas (1987) suggested that for silage-based diets there was little evidence that the marginal SR increased with increasing concentrate allowances, a view supported by recent grazing studies (Robaina *et al.*, 1998). Stockdale and Trigg (1985) investigated the effect of both pasture allowance and level of concentrate feeding, and at the higher pasture allowance (25 kg DM/cow/day) demonstrated a decrease in SR as the level of supplementary feed increased. Feeding concentrates at 1.8, 3.5 and 6.2 kg DM/cow/day resulted in similar pasture intake, effectively diluting the SR from 0.9 at a supplement intake of 1.8 kg DM/cow/day, to 0.3 when the supplement intake was 6.2 kg DM/cow/day (Stockdale and Trigg, 1985). Saker and Holmes (1974) also

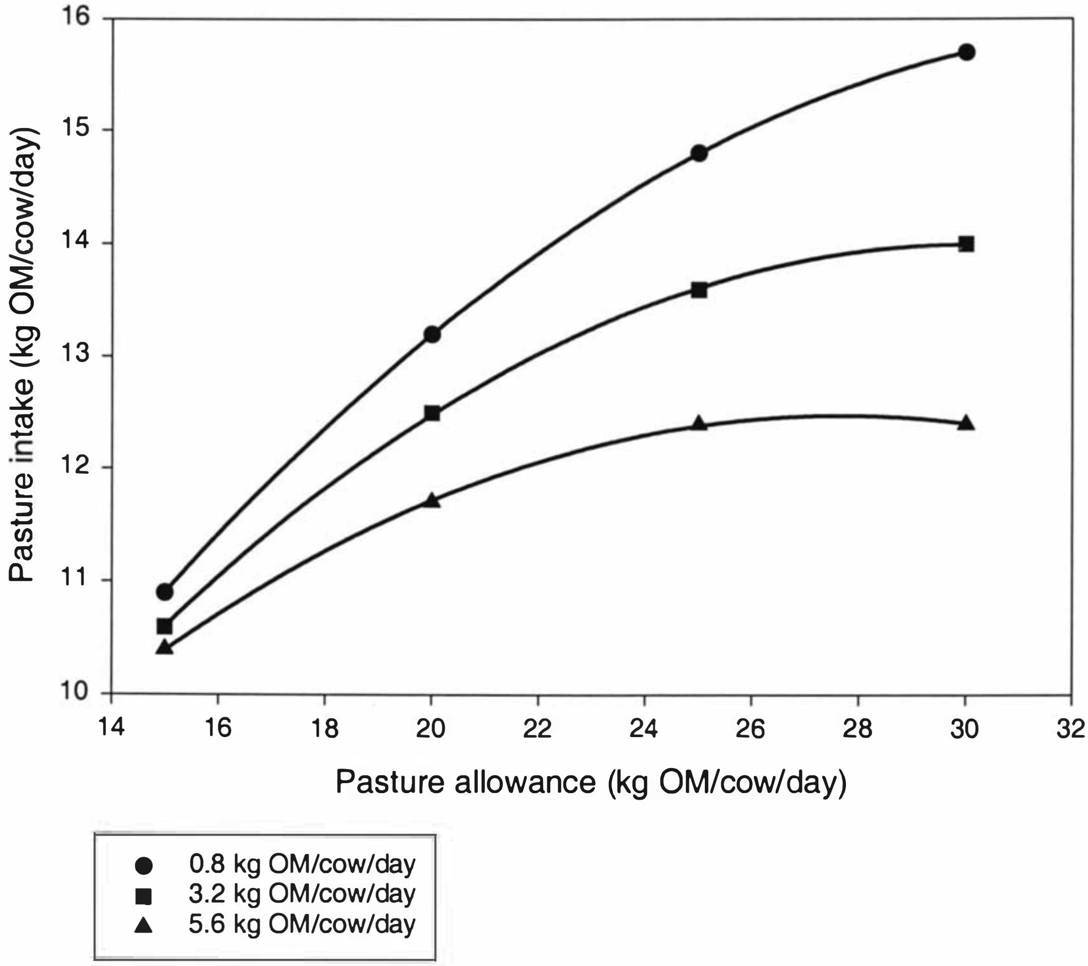


Figure 2.4: The effect of pasture organic matter (OM) allowance on pasture OM intake at three levels of supplementary feed intake (Meijs and Hoekstra, 1984).

measured a decline in substitution rate as concentrate intake of dry cows increased from 1.6 to 6.2 kg DM/cow/day.

It should be noted that in an experimental context, the incremental increases in supplement allowance are generally much smaller than those of pasture allowance, and any effects are, therefore, more difficult to measure. For example, in the experiments of Robaina *et al.* (1998), increasing the amount of supplement offered from 1.8 to 6.4 kg DM/cow/day had little effect on SR, whereas increasing pasture allowance from 19 to 39 kg DM/cow/day increased SR from 0.2 to 0.5. In a series of eight experiments, Faverdin *et al.* (1991) clearly demonstrated increasing substitution rates of hay, pasture silage and maize silage as the level of concentrate feeding increased. The increase in SR of 0.1 for each additional kg DM offered as concentrate was similar to that suggested by Ostergaard (1979).

On balance, there is sufficient evidence to assume that when cows are consuming high quality forages, substitution rate increases as the energy intake of the cow increases from either forage intake or increasing levels of supplementary feeding.

2.3.3.2 Effects of the nutritional characteristics of the forage

If the pasture is of particularly low quality, the pasture DMI may be restricted by rumen fill. Starchy concentrates can reduce the rates of digestion and clearance of fibre from the rumen, and therefore reduce pasture DMI (Scharp, 1983; Mould *et al.*, 1983; Mould, 1993). Stockdale and Trigg (1985) increased pasture DMI of unsupplemented late lactation cows grazing low quality (58.7% digestible dry-matter (DMD); 68.5% neutral detergent fibre (NDF)) paspalum (*Paspalum dilatatum*) from 8.0 to 10.6 kg DM/cow/day when allowance was increased from 15.3 to 25.9 kg DM/cow/day. When groups of cows at each pasture allowance were offered high energy pellets to achieve supplementary feed intakes of 1.8, 3.6 and 6.3 kg DM/cow/day, pasture intake was reduced to 8.6 (±0.61) kg DM/cow/day for all treatments other than cows offered the highest level of supplement at the low pasture allowance, when pasture DMI dropped to 6.5 (±0.45) kg DM/cow/day. In this example the low pasture DMI, and the subsequent low SR measured, were probably associated with the low quality pasture being offered. If pasture DMI is restricted by rumen fill or physical constraints of ingestion at levels well below that required to satisfy the nutrient demand of the cow, it is feasible that offering highly digestible concentrates may not alter pasture DMI.

It has been demonstrated that the substitution of conserved forage for concentrates is directly proportional to the digestibility of hay (Blaxter and Wilson, 1963; Leaver, 1973; Vadiveloo and Holmes, 1979) and pasture silage (Moisey and Leaver 1984; Phipps, 1987). Higher digestibility forages exhibit higher intake characteristics, and are therefore more able to satisfy the nutrient requirements of the cow.

2.3.3.3 Effects of the nutritional characteristics of the supplement

Feeding starch to ruminants often reduces cellulolytic activity in the rumen, reducing the rate of fibre digestion (Scharp, 1983; Mould *et al.*, 1983). For this reason it has been suggested that the use of fibre-based supplementary feeds may result in lower substitution rates than starchy concentrates based on cereal grains (Kellaway and Porta, 1993). On silage-based diets, Thomas *et al.* (1986) and Sutton *et al.* (1987) demonstrated higher forage DMI when fibre-based concentrates were fed than when starchy concentrates were fed, although the type of concentrate had no effect on SR when the amount of supplement offered was increased. Conversely, Castle *et al.* (1981) found that type of concentrate had no effect on forage intake, and Mayne and Gordon (1984) actually increased silage intake when barley was fed. The treatment of cereal grains with sodium hydroxide to allow a slow microbial digestion, thereby avoiding the need to crush the grain which results in rapid microbial digestion, has been shown to reduce the SR where hay has been the basal forage (Orskov and Fraser, 1975).

Meijs (1986) reported that high fibre concentrates resulted in lower substitution rates than high starch concentrates when offered to grazing dairy cows. Feeding approximately 6 kg DM/cow/day as cereal grain-based concentrate (starch) or a fibre-based concentrate resulted in pasture intake of 13.0 and 14.3 kg DM/cow, respectively, when averaged over two trials. However, because of a lower organic matter digestibility (OMD), the fibre-based concentrate supplied approximately 62 MJME/cow/day compared with 67 from the starch-based concentrate, resulting in total ME intakes of 193 and 200 MJME/cow/day for cows eating the starch and fibre-based concentrates, respectively. Nevertheless, cows offered the fibre-based concentrates produced 5% more milk, and gained less liveweight than cows offered the starch-based concentrates. However, it is likely these differences are due to differences in the products of rumen fermentation rather than to any deleterious effects on rumen function. Fisher *et al.* (1996) obtained similar results, but did not demonstrate significant differences in pasture intake or milk production resulting from starch- and fibre-based concentrates offered to cows grazing two sward densities.

van Vuuren *et al.* (1986) studied the effects of starch and fibre concentrates on rumen parameters and found that starch lowered rumen pH for a few hours after feeding, but that rumen conditions were dominated by the physical and chemical parameters of the pasture being grazed. Again, the effect of different supplementary feeds offered is dominated by the resultant change to the energy status of the cow. Small differences in productivity are more likely to be attributable to proportions of VFA formed in the rumen than to differences in total energy yield of the diet.

The effect of the supplement on digestion, and the products of digestion, cannot be separated from any effects on the overall energy balance of the cow. In this context the supplement cannot be viewed in isolation from the basal diet or the state of the cow. If the nutrients provided by the supplement overcome a limitation to digestion, and the animal is initially in negative energy balance, SR is likely to be small. However if the animal is initially in positive energy balance, and the supplement improves the efficiency of digestion, then SR will be large.

2.3.3.4 Effects of supplementary feeding on grazing behaviour

The decrease in herbage intake is generally manifested as a reduction in grazing time (Mayne and Wright, 1988). Marsh *et al.* (1971) measured a reduction in grazing time of 22 minutes/kg concentrate, and Cowan *et al.* (1977) measured a reduction of 23 minutes/kg concentrate offered. The effect of supplementary feeding on grazing time appears to be largest when pasture is scarce. Rook *et al.* (1994b) observed that continuously stocked cows in early lactation offered spring pasture of 4 cm grazed for 765 minutes to attain a pasture DMI of 13.9 kg DM/cow/day (17.8 g

DM/minute), and only 639 minutes to attain 16.8 kg DMI/cow/day (26.2 g DM/minute) on 8 cm pastures (Table 2.4). When 3.4 kg DM/cow/day was offered as supplementary feed, grazing time and DMI fell to 553 (-212) minutes and 12.2 kg (22.6 g DM/minute) at the low sward height and 606 (-33) minutes and 16.5 kg (28.0 g DM/minute) at the high sward height.

These observations suggest the energy requirements of the cow interact with intake rate. When supplementary feeding partially satisfied the nutrient requirements of the cow she stopped grazing while maintaining an intake rate similar to that of more generously fed cows. Although the supplement would have affected the cows grazing 8 cm swards in a similar fashion, these cows grazed for longer, attaining higher pasture and total DMI but still stopped grazing while maintaining the highest pasture intake rate of any group. Nevertheless, continuous grazing of tall swards provides the optimum conditions for high pasture DMI (Patterson *et al.* 1998).

2.3.3.5 Effects of the nutritional requirements of the cow

Faverdin *et al.* (1991) demonstrated that within experiments, SR of forage for concentrate on an energetic basis could be predicted by the difference between the supplemented and unsupplemented milk yield as a measure of the relative level of underfeeding. Probably the most important factor is the desire of the cow to eat enough to satisfy her productive targets. Rather than total DMI, it is the yield of energy and nutrients from the rumen and digestive tract, relative to the requirements of the cow and the energy expenditure of attaining the feed, that is likely to regulate intake of individual cows. Several competing factors influence the relationship between pasture allowance, supplement allowance, total intake, and substitution rate.

2.3.3.6 Total energy allowance and pasture substitution

According to the model of Oldham and Emmans (1989), energy requirements have a dominant effect on energy intake. Cows will generally consume supplementary feed in preference to pasture because of the relative ease of ingestion, particularly if the supplement contains a higher concentration of ME/kg DM than the pasture on offer. It is proposed that the concept of forage substitution is simply the inverse of the pasture allowance relationship. The cow eats a decreasing proportion of the nutrients on offer as her requirements for additional feed decreases. As the

Table 2.4: The effect on herbage intake, yield of milk and milk constituents and liveweight of offering concentrates to early lactation cows continuously grazing spring pasture at three grazing heights (Rook *et al.* 1994a; Rook *et al.* 1994b).

Treatment	4U	4S	6U	6S	8U	8S	SED
Mean pasture height (cm)	4	4	6	6	8	8	
Supplement (kg DM/c/d)	Nil	3.4	Nil	3.4	Nil	3.4	
Herbage intake (kg DM/c/d)	13.9	12.2	15.3	13.8	16.8	16.5	1.61
Substitution Rate		0.50		0.44		0.01	
Total grazing time(min/d)	765	553	651	660	639	606	68.2
Grazing intake rate (g/min)	17.8	22.6	24.3	21.1	26.2	28.0	2.56
Milk yield (kg/c/d)	17.2	20.8	21.2	24.6	21.5	26.1	1.29
Milkfat yield (kg/c/d)	0.83	0.97	0.96	1.11	1.05	1.20	0.08
Protein yield (kg/c/d)	0.48	0.60	0.60	0.71	0.63	0.80	0.04
Lactose yield (kg/c/d)	0.80	10.5	10.4	1.18	1.07	1.28	0.06
Mean liveweight (kg/c)	498	503	542	547	531	571	9.5

cow increases intake and she becomes progressively closer to satisfying metabolic demand, the drive to eat decreases. Therefore, the relationship between total feed energy allowance and the total amount of feed energy eaten is generally curvilinear (SCA, 1990).

This curvilinear relationship between total feed allowance and total feed intake is clearly demonstrated within individual experiments when feed is expressed as ME (Figure 2.5). This suggests that it is the total amount of dietary energy offered (pasture and supplement), relative to the energy requirements of the cow, which determines feed energy intake, and therefore SR. As increasing feed availability increasingly satisfies the nutritional requirements of the cow, a decreasing proportion of the feed on offer is eaten. This is usually manifest as a decrease in pasture intake because the entire supplement is usually eaten due to its relative ease of ingestion. In a practical sense, if the amount of feed offered becomes so generous that supplement is rejected, the amount of supplement offered is usually decreased until the herd eats it all.

2.3.4 Milk yield responses of pasture-fed cows to supplementary feeds

Supplementary feeds are able to increase animal performance only by the extent to which they result in an increase in total energy and nutrient yield to the cow. Offering increasing quantities of energy yielding supplements generally results in a curvilinear increase in milk yield (Leaver, 1985). This curvilinear response is a result of both the increased substitution of pasture for supplement, and increased partitioning of additional energy toward replenishing body fat and protein reserves by the cow as her nutrient requirements for her target milk yield become increasingly satisfied (Broster and Thomas, 1981).

Kellaway and Porta (1993) and Stockdale *et al.* (1997) have comprehensively reviewed the responses in milk yield and liveweight to supplementary feeds of cows grazing temperate pasture. Some of the key factors known to influence the magnitude of the milksolids and liveweight response are; the amount of pasture and supplement offered, the nutritional composition of the pasture and supplement, stage of lactation and the genetic merit of the supplemented cows. Some of these factors

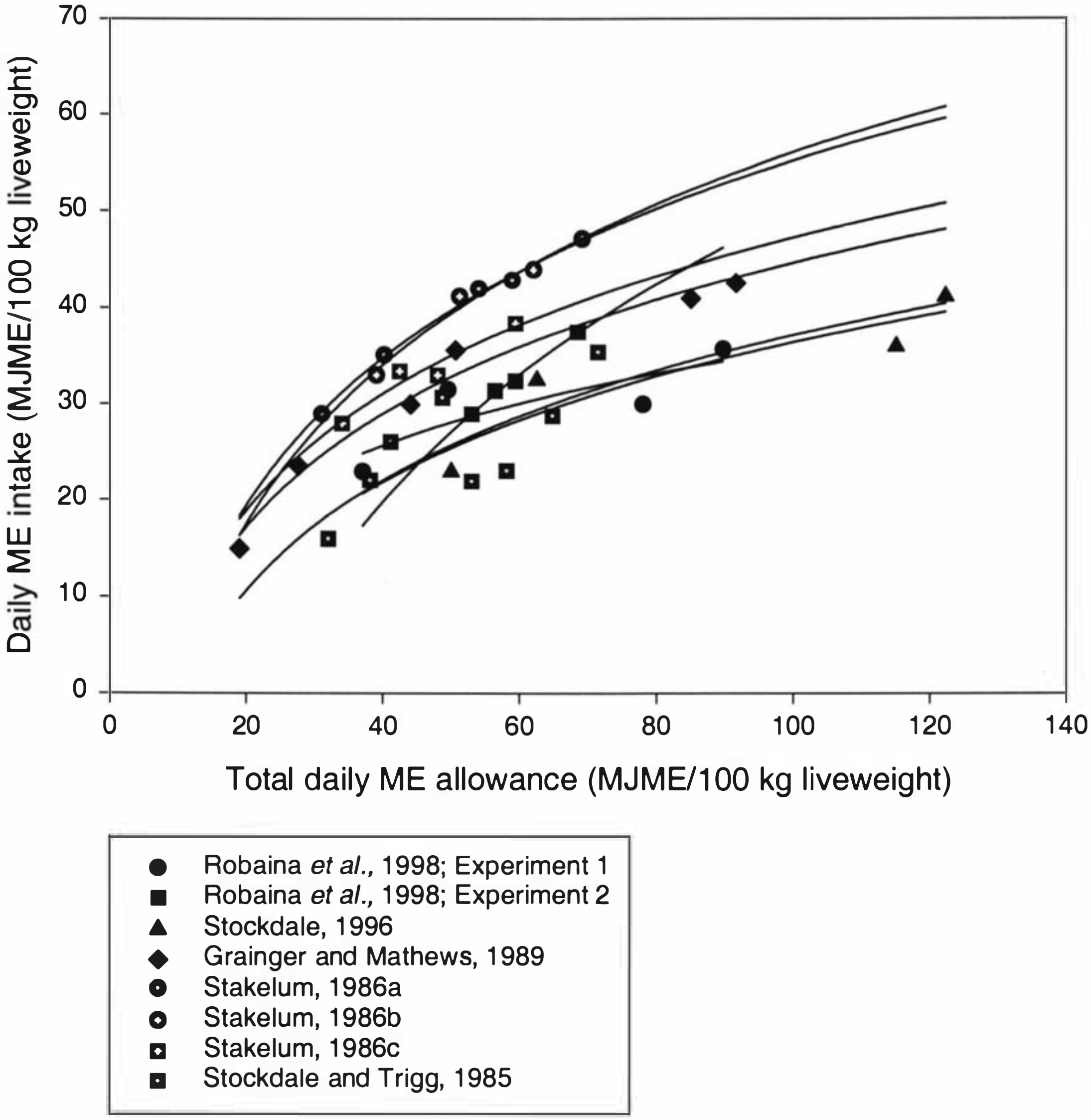


Figure 2.5: The effect of total feed ME allowance (pasture plus supplement) on total feed ME intake, measured in some recent experiments.

affect the magnitude of the animal response because of their affect on pasture substitution, which has been discussed above. The discussion will now focus on the response of cows to a change in their nutrient intake due to consumption of supplementary feed.

2.3.4.1 Pasture intake

Marginal milk yield responses to supplementary feeds generally increase as the basal pasture DMI decreases. Stockdale and Trigg (1989) studied supplementary feeding responses when energy supply was altered by changing the amount of pasture and supplement offered indoors, and when energy requirements were changed by using cows in early and late lactation. At low basal pasture intakes (7 kg DM/cow/day) offering 2 and 4 kg DM/cow/day resulted in linear increases in milk yield in both early and late lactation (Figure 2.6). Cows offered a higher basal pasture intake (12 kg DM/cow), increased their milk yield when offered 2 kg DM/cow of supplement, but no further increase in milk yield resulted from 4 kg DM/cow offered as supplement. The difference in milk yield between cows offered the different amounts of pasture were generally larger when no supplement was offered than when 4 kg DM/cow was offered. Many similar results have been reported (Robinson and Rogers, 1983; Grainger and Mathews, 1989; Grainger, 1990; Stockdale, 1996; Stockdale, 1997b; Robaina *et al.*, 1998).

In contrast, Stockdale and Trigg (1985) observed similar increases in milk yield when concentrates were offered to cows grazing low (15 kg DM/cow/day) and high (26 kg DM/cow/day) allowances of low quality paspalum based pasture. The quality of these pastures was such that the marginal milk yield response to additional pasture was only half the marginal response to concentrates (Stockdale and Trigg, 1985).

2.3.4.2 Amount of supplement offered

Increasing the amount of supplement offered generally results in a curvilinear increase in milk yield as the extra supplement increasingly satisfies the cow's demand for extra feed (Broster and Thomas, 1981; Stockdale *et al.*, 1987; Stockdale and Trigg, 1989; Stockdale *et al.*, 1990; Stockdale, 1995; Robaina *et al.*, 1998).

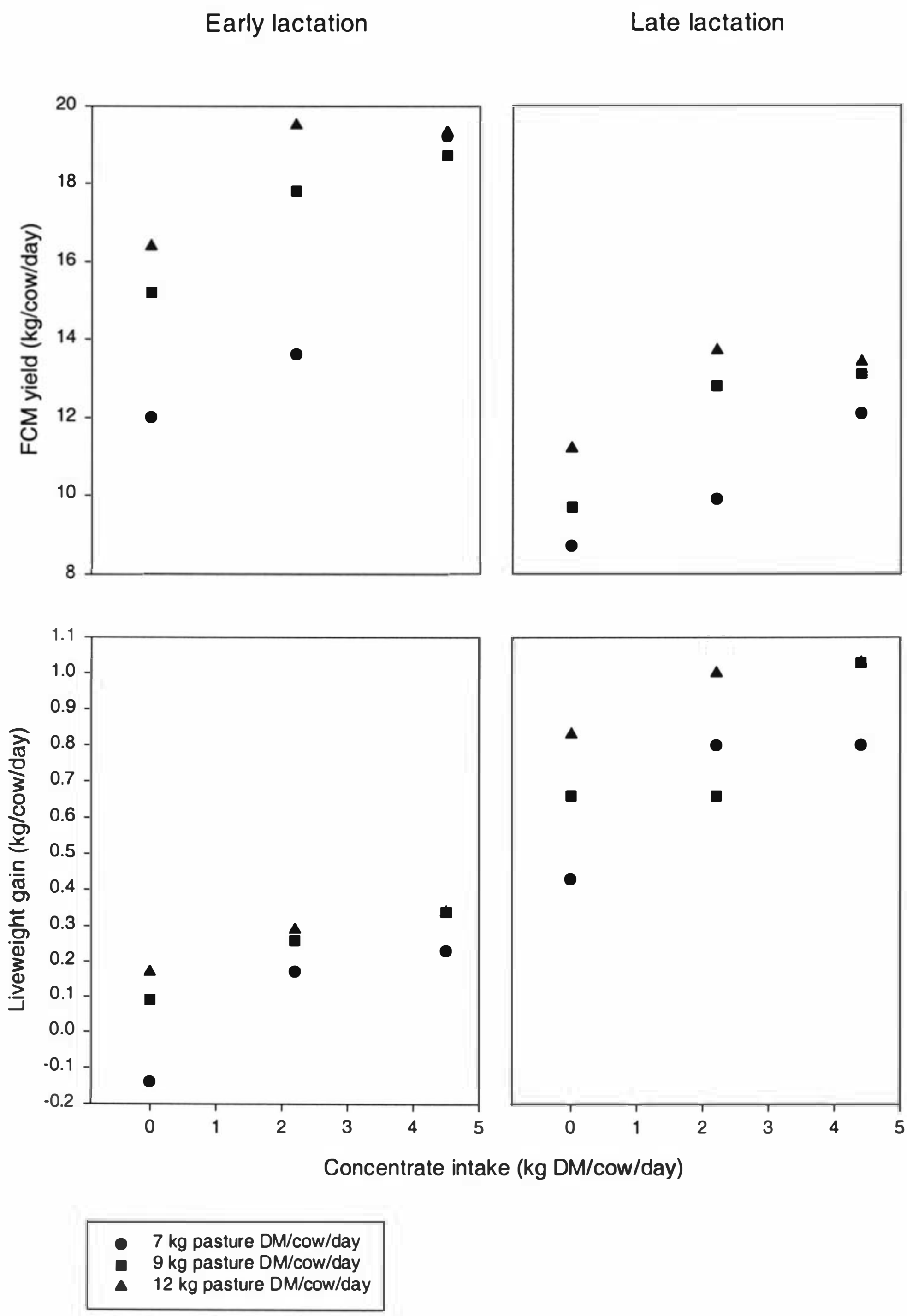


Figure 2.6: The effect of concentrate dry matter (DM) intake on the 4% fat-corrected milk yield and liveweight gain of early and late lactation cows at three levels of pasture intake (Stockdale and Trigg, 1989).

Early and late lactation cows offered 9 or 12 kg DM/cow/day of pasture indoors demonstrated similar FCM yields (18 to 20 kg/cow/day) when offered either 2.2 or 4.4 kg DM/cow/day as concentrates (Stockdale and Trigg, 1989; Figure 2.6). At very low levels of feeding, Stockdale *et al.* (1990) demonstrated that mid lactation cows consuming approximately 7.0 kg DM/cow/day as high quality pasture produced an additional 1 kg milk/kg DM offered as supplementary feeding levels were increased. However, the increase in milkfat yield with increasing levels of supplementary feeding tended to be curvilinear, as the milkfat content of the milk decreased linearly with increasing levels of supplementary feeding. This decline in milkfat content was associated with a change in VFA production, demonstrated by a decline in rumen acetic acid concentration three hours after supplementary feeding (Stockdale *et al.*, 1990).

When mid lactation cows grazing at an allowance of 26 kg DM/cow/day of high quality pasture were offered nil, 1.8, 3.4 or 6.7 kg DM as crushed barley, FCM yields increased from 13.5 to 16.4, 16.6 and 19.1 kg/cow/day (Robaina *et al.*, 1998). Curvilinear milk yield responses to increasing amounts of supplement are often described in terms of declining marginal milk yield responses. For example, from the experiment outlined above, Robaina *et al.* (1998) described responses declining from 1.6 kg to 0.8 kg FCM/kg DM as the amount of supplement offered was increased from 1.8 kg to 6.7 kg DM/cow/day. Even when late lactation cows were grazing very low quality pasture, increasing the amount of supplement resulted in curvilinear increases in FCM yield (Stockdale and Trigg, 1985). Interestingly, this was in contrast to the effect that increasing the allowance of low quality pasture had on marginal milk yield responses (see above).

2.3.4.3 Pasture quality

It is reasonable to expect that marginal milk yield responses to supplements might increase as nutritional quality of the pasture on offer declines. If pasture quality is sufficiently low to limit DMI, and therefore prevent the cow from attaining her target milk yield, large responses might be expected. In one example, cows supplemented with 5 kg DM/cow/day of a maize silage-based supplement increased milk yield by 5.3 kg/cow/day when grazing a low quality (0.59 DMD) paspalum dominant pasture, but only 3.3 kg/cow/day when grazing a high quality white clover

(*Trifolium repens*) based pasture (Stockdale, 1997a). At the same pasture allowance, both supplemented and unsupplemented cows grazing the higher quality pasture had higher pasture DMI than their counterparts grazing the low quality pasture.

Using a series of grazing studies, Stockdale (1999a) demonstrated a strong negative relationship between the quality of the pasture on offer and the marginal fat corrected milk yield response (MR) to supplements according to the relationship: MR = 3.5 – 0.28 (±0.04) pasture ME, (R^2 = 80.6; rsd = 0.14). A high level of agreement was obtained when the model was tested against a data set of six recent experiments conducted in Ireland, New Zealand and Australia (Stockdale, 1999a).

Not only do high quality pastures yield more ME per kg DM eaten, but they usually enable higher DMI (Holmes, 1987). Cows grazing high quality pasture are likely to have higher ME intake and higher milk yields (closer to their target milk yield) than cows grazing low quality pasture. Therefore, there is less potential to increase yield by offering a supplement when cows are grazing high quality pasture than when cows are grazing low quality pasture.

2.3.4.4 Nutritional characteristics of the supplement offered

Little attention has been given to the specific nutrient composition of supplementary feeds used in experiments. The vast majority of experiments have been conducted with cereal grain-based concentrates, either as crushed grain or blended pellets or meal. Some have offered maize or pasture silages, or specific protein-containing supplements.

2.3.4.4.1 Energy supplements

Generally, when cows are offered high quality pasture, there is little difference between the cereal-based supplements (Stockdale *et al.,* 1990). In fact, even when the pasture on offer might be expected to bestow considerable nutritional limitations, the responses to supplements are often simply in direct proportion to the ME that they provide (Stockdale, 1995; Stockdale, 1999b). Therefore, larger responses (per kg DM) might be expected from energy dense feeds, such as cereal grains than from maize silage or pasture hay.

2.3.4.4.2 Processing cereal grains

When whole, unprocessed cereal is fed to adult cattle, 55% of the grain can escape digestion and remain intact in excreta (Nordin and Campling, 1976). Barnes and Orskov (1982), and more recently Tait and Beames (1988), have reviewed simple methods of preserving and processing cereal grains for ruminants. Campling (1991) summarised much of the work since 1975 involving physical or chemical processing of barley, oats, wheat, and maize for milking cows.

Cereal grains must be processed to some extent because the outer covering or coat of cereal grains is resistant to attack by the organisms and enzymes within the rumen. There is considerable variation between cereals in the resistance to rumen digestion. Husked grains are more resistant to attack than naked grain, while legume seeds are the least resistant. Nordin and Campling (1976) suspended samples of cereals in the rumen of fistulated cattle and found that dry matter disappearance of milled grain after 48 hours was around 85%, but when whole grain was used, dry matter disappearance was only 15%. As the particle size of the milled grain decreases, the rate of digestion increases due to the increased surface area.

Starch is the main energy source when feeding cereal grains to dairy cattle. The rumen is the main site of starch digestion. Grains that are extensively degraded in the rumen appear to have higher overall starch digestibility. Therefore, the lower the ruminal escape the higher the total starch utilisation (Theurer, 1986). At least 90% of the starch is fermented in the rumen when oats, barley, or wheat are fed to ruminants as crushed grain. As already mentioned, maize and sorghum are different. Due to a slower rate of starch digestion, up to 40% of starch can escape ruminal fermentation. Steam flaking consistently improves total starch digestibility over dry rolled processes from about 91 to 99% when cattle are fed maize or sorghum diets (Theurer, 1986). However, these effects of processing treatments beyond simple crushing of the grain are much larger for maize and sorghum than for oats, barley, or wheat (Hale, 1973).

Sudden dietary changes and fast digestion rates of feeds in the rumen can have a deleterious effect on microbial activity and subsequent products of digestion. Bacteria fermenting cellulose and hemicellulose give rise to VFA in the proportions

65 to 75% acetic acid, 15 to 25% propionic acid, and 8 to 15% butyric acid (AFRC, 1998). When cereals are fed the proportions of these acids change. A higher proportion of propionic is formed when starch is fermented. When cereals make up a high proportion of the diet (>30%) very high proportions of propionic (up to 50%) and lactic acids are formed (Orskov, 1986). Armstrong and Blaxter (1957) showed that increasing the degree of processing of cereal grains increased levels of rumen propionate at the expense of acetate even further.

A chemical technique involving the treatment of grain by spraying a concentrated solution of caustic soda (NaOH) was reported by Orskov and Reid, (1979). The NaOH disrupts the fibrous seed coat sufficiently to allow the digestive enzymes and bacteria to act on the starch. Starch release into the rumen is more controlled because the grains are still whole, and therefore rumen pH is not depressed to the same extent as would result from feeding physically processed grains. (Barnes and Orskov, 1982). Cattle receiving NaOH treated cereal diets maintained a higher rumen pH and had a lower proportion of propionic acid in the rumen than cattle receiving rolled grain (Orskov and Reid, 1979). The disadvantages of this method are that the flow characteristics of the grain are changed, and treatment must be completed several days before the grain can be fed.

High levels of propionic acid can cause problems for lactation. If the propionic acid absorbed exceeds the ability of the liver to convert it to glucose, insulin production will be stimulated. This causes an increased uptake of nutrients by tissues and a reduction in milk production, in particular milkfat (Orskov, 1986). A reduction in milkfat production resulted from a severe reduction in the fat content of milk when Stockdale *et al.* (1987) fed more than 6 kg DM per cow of pelleted cereal as a supplement to pasture. This was associated with a sharp increase in propionic acid production in cows with high pellet intakes.

Low rumen pH associated with rapidly fermentable supplements can cause a depression in the rate of fermentation of the cell wall components of forage, and subsequently a reduction in forage intake (McDonnell *et al.*, 1979). This effect can occur when the level of cereal supplementation is as low as 15 to 20% of the diet (Mulholland, *et al.*, 1976). Many workers have overcome the problems in sheep, while maintaining or enhancing performance, by feeding whole grain. Whole grain results in a better balance of VFA and a higher rumen pH. The release of starch from whole grain is much slower than for processed grain because not all the grain is crushed during eating. The particle size of those grains that are chewed is larger than that resulting from rolling or crushing. The subsequent release of VFA's is slower and more saliva is produced through rumination, resulting in a higher rumen pH (Barnes and Orskov, 1982).

Digestibility and intake of hay has been shown to be higher in sheep fed whole rather than processed grain (Orskov and Fraser, 1975). A higher rumen pH, and a more controlled rate of digestion resulting from NaOH treated grain interferes less with the digestion and intake of roughages. The intake of hay in fattening cattle has been increased 40% when NaOH treated grain was used as opposed to ground, pelleted barley (Orskov *et al.*, 1977). These increases in cellulose digestion are only due in part to an increase in the rumen pH. The rate at which feed substrates go into suspension seems to be of greater importance (Orskov, 1979b). Orskov and Hovell (1978, cited in Orskov, 1979a) showed very low cellulose digestion resulted when sugar cane was fed to cattle, despite a high ruminal pH. Here the soluble carbohydrate was so high that cellulose digestion was severely reduced leading to very low intakes.

To minimise the impact of cereal supplementation on rumen function, the rate of digestion should be controlled. A supplement which is slowly digested decreases fluctuations of pH and microbial population of the rumen contents. Maintaining the structure and particle size of the grain can reduce the rate of fermentation. This is probably best achieved via chemical treatment of cereal. The most appropriate physical method is light rolling, resulting in cracking the grain.

2.3.4.4.3 Protein supplements

Cows with a milk yield of 13 kg/cow/day require feeds with a CP concentration of 15g/100g DM, increasing to 18g/100g DM at milk yields of 33 kg/cow/day (NRC, 1989). While the CP concentration of fresh leafy pasture is usually between 20 and 25g/100g DM, pasture CP concentration can decline to

10g/100g DM when stem and dead material make up a high proportion of the sward, particularly during summer and autumn (Holmes *et al.,* 1987).

It is generally accepted that increasing the supply of amino acids to the intestine will result in an increase in milk production (Minson, 1990). Amino acid supply can be increased via an increase in the rate of microbial protein synthesis, or by directly increasing the proportion of dietary amino acids that escape the rumen (undegradable protein; UDP). If the CP concentration in the diet is too low, insufficient microbial protein will be formed and the amino acid supply to the intestine can be increased by simply increasing the dietary CP concentration. When the diet contains high concentrations of quickly degradable protein, the use of high-energy supplements such as cereal grains can enhance the rate of rumen microbial growth by allowing a higher proportion of rumen ammonia to be incorporated into microbial protein, thereby acting as a protein supplement. An increase in the proportion of amino acids escaping rumen degradation, and therefore being supplied directly to the intestine, can be achieved by either changing the nature of the protein, protecting the proteins from proteolysis, or increasing rumen passage rate (AFRC, 1998).

Protein supplements can be expected to result in higher milk yields than cereal grain supplements when the pasture/cereal diet is protein-deficient. Cows consuming diets based on low CP concentration cereal hay consistently demonstrated higher milk yields when offered legume grain supplements than when offered cereal grain supplements (Bartsch *et al.,* 1987 (cited by Kellaway and Porta, 1993); Valentine and Bartsch, 1990), but not when high quality pasture provided adequate CP (Castle *et al.*, 1979; Bartsch *et al.,* 1987 (cited by Kellaway and Porta, 1993); Valentine and Bartsch, 1989; Hough, 1991 (cited by Kellaway and Porta, 1993); Rusdi and van Houtert, 1997; Neil and Thomson, 1997). Likewise, higher milk yields have been attained from cows offered protein supplements than from cows offered cereal grain supplements when the cows were grazing pastures containing a low (<14g/100g DM) CP concentration (Hodge and Rogers, 1984; Moate *et al.,* 1999).

Several trials have investigated the feeding of UDP in an attempt to directly increase the supply of amino acid to the intestine of high producing pasture-fed dairy cows. The milk yield responses have been found to be positive (Stobbs *et al.*, 1977; Rogers *et al.*, 1980; Minson 1981) or non-existent (Wilson, 1970; Brookes, 1984; Penno *et al.,* 1995a; Rusdi and van Hourtert, 1997).

Stobbs *et al.* (1977) measured a 3.3 kg/cow/day increase in milk yield when 1 kg formal-casein was fed to cows in early lactation. Although the cows were grazing on tropical pastures (Rhodes Grass; *Chloris gayana*), they ingested young leafy pasture containing 20g CP/100g DM, well above the recognised minimum requirement. Rogers *et al.* (1980) increased milk yield by 2.0 kg/cow/day when cows eating ryegrass pasture, containing 17.5g CP/100g DM, were supplemented with 1 kg formal-casein. Smaller responses to 1 kg DM/cow/day of formal-casein were measured by Minson (1981), which increased milk yield from 15.1 to 15.9 kg/cow/day, when cows grazed ryegrass pastures containing 27.5g CP/100g DM. Minson (1981) claimed that the extra milk yield achieved in all three experiments could be attributed to increased energy intake. Certainly, the low milk yields reported indicate that energy intake was limiting in all three experiments. However, the large increases in milk yield reported by both Rogers *et al.* (1980) and Stobbs *et al.* (1977) exceeded the expected response from energy alone. Stobbs *et al.* (1977) cited increased liveweight, and an increase in the proportion of short-chain fatty acids in the milk as evidence that pasture intake was higher when protected casein was fed. However, this was not supported by either Minson (1981), who estimated intake indirectly using grazing time, or Rogers *et al.* (1980) who measured intake directly. Recently, Harris *et al.* (1998) reported higher milk yield from cows eating tannin-containing legumes (*Lotus corniculatus*) than cows eating similar amounts of white clover or ryegrass. Further experiments, using polyethylene glycol to block the protein-protecting action of the tannins, clearly demonstrated the increased milk yield was indeed caused by the increased flow of undegraded amino acids from the rumen (Woodward *et al.,* 1999).

Wilson (1970) reported two experiments where 450g of either normal casein or protected casein was fed to cows eating pasture. In the first experiment conducted in June, unprotected and protected casein increased milk yield from 15.0 to 15.9 and 16.7 kg/cow/day, respectively. However, milk yield was not affected by treatment in a second experiment conducted in November. More recent experiments investigating the use of UDP supplements offered to high yielding cows in early lactation have consistently demonstrated no response. Four pairs of monozygous cows consuming *ad lib* ryegrass white clover pasture (27g CP/100g DM) were offered 1 kg/day casein or 1 kg/day rumen protected casein (Brookes, 1984). No differences in DM intake, milk yield, or milk composition were measured. These results have been supported by Penno *et al.* (1995a), Rusdi and van Hourtert (1997) and Stockdale *et al.* (1997).

Both the NRC (1989) and AFRC (1993) estimates of protein requirements suggest the diet of the New Zealand cow grazing spring pasture has an abundance of rumen degradable protein (RDP). Calculations based on ARC (1991) indicate that pasture also supplies adequate UDP. However, the NRC estimations indicate that spring pasture has a deficiency of 380g/cow/day of UDP. Robinson *et al.* (1991) discussed this discrepancy and suggested that the NRC estimates are too high. Nevertheless, the variability in experimental results suggest that at times, pasture containing adequate concentrations of CP does not provide an adequate supply of amino acids to the intestine to allow target milk yields to be achieved.

A further explanation for the variability in results may be found in the basal level of feeding of cows offered the UDP supplements. The literature suggests that UDP supplements may have a greater effect when cows are in negative energy balance. Cows of high genetic merit are able to mobilise large quantities of body fat to provide energy to support milk production. It is generally accepted that the ability of body protein to supply amino acids for milk production is limited. Orskov *et al.* (1981) measured increased milk production and liveweight loss when cows were offered UDP supplements at daily dietary ME intakes below 135 MJME, but no response when daily ME intakes were above 160 MJME/day. Offering UDP supplements to cows in negative energy balance may provide additional amino acids, allowing an increase in milk production, and subsequently facilitating increased liveweight loss. This may explain the large responses to UDP supplements in experiments from low producing cows, while experiments with higher producing cows often do not show increases in milk yield.

As noted by Kellaway and Porta (1993), most experiments have compared the responses of pasture-fed cows to protein supplements or cereal grain supplements, or to protein supplements alone. However, of greater practical interest is the response of cows receiving mixed diets, comprising pasture and cereal grain or maize silage, to protein supplements. Firstly, a mixed diet is more likely to induce a protein deficiency because of the low CP concentration of most cereal-based supplements. Secondly, amino acid supply may begin to limit the milk yield of cows once the limitation of ME intake is removed by providing energy rich supplements.

The use of iso-energetic protein supplements, with various rates of rumen degradability, were evaluated with cows consuming diets of pasture and maize silage by Macdonald *et al.* (1998). While the CP concentration of the pasture offered was 23.0, 17.0 and 19.5g/100g DM in the spring summer and autumn, respectively, offering a large amount of maize silage resulted in the CP concentration of the control diet (no protein supplement) being only 14.5, 11.0 and 12.5g/100g DM in the spring, summer and autumn, respectively. A non-protein-nitrogen supplement (urea) had no effect on milk yield in any season. Protein-rich supplements of high rumen degradability (soybean meal) increased milk protein yields in summer and autumn, while supplements of low rumen degradability (fishmeal) increased milk and milk protein yield in spring, summer and autumn. Responses were largest in summer when substituting about 13 MJME of maize silage for fishmeal (1 kg/cow/day) increased milk yields from 10.5 to 13.1 kg/cow/day and milk protein yields from 380 to 480 g /cow/day. Replacing sunflower meal with fishmeal, as the protein source in iso-nitrogenous concentrates based on maize grain and wheat bran, has resulted in increased milk yield offered to grazing cows in early lactation (Schroeder and Gagliostro, 2000). Moran and Stockdale (1992) also demonstrated the importance of a true protein supplement (whole cotton-seed) when they offered large amounts of maize silage to pasture-fed cows which resulted in protein-deficient diets. Stockdale (1995) observed that the marginal milk yield response of pasture-fed cows to maize silage rapidly declined once the CP concentration of the total diet fell below 14g/100g DM.

2.3.4.5 State of the cow: stage of lactation and nutritional history

As lactation progresses, homeorhesis results in a higher proportion of ingested nutrients being partitioned to replenish body reserves at the expense of milk yield. Irrespective of nutrient supply, the secretory tissue of the mammary gland gradually senesces as lactation advances. However, the rate of senescence is even greater if the nutrition of the cow has been inadequate through earlier lactation. A regression analysis based on the experiments summarised in Table 2.2 suggest milk yield by grazing dairy cows decreases at the rate of 0.037 kg 4%FCM per day for each additional day into lactation (Table 2.5). Thus, in addition to any homeorhetic induced effects, as potential milk yield declines, the nutrient demand of the mammary gland also decreases. Therefore, as lactation proceeds, the nutrient requirements for lactation are met more readily, and increasing proportions of the energy and nutrients available to the body tissues are used to replenish reserves of body fat and protein.

Until recently, it has generally been assumed that cows in early lactation demonstrate larger marginal milk yield responses to supplementary feeds than cows in late lactation. This has been based on the assumptions that milk yield potential is greater in early lactation, and that a higher proportion of energy and nutrients are partitioned toward milk yield rather than liveweight gain in early lactation (Stockdale and Trigg, 1985; Stockdale and Trigg, 1989, Kelloway and Porta, 1993). However, in the experiments reviewed in Table 2.2, while milk yield certainly declined with advancing stage of lactation, there was little effect of stage of lactation on the marginal responses to supplements. Early, mid and late lactation cows demonstrated average marginal milksolids responses of 54, 38 and 56 g MS/kg DM, respectively (Table 2.6).

However, few studies have directly compared the effect of stage of lactation on the milk yield response of dairy cows to increases in feeding levels, or to supplementary feeds. Milk yield responses to concentrates have been reported to decline from 1.9 kg/kg DM to 0.9 kg/kg DM as lactation advanced from early lactation (29 – 81 days in milk; DIM) to late lactation (205 – 224 DIM) (Stockdale *et al.*, 1987). Likewise, when cows eating about 7 kg DM as pasture were offered 4.4 kg DM as concentrates, the milk yield of early lactation cows increased from 10.5 to 18.9 kg/cow/day compared with that of cows eating pasture alone, whereas the milk yield of late lactation cows only increased from 7.6 to 11.5 kg/cow/day (Stockdale and Trigg, 1989; Figure 2.6). However, when cows were eating generous amounts of pasture (about 12 kg DM/cow/day) there was little difference between the milk

Table 2.5: Effect of metabolisable energy intake (MEI) and stage of lactation (days-in-milk; DIM) on 4% fat corrected milk yield (MY; kg/c/d) of groups of cows offered pasture only (48 observations), or pasture and supplements (73 observations), in 15 supplementary feeding studies (Table 2.2).

Reference	**Regression equations**	R^2	**r.s.d**
Pasture only	MY = 12.1(±1.49) + 0.070(±0.010)MEI - 0.042(±0.005)DIM	0.79	2.5
Pasture and supplement	MY = 12.9(±1.49) + 0.060(±0.008)MEI - 0.035(±0.004)DIM	0.72	2.5
All treatments	MY = 12.2(±0.995) + 0.066(±0.006)MEI - 0.037(±0.003)DIM	0.75	2.5

Table 2.6: A comparison of milk and milksolids responses to supplementary feeds reported from experiments with early, mid and late lactation cows published since 1979, summarised in Table 2.2.

Stage of lactation	**Early**	**Mid**	**Late**
Studies	15	13	12
Observations	46	39	46
Performance of unsupplemented cows			
Pasture DMI (kg/c/d)	12.2 (±3.8)	11.3 (±3.0)	10.5 (±2.9)
Stage of lactation (days-in-milk)	42 (±26)	105 (±53)	210 (±27)
Milk yield (kg/c/d)	18.9 (±4.5)	14.4 (±4.1)	10.3 (±2.9)
Liveweight (kg)	489 (±34)	479 (±47)	475 (±41)
Marginal responses to supplements			
Milk (kg/kg DM)	0.7 (±0.8)	0.6 (±0.7)	0.8 (±0.4)
Milksolids (g MS/kg DM)	54 (±30)	39 (±49)	56 (±33)
Milksolids (g MS/MJME)	4.2 (±2.4)	3.8 (±3.9)	4.6 (±2.8)

yield response of early and late lactation cows to supplements. In contrast to these studies, Grainger (1990) demonstrated that stage of lactation had little influence on the milk yield response of cows to increasing pasture intake. While direct comparisons to early lactation cows were not made, large milk yield responses of late lactation cows have also recently been observed by Crosse and Gleeson (1987), Stockdale (1996), Stockdale (1997b), and Robaina, *et al.* (1998).

Recent nutritional history is, perhaps, of critical importance when interpreting the three studies cited where the milk yield response of early and late lactation cows to increased feeding levels were directly compared (Stockdale *et al.*, 1987; Stockdale and Trigg, 1989; Grainger, 1990). Oldham and Emmans (1989) suggested that the target milk yield of the cow is determined by genetic merit, stage of lactation and nutritional history. All three studies reported the milk yield of the cows before the experimental treatments were imposed, providing an insight to the changes in feeding level that occurred.

Stockdale *et al.* (1987), Stockdale and Trigg (1989) and Grainger (1990) all imposed common absolute feeding treatments on cows at different stages of lactation, despite large differences in actual and potential milk yield. For example, Stockdale *et al.* (1987) compared early and late lactation cows consuming a severely restricted allocation of pasture (about 7 kg DM/cow/day) plus different amounts of concentrates, with control groups consuming only the restricted allowance of pasture. This common restricted feed allowance imposed a more severe feed restriction on the cows in early lactation than on the late lactation cows, because the early lactation cows had milksolids yields that were much higher (by about 500g MS/cow/day) than late lactation cows immediately before the treatments were imposed. The decrease in milksolids yield caused by the imposition of the restricted allowance was much larger (x 2) in the early lactation cows than in the late lactation cows (Stockdale *et al.*, 1987). Similarly, Stockdale and Trigg (1989) imposed a common feeding restriction that resulted in a decrease of 9.2 kg/cow in the daily milk yield of early lactation cows offered the control treatment, compared to a decrease of only 4.0 kg/cow/day by late lactation cows.

Associated with these recent, and different, changes in level of feeding relative to feed requirements, the responses of late-lactation cows to feed restrictions were much smaller (x 0.5) than the responses of early-lactation cows in both the studies of Stockdale *et al.* (1987) and Stockdale and Trigg (1989). Because of their stage of lactation, and recent nutritional history, the late lactation cows were closer to their previous milk yield than the early lactation cows. Thus, as feeding levels were increased with supplementary feeds, the early lactation cows partitioned a greater proportion of the additional energy toward milk yield, and a lesser proportion to liveweight gain (Stockdale *et al.*, 1987; Stockdale and Trigg, 1989). Interestingly, the most generous supplementary feeding treatments in both studies simply allowed early and late lactation cows to maintain their pre-treatment milk yield. Further, when the amount of pasture offered to the control cows was more generous, and the decrease in milk yield of the early and late lactation cows became less severe, the responses attributed to supplementary feeding also declined (Stockdale and Trigg, 1989).

In contrast to the earlier work, the reduction in milk yield when experimental treatments were imposed by Grainger (1990) were approximately half to one third of those reported by Stockdale *et al.* (1987) and Stockdale and Trigg (1989). Further, there was little difference between the decrease in milk yield of the early and late lactation cows. Correspondingly, the responses of early and late lactation cows to additional feed were similar (Grainger, 1990).

2.3.5 Total feed allowance and milk yield of cows receiving pasture and supplement

On the basis of the evidence reviewed above, it is proposed that the magnitude of the milk yield response to extra feed is determined by the cows relative feed deficit, or the extent to which the basal level of feeding restricts the cow from attaining her target milk yield at the time of supplementary feeding. In keeping with the model of Oldham and Emmans (1989), it is suggested that large immediate milk yield responses will be achieved when a large relative feed deficit exists, and negligible responses will be achieved when there is no relative feed deficit. In the context of grazing dairy cows, the relative level of underfeeding must consider the amount of feed on offer, the quality of that feed, and the cow's demand for feed, determined by liveweight and target milk yield. While target milk yield is determined by genetic merit, stage of lactation and nutritional history, the best indicator of target milk yield in a particular case can be described by the milk yield of the cow when generously fed immediately before experimental treatments are imposed. Some experiments where all these factors were reported are summarised in Table 2.7.

The effect of total ME allowance (pasture plus supplement) on FCM yield is presented in Figure 2.7. As might be expected, total ME allowance and stage of lactation had a large effect on milk yield. The higher milk yields observed by Grainger and Mathews (1989) were associated with the early stage of lactation of the experimental cows. Likewise, the lower milk yields of Stakelum *et al.* (1986a) were produced by cows in very late lactation (Table 2.7). Further, when the experiments were analysed together, and adjusted for days in milk, there was little difference between the FCM response to additional metabolisable energy intake (MEI), irrespective of whether the cows were eating pasture alone or pasture and supplement (Table 2.5).

Within experiments, increasing total MEI, either by offering more supplements or by increasing pasture allowance, generally resulted in a linear increase in FCM yield (Table 2.8). The largest marginal FCM yield responses to increased MEI were reported by Robaina *et al.* (1998) and the smallest by Stakelum (1986a). The large marginal responses reported by Robaina *et al.* (1998) were associated with a 40% decline in FCM yield of cows receiving the lowest total MEA, when compared to their pre-treatment FCM yield (Table 2.7). Conversely, the small marginal responses reported by Stakelum (1986a) were associated with a decline in FCM yield of only 25%, and the feeding treatments in three of the four experimental groups were sufficient to maintain their pre-treatment FCM yield.

Thus, the evidence presented suggests that the absolute milk yield of a cow is largely determined by her genetic merit, stage of lactation and level of feeding. Subsequently, the milk yield response of a grazing dairy cow to a change in feeding level is largely determined by the magnitude of the increase in total ME supply, and

Table 2.7: Pre-treatment stage of lactation, as measured by days in milk (DIM), and 4% fat corrected milk yield (FCM/100 kg Lwt), daily pasture allowance (kg DM/cow and MJME/cow/100 kg Lwt), supplement and pasture metabolisable energy intake (MJME/100 kg Lwt), milk yield and substitution rate (MJME pasture:MJME supplement) for some recent studies investigating supplementary feeding of grazing dairy cows.

Reference	Pre-treatment stage of lactation and milk yield		Pasture allowance		Supplement intake		Pasture intake	Milk yield	Substitution
	DIM	(FCM/100 kg Lwt)	(kg DM/c)	(MJME/c/ 100 kg Lwt)	(kg DM/c)	(MJME/c/ 100 kg Lwt)	MJME/100 kg Lwt)	(4% FCM/100 kg Lwt)	(MJME:MJ ME)
Robaina *at al.*,(1998); Experiment 1									
	195	3.5	39	78			30	2.8	
	195	3.5	39	79	4.4	10.7	25	3.4	0.46
	195	3.5	19	37			23	2.2	
	195	3.5	19	39	4.4	10.5	21	3.1	0.19
Robaina *et al.* (1998); Experiment 2.									
	180	4.2	26	53			29	2.5	
	180	4.2	26	52	1.8	4.4	27	3.1	0.52
	180	4.2	26	51	3.4	8.4	24	3.1	0.28
	180	4.2	26	52	6.7	16.5	21	3.6	0.50
Stockdale (1996)									
	213	3.1	39	115			36	3.7	
	213	3.1	39	111	4.3	11.2	30	3.9	0.53
	213	3.1	19	50			23	2.5	
	213	3.0	19	51	4.3	11.5	21	3.3	0.12
Opatpatanakit *et al.* (1993)									
		3.0	52	104			31	2.8	
		3.0	48	98	3.6	8.3	27	2.9	0.57
		3.0	47	95	6.6	15.0	23	2.9	0.56
Grainger and Mathews (1989)									

	21	4.4	33	85			41	5.4	
	21	4.4	33	84	3.2	7.6	35	5.4	0.75
	21	4.4	17	44			30	4.8	
	21	4.4	17	43	3.2	7.6	28	5.2	0.31
	21	4.4	8	19			15	3.8	
	21	4.4	8	20	3.2	7.6	16	4.1	0.11
Stakelum (1986a)									
	234	2.0	24	54			42	1.9	
	234	1.9	24	51	3.3	7.9	35	1.9	0.56
	217	2.0	16	31			29	1.5	
	217	2.0	16	32	3.3	8.1	27	1.8	0.24
Stakelum (1986b)									
	78		24	62			44		
	78		24	59	3.7	10.1	37		0.43
	78		16	39			33		
	78		16	41	3.6	10.2	31		0.35
Stakelum (1986c)									
	192		24	48			33		
	192		24	50	3.9	9.4	29		0.62
	192		16	34			28		
	192		16	33	3.9	9.4	24		0.30
Stockdale and Trigg (1885)									
	240	2.8	15	32			16	2.1	
	240	2.8	16	33	1.8	5.1	17	2.8	0.04
	240	2.8	15	31	3.6	10.1	16	2.9	0.00
	240	2.8	15	31	6.3	17.7	13	2.9	0.17
	240	2.8	26	53			22	2.4	
	240	2.8	26	53	1.8	5.1	18	2.9	0.69
	240	2.8	27	55	3.5	9.8	19	3.1	0.31
	240	2.8	26	54	6.2	17.4	18	3.2	0.22

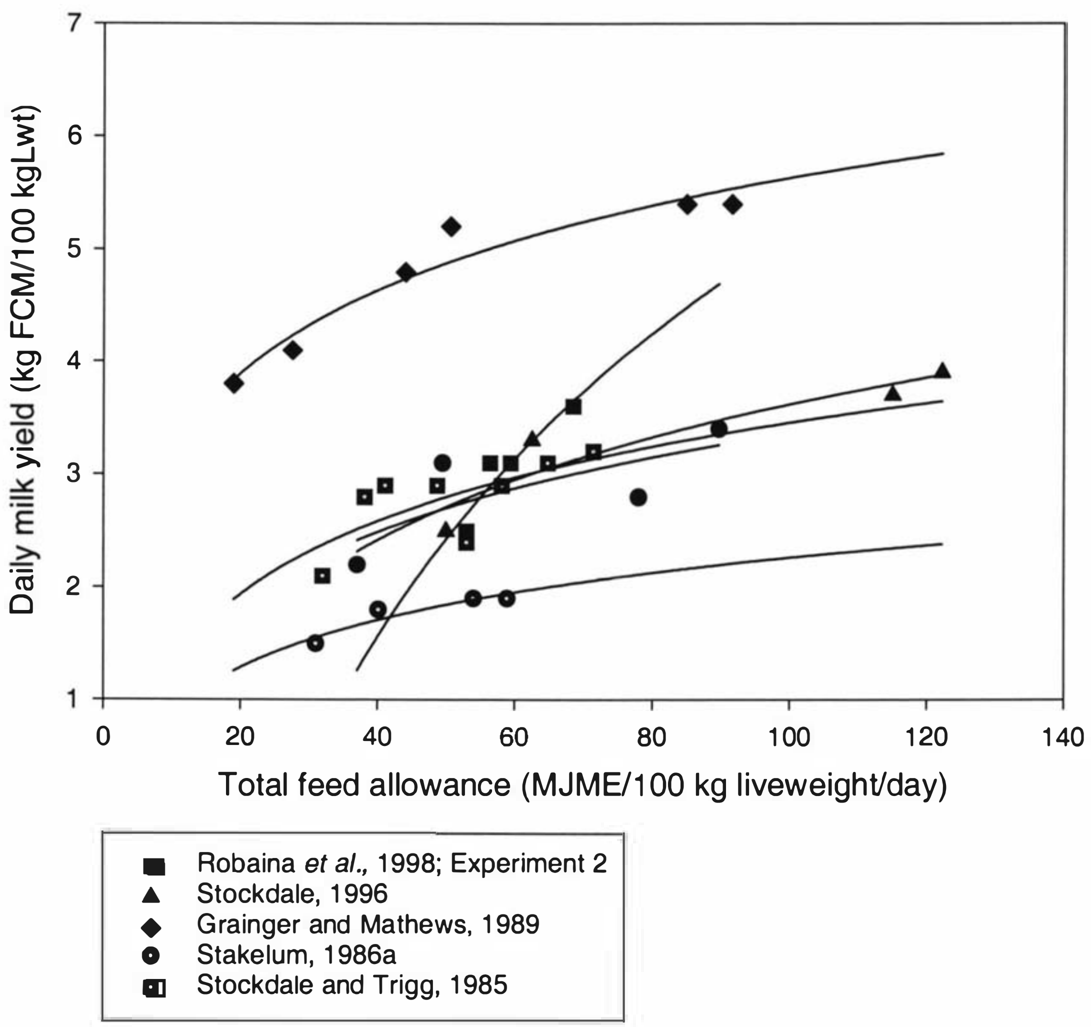


Figure 2.7: The effect of total feed ME allowance (pasture plus supplement) on 4% fat-corrected milk yield (FCM), measured in some recent experiments.

Table 2.8: The effect of total metabolisable energy intake (MEI, MJ/c/d) on 4% fat-corrected milk yield (MY, kg/c/d)) in some experiments investigating supplementary feeding of grazing dairy cows.

Reference	Regression equations	R^2	r.s.d
Early lactation			
Grainger and Mathews (1989)	MY = 0.044(±0.007)MEI + 15.91(±1.01)	0.91	1.05
Late lactation			
Robaina *et al.* (1998) Expt.1	MY = 0.101(±0.007)MEI - 0.71(±1.01)	0.99	0.30
Robaina *et al.* (1998) Expt.2	MY = 0.117(±0.026)MEI – 4.01(±4.58)	0.91	0.85
Stockdale, 1996)	MY = 0.084(±0.010)MEI + 2.52(±1.41)	0.97	0.55
Stakelum (1986a)	MY = 0.025(±0.009)MEI + 4.54(±1.85)	0.75	0.57
Stockdale and Trigg (1985)	MY = 0.053(±0.013)MEI + 6.20(±1.50)	0.72	0.91

by the cows' ability to respond by increasing milk yield. A cow only has the ability to respond when her target milk yield (as determined by genetic merit, stage of lactation and nutritional history) is greater than her actual milk yield (as determined by her target milk yield and current level of nutrition). The largest marginal milk yield responses have been reported from experiments where a severe feed restriction was imposed on high yielding cows, resulting in a large reduction in the milk yield of the unsupplemented cows. Thus, the magnitude of response to an increase in feeding level is determined by the difference between the cows' ME requirements to attain her target milk yield and rate of liveweight gain, and her actual MEI (MEI_{target} – MEI_{actual}).

2.3.6 Immediate and carryover effects

The discussion thus far has focused on immediate milk yield responses, that is the change in milk yield that occurs **during** the period of supplementary feeding. However, it is widely recognised that supplementary feeding often continue to influence milk **after** the feeding of the supplement has ceased, known as the carryover effect (Kellaway and Porta, 1993).

The carryover effect of supplementary feeding varies widely both within and between seasons. The results of some experiments, which have measured the milk yield of dairy cows immediately after the cessation of supplementary feeding, are presented in Table 2.9. Generally, positive carryover responses have been observed during the weeks after the cessation of supplementary feeding in experiments where the supplementary feeding had resulted in large immediate milk yield responses. When present, the magnitude of carryover effects was about equal to the immediate effect. The extra milk yield that occurred after the period of supplementary feeding has often been attributed to the mobilisation of body reserves accumulated as a result of supplementary feeding or to the repletion of body reserves during this period by non-supplemented cows (Kellaway and Porta, 1993). When feeding levels during the period after supplementary feeding are generous, these body reserves may remain and would be available later in lactation, or in the next lactation (Broster and Broster, 1984).

Table 2.9: The immediate and carryover fat corrected milk (FCM) yield responses to supplementary feeds from some recent experiments.

Robinson and Rogers (1983)				
Pasture allowance (kg DM/cow/day)	14	14	40	40
Supplement offered (kg DM/cow/day)	nil	3.3	nil	3.3
Milk yield during 35 day feeding period (kg FCM/cow/day)	20.4	21.3	23.2	21.7
Liveweight at end of supplementary feeding period (kg/cow)	412	418	437	443
Milk yield during 35 day carryover period (kg FCM/cow/day)	20.1	19.5	19.6	18.8
Liveweight at end of carry-over period (kg/cow)	434	442	453	450
Stakelum (1986a)				
Pasture allowance (kg DM/cow/day)	16	16	24	24
Supplement offered (kg DM/cow/day)	Nil	3.3	Nil	3.3
Milk yield during 21 day feeding period (kg FCM/cow/day)	7.8	9.3	9.5	9.9
Milk yield during 21 day carryover period (kg FCM/cow/day)	8.0	8.3	9.5	8.8
Stakelum (1986a)				
Pasture allowance (kg DM/cow/day)	20	20		
Supplement offered (kg DM/cow/day)	Nil	3.8		
Milk yield during 21 day feeding period (kg FCM/cow/day)	17.5	18.5		
Milk yield during 21 day carryover period (kg FCM/cow/day)	16.2	17.6		
Stakelum (1986b)				
Pasture allowance (kg DM/cow/day)	20	20		
Supplement offered (kg DM/cow/day)	Nil	3.8		
Milk yield during 21 day feeding period (kg FCM/cow/day)	12.2	14.1		
Milk yield during 21 day carryover period (kg FCM/cow/day)	11.5	13.6		

Carryover responses may also be associated with the levels of milk yield that have been achieved during the period of supplementary feeding. O'Brien *et al.* (1996) offered supplements of either pasture silage or concentrates at 2 or 4 kg DM/cow/day to late lactation cows grazing pasture (Table 2.10). Offering 4 kg DM/cow/day as pasture silage decreased FCM yield, but increased liveweight gain during the 70-day supplementary feeding period. Alternatively, offering 4 kg DM/cow/day as concentrates increased both FCM yield and liveweight gain. After the cessation of supplementary feeding all cows were removed from grazing, housed and offered *ad libitum* access to pasture silage. Cows that had been offered the high allowance of pasture silage continued to yield 1.9 kg/cow/day less FCM than those that had received no supplement, despite the additional 20 kg liveweight that had been accumulated as a result of silage supplement. In contrast, cows that had received the high allowance of concentrate continued to yield 2.9 kg/cow/day more FCM for a period of 35 days immediately after the period of supplementary feeding (O'Brien *et al.,* 1996). In this example, the carryover responses were probably caused by the higher milk yields (6.3 kg FCM/cow/day) rather than the small differences in liveweight (9.5 kg/cow) that resulted from the concentrate supplementation.

In a six-month experiment, Stockdale (1999c) compared milk yield responses of grazing dairy cows to short and long-term supplementary feeding. All groups of cows were offered a pasture allowance of about 40 kg DM/cow/day. One group was offered only pasture throughout the six-month experiment. A second group was continuously offered 5 kg DM as a cereal grain-based concentrate. On three occasions during the trial, supplement was removed from a group of cows that had previously been offered the pasture and supplement, for a period of 28 days. Continuously offering supplementary feed increased average daily FCM yield from 18.9 to 24.5 kg/cow, whereas removing supplementary feed reduced FCM yield from 23.8 to 19.6 kg/cow (Stockdale, 1999c). Interestingly there was little difference between the milk yields of cows from which supplements had been removed, and those that had not been offered any supplements. It was not until the final supplement-removal period, that occurred about 150 days after the trial began, that the milk yield of cows from which supplement had been removed was higher than in

Table 2.10: An example of carryover milk yield responses associated with increases in immediate milk yield and liveweight gain resulting from supplementary feeding of grazing cows with pasture silage or concentrates (O'Brien *et al.*, 1996).

Type of supplement		**Pasture Silage**		**Concentrate**	
Supplement offered (kg DM/cow/day)	Nil	2	4	2	4
Immediate milk yield (kg FCM/cow/day)	12.5	12.4	10.7	15.4	17.0
Liveweight gain (g/cow/day)	75	-6	291	377	421
Carryover milk yield (kg FCM/cow/day)	9.0	9.0	7.1	10.9	11.9

cows that had never received concentrates. This suggests that carryover milk yield responses are small when cows are generously fed.

2.4 Responses to supplementary feed in farm systems

Few full lactation grazing studies investigating the response of the whole farm system to supplements have been undertaken (Broster *et al*, 1993). Summaries of five long-term supplementary feeding studies conducted with grazing dairy cows are presented in Table 2.11. In addition to the responses being greater than those generally reported in short-term studies, they appear to demonstrate greater consistency. The marginal milkfat and protein yield responses measured in complete season studies were about two-fold greater than those of 23 g milkfat and 25 g protein/kg DM from short-term studies (Table 2.2). Remaining variation can be further explained by the relative energy contents of the supplementary feeds, with concentrate-based supplements generally demonstrating a larger response than those from pasture and maize silage.

Short and long-term grazing studies may underestimate the milk yield response dairy farmers are likely to generate by offering supplement to a herd of cows for several reasons. In addition to the immediate milk yield responses resulting from the short-term increase in intake of energy and nutrients, and the carryover responses resulting from increased body reserves, further increases may be caused within a closed farm system by subsequent increases in pasture intake resulting from pasture substitution that occurred during the period of supplementary feeding.

In grazing systems, pasture substitution is manifested as an increase in post grazing pasture mass. If the supplementary feeding takes place during a period of pasture deficit, increased post-grazing pasture mass may result in increased net herbage accumulation (Parsons and Chapman, 1998). However, even if net herbage accumulation is unaffected, the pasture mass at the subsequent grazing will be greater, providing the potential for the herd to achieve increased pasture DMI.

Table 2.11: Mean milkfat and protein response to supplementary feeding of grazing dairy cows measured in long-term experiments.

Reference	Duration	Supplement	FCM (kg/cow/day)	Milkfat (g/kg DM)	Protein (g/kg DM)
Hoden *et al.* (1991)	2 x 6 months	Concentrate pellets	0.6	17	12
Leaver and Campling (1993)	2 x 6 months	50:50 NaOH treated straw:brewers grain	0.7	43	34
Clark (1993)	1 season	Pasture silage	0.6	40	22
Penno *et al.* (1996)	2 seasons	Rolled maize grain	1.0	47	38
Thomson *et al.* (1997)	3 seasons	Concentrate pellets	1.6	76	58
Mean response			0.9	45	33

In a farmlet study, Clark (1993) found that 65% of the additional milk production that resulted from feeding 150 kg DM/cow as pasture silage in spring occurred after the conclusion of the supplementary feeding period. The large carryover effect continued for many weeks after the cessation of supplementary feeding, but was not associated with either increased average pasture mass on the farmlet or increased liveweight. Penno *et al.* (1995b) suggested, from two farmlet trials involving the use of concentrate feeding, that at moderate stocking rates the effects of supplementary feeding was negligible in spring, and improved as the season progressed. However, part of the different pattern of responses measured by Penno *et al.* (1995b) may have been attributed to the accumulation of carryover effects caused by supplementary feeding earlier in lactation. Accumulative increases in response during long-term trials have also been observed by Stockdale (1999c) and Leaver and Campling (1993) and are generally associated with the accumulation of body reserves.

2.5 Conclusion and implications

There are wide variations between experiments in the absolute milk yield response of grazing cows to a change in feed supply. The most important factor that determines the magnitude of the response is the relative feed deficit of the cow immediately before supplementary feeding (MEI_{target} – MEI_{actual}). Therefore, the difficulty in predicting milk yield responses is directly attributable to the difficulty in defining the relative feed deficit of a group of cows in any particular situation.

It is proposed that the magnitude of any increase in total DMI resulting from supplementary feed being offered is closely related to the relative feed deficit. The cow responds to extra energy and nutrients provided by increased DMI by increasing milk yield and/or increasing body reserves. In the short-term, the greater the immediate requirement for additional feed, relative to the unsupplemented feed supply, the larger the immediate milk yield response that can be expected. In the long-term, however, extra body reserves also contribute to milk yield. Therefore, an improved understanding of the relationship between the relative feed deficit of the cow and pasture substitution is a logical next step to enable the accurate prediction of long-term milk yield responses of grazing dairy cows to supplementary feed.

Determining the validity of the relative feed deficit concept requires direct experimental evidence of the relationship between a measure of relative feed deficit and supplementary feeding response. Relative feed deficit can be varied by manipulating the feed requirements of the herd or by varying the amount and quality of pasture offered. The feed requirements of the herd can be manipulated by altering the genetic merit, the stage of lactation or the nutritional history of the cows. The energy and nutrients provided by pasture can be varied by offering different allowances of pasture or by offering pasture of different structural and chemical composition. In a practical sense, farmers have the opportunity to choose the supplements they offer the herd, when those supplements are offered, and the amount they offer. Therefore, it is logical to focus on these variables first.

2.6 References

AFRC 1993. *Energy and Protein Requirements of Ruminants.* CAB International, Wallingford.

AFRC 1998. *Responses in the Yield of Milk Constituents to the Intake of Nutrients by Dairy Cows.* CAB International, Wallingford.

Anil, M. H., Mbanya, J. N., Symonds, H. W. and Forbes, J. M. 1993. Responses in the voluntary intake of hay or silage by lactating cows to intra ruminal infusions of sodium acetate, sodium propionate or rumen distension. *British Journal of Nutrition* **69**: 699-712.

Anil, M. H. and Forbes, J. M. 1980. Effects of insulin and gastro-intestinal hormones on feeding and plasma insulin levels in sheep. *Hormone and Metabolic Research* **12**: 234-236.

Armstrong, D. G., and Blaxter, K. L., 1957. The utilisation of acetic, propionic and butyric acids by fattening sheep. *British Journal of Nutrition* **11**: 413-425.

Arnold, G. W. 1981. Grazing Behaviour. In: *Grazing Animals.* Ed. F. H. W. Morley. Elsevier, Amsterdam. Pages 79-104.

Baile, C. A., and Forbes, J. M. 1974. Control of feed intake and regulation of energy balance in ruminants. *Physiology Reviews* **54** : 160-214.

Baldwin, R. L., France, J. and Gill, M. 1987. Metabolism of the lactating cow. 1. Animal elements of a mechanistic model. *Journal of Dairy Science* **54**: 77-105.

Barnes, B. J., and Orskov, E. R., 1982. Grain for ruminants; Simple processing and preserving techniques. *World Animal Review* **42**: 38-44.

Bauman, D. E. and Currie, W. B. 1980. Partitioning of nutrients during pregnancy and lactation. *Journal of Dairy Science* **63**: 1514-1529.

Baumgardt, B. R. 1970. In: *Physiology of Digestion and Metabolism in the Ruminant*. Ed. A. T. Phillipson. Oriel Press Ltd, Newcastle upon Tyne, England. Pages 235-253.

Beever, D. E. and Oldham, J. D. 1986. Nutrient supply and utilisation. *Principles and Practice of Feeding Dairy Cows.* Eds. W.H. Broster, R. H. Phipps, and C.L. Johnson. Technical Bulletin 8. National Institute of Dairying Research, Shinfield.

Bines, J. A. 1971. Metabolic and physical control of food intake in ruminants. *Proceedings of the Nutrition Society* **30**: 116-122.

Bines, J. A. 1985. Feeding systems and food intake by housed dairy cows. *Proceedings of the Nutrition Society* **44**: 355-362.

Blaxter, K. L. 1959. Dairy Cows. In: *Scientific Principals of Feeding Farm Livestock*. Farmer and Stockbreeder, London. Pages 21-36.

Blaxter, K. L. and Wilson, R. S. 1963. The assessment of a crop husbandry technique in terms of animal production. *Animal Production* **5**: 27-42.

Brookes, I. M. 1984. Effects of formaldehyde-treated and untreated casein supplements on performance of dairy cows offered ryegrass-clover pasture. *New Zealand Journal of Agricultural Research* **27**: 491-493.

Broster, W. H. and Thomas, C. 1981. The influence of level and pattern of concentrate input on milk output. In: *Recent Advances in Animal Nutrition*. Ed. W. Haresign. Butterworths, London. Pages 49-69.

Broster, W. H., and V. J. Broster. 1984. Long term effects of plane of nutrition on the performance of the dairy cow. *Journal of Dairy Research* **51:** 149-196.

Broster, W. H., V. J. Broster, and Clements, A. J. 1993. Feed utilisation of the dairy cow over multiple lactations: A review. *Livestock Production Science* **34:** 1-21.

Broster, W. H. and Broster, V. J. 1998. Review Article: Body score of dairy cattle. *Journal of Dairy Research* **65:** 155-173.

Bryant, A.M. 1980. Effect of herbage allowance on dairy cow performance. *Proceedings of the New Zealand Society of Animal Production* **40:** 50-58.

Bryant, A. M. and Trigg, T. E. 1981. Progress report on the performance of Jersey cows differing in breeding index. *Proceedings of the New Zealand Society of Animal Production* **41**: 39-43.

Caird, L. and Holmes, W. 1986. The prediction of voluntary intake of grazing dairy cows. *Journal of Agricultural Science (Cambridge)* **107**: 43-54.

Campling, R. C. 1966. A preliminary study of the effect of pregnancy and of lactation on the voluntary intake of food by cows. *British Journal of Nutrition* **20**: 25-39.

Campling, R. C. 1970. Physical regulation of voluntary intake. In: *Physiology of Digestion and Metabolism in the Ruminant*. Ed. A. T. Phillipson. Oriel Press Ltd, Newcastle upon Tyne, England. Pages 226-234.

Campling, R. C., 1991. Processing cereal grains for cattle - a review. *Livestock Production Science* **28**: 223-234.

Castle, M. E., Watson, J. N. and Leaver, J. D. 1979. A comparison between barley and groundnut as supplements for dairy cows at pasture. *Grass and Forage Science* **34**: 197-201.

Castle, M. E., Gill, M. S. and Watson, J. N. 1981. Silage and milk production: a comparison between barley and dried sugar-beet pulp as silage supplements. *Grass and Forage Science* **36**: 319-324.

Chacon, E. and Stobbs, T. H. 1976. Influence of progressive defoliation of a grass sward on the eating behaviour of cattle. *Australian Journal of Agricultural Research* **27**: 709-727.

Clark, D. A. 1993. Silage for milk production. *Proceedings of the Ruakura Farmers' Conference* **45:** 41-46.

Combellas, J. and Hodgson, J. 1979. Herbage intake and milk production by grazing dairy cows 1. The effect of variation in herbage mass and daily herbage allowance in a short-term trial. *Grass and Forage Science* **34**: 209-214.

Conrad, H. R. 1966. Physiological and physical factors limiting intake. *Journal of Animal Science* **25**: 227-235.

Coulon, J. B. and Remond, B. 1991. Variations in milk output and milk protein content in response to level the level of energy supply to the dairy cow: A review. *Livestock Production Science* **29**: 31-47.

Cowan, R. T., Davison, T. M. and O'Grady, P. 1977. Influence of concentrate feeding on milk production and pasture utilisation by Friesian cows grazing tropical grass-legume pasture. *Australian Journal of Experimental Agricultural and Animal Husbandry* **17**: 373-379.

Crosse, S. and Gleeson, P. 1987. Supplementation of autumn grass with silage and concentrates for grazing dairy cows in late lactation. *Irish Journal of Agricultural Research* **26**: 69-75.

Davis, S. R., Farr, V. C., Auldist, M. J. and Kolver, E. S. 2000. Effects of diet on udder function and regression in Holstein-Friesian cattle. *Proceedings of the New Zealand Society of Animal Production* **60**: 275-276.

de Jong, A. 1986. The role of metabolites and hormones as feedbacks in the control of food intake in ruminants. In: *Control of Digestion and Metabolism in the ruminant.* Eds. L. P. Milligan, W. L. Grovum and A. Dobson. Prentice-Hall, New Jersey. Pages 459-478.

Dillon, P., Crosse, S. and O'Brien, B. 1997. Effects of concentrate supplementation of grazing dairy cows in early lactation on milk processing quality. *Irish Journal of Agriculture and Food Research* **36**: 145-159.

Dobos, R. C., Fulkerson, W. J. and Michell, P. J. 1987. Effects on milk production of feeding wheat supplements to grazing dairy cows in early lactation. *Australian Journal of Experimental Agriculture* **27**: 41-44.

Ehrlich, W. K., Cowan, R. T. and Reid, A. 1993. Use of whole cotton seed as a dietary supplement for grazing dairy cows. *Australian Journal of Experimental Agriculture* **33**: 283-286.

Emmans, G. C. and Fisher, C. 1986. Problems in nutritional theory. In: *Nutrient Requirements of Poultry and Nutritional Research.* Eds. C. Fisher and K.N. Boorman Butterworths, London. Pages 9-39.

Faverdin, P. Dulphy, J. P., Coulon, J. B., Verte, R., Garel, J. P., Rouel, J. and Marquis, B. 1991. Substitution of roughage by concentrates for dairy cows. *Livestock Production Science* **27:** 137-156.

Fisher, C., Morris, T. R. and Jennings, R. C. 1973. A model for the description and prediction of the response of laying hens to amino acid intake. *British Poultry Science* **14**: 469-484.

Fisher, G. E. J., Dowdeswell, A. M. and Perrott, G. 1996. The effects of sward characteristics and supplement type on the herbage intake and milk production of summer-calving cows. *Grass and Forage Science* **51**: 121-130.

Fox, D. G., Sniffen, C. J., O'Connor, J. D., Russell, B. J. and Van Soest, P. J. 1992. A Net Carbohydrate and Protein System for evaluating cattle diets. *Journal of Animal Science* **70:** 3578-3596.

Forbes, J. M. 1995. Voluntary intake – A limiting factor to production in high yielding cows? In: *Breeding and Feeding the High Generic Merit Cow*, British Society of Animal Science Occasional Publication No. 19. Pages 13-19.

Girdler, C. P., Thomas, P. C. and Chamberlain, D. G. 1984. Exogenous supply of glucose precursors and nitrogen utilisation in sheep. *Proceedings of the Nutrition Society* **45**: 43.

Grovum, W. L. 1995. Mechanisms explaining the effects of short chain fatty acids in ruminants. In: *Ruminant Physiology: digestion, metabolism, growth and reproduction*. Eds W. V. Engelhardt, S. Leonhard-Marek, G. Breres and D. Giesecke. Ferdinand Enke Verlag, Stuttgart. Pages 173-198.

Grainger, C. 1990. Effect of stage of lactation and feeding level on milk yield response by stall-fed dairy cows to change in pasture intake. *Australian Journal of Experimental Agriculture* **30:** 495-501.

Grainger, C. and Mathews, G. L. 1989. Positive relationship between substitution rate and pasture allowance for cows receiving concentrates. *Australian Journal of Experimental Agriculture* **29:** 355-360.

Hale, W. H., 1973. Influence of processing on the utilisation of grains (Starch) by ruminants. *Journal of Animal Science* **37**:1075-1080.

Harris, S. L., Clark, D. A. and Laboyrie, P. J. 1998. Birdsfoot trefoil – an alternative legume for New Zealand dairy pastures. *Proceedings of the New Zealand Grasslands Association* **60**: 99-103.

Hoden, A., Peyraud, J. L., Muller, A., Delaby, L., Faverdin, P., Peccatte, J. R. and Fargetton, M. 1991. Simplified rotational grazing management for dairy cows: effect of stocking rate and concentrate. *Journal of Agricultural Research (Cambridge)* **116**: 417-428.

Hodge, A. and Rogers, G. 1982. Comparison of wilted silage and concentrates for milk production. *Department of Agriculture, Victoria. Dairy Production Research Report*, 1982:75.

Hodge, A. and Rogers, G. L. 1984. Protein and energy concentrates for milk production. *Proceedings of the Australian Society of Animal Production* **15**: 695.

Hodgson, J. 1981. Variations in the surface characteristics of the sward and the short-term rate of herbage intake by calves and lambs. *Grass and Forage Science* **36**: 49-57.

Holmes, C. W. 1987. Pastures for dairy cows. In Livestock Feeding on Pasture. Ed. A. M. Nicol. *New Zealand Society of Animal Production, Occasional Publication* **10:** 133-143.

Holmes, C. W. 1995. Genotype x environment interactions in dairy cattle: a New Zealand Perspective In: *Breeding and Feeding the High Generic Merit Cow*, British Society of Animal Science Occasional Publication No. 19. Pages 51-58.

Holmes, C. W., Wilson, G. F., Mackenzie, D. D. S., Flux, D. S., Brookes, I. M., and Davey, A. W. F. 1987. *Milk Production from Pasture.* Eds. C. W. Holmes and G.F. Wilson. Butterworths, Wellington.

Huntington, G.B. 1984. Net absorption of glucose and nitrogenous compounds by lactating dairy cows. *Journal of Dairy Science* **67**: 1919-1927.

INRA. 1988. *Ruminant Nutrition. Recommended Allowances and Feed Tables.* John Libby Eurotext, Paris France.

Johnson, W. L., Trimberger, G. W., Wright, M. J. Van Vleck, L. D. and Henderson, C. R. 1966. Voluntary intake of forage by Holstein cows as influenced by lactation, gestation, body weight and frequency of calving. *Journal of Dairy Science* **49**: 856-864.

Journet, M. and Demarquilly, C. 1979. Grazing. In *Feeding Strategy for the High Yielding Dairy Cow.* Eds W.H. Broster and H. Swan, Granada Publishing, London. Pages 295-321.

Kellaway, R. C. and Porta, S. 1993. Feeding concentrates: supplements for dairy cows. E. Hopkins, ed. Agmedia, Melbourne, Australia.

King, K. R., Stockdale, C. R. and Trigg, T. E. 1990. Influence of high energy supplements containing fatty acids on the productivity of pasture-fed dairy cows. *Australian Journal of Experimental Agriculture* **30**: 11-16.

Kolver, E. S., and Muller, L. D. 1998. Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. *Journal of Dairy Science* **81:** 1403-1411.

Kuhn, N. J. 1983. The biosynthesis of lactose. In: *Biochemistry of Lactation*. Ed. T.B. Mepham. Elsevier, Amsterdam.

Leaver, J. D., Campling, R. C. and Holmes, W. 1968. The use of supplementary feeds for grazing dairy cows. *Dairy Science Abstracts 30* **7**: 355-361.

Leaver, J. D. and Campling, R. C. 1993. The effect of offering brewers grain/treated straw supplement to grazing dairy cows. *Grass and Forage Science* **48**: 101-108.

Leaver, J. D. 1973. Rearing of dairy cattle. 4. Effect of concentrate supplementation on the liveweight gain and feed intake of calves offered roughage ad libitum. *Animal Production* **17**: 43-52.

Leaver, J. D. 1985. Milk production from grazed temperate grassland. *Journal of Dairy Science* **52**: 313-344.

Le Du, Y. L. P., Combellas, J., Hodgson, J. and Baker, R. D. 1979. Herbage intake and milk production by grazing dairy cows 2. The effect of level of winter feeding and daily herbage allowance. *Grass and Forage Science* **34**: 249-260.

Leek, B. F. 1986. Sensory receptors in the ruminant alimentary tract. In: *Control of Digestion and Metabolism in the ruminant.* Eds. L. P. Milligan, W. L. Grovum and A. Dobson. Prentice-Hall, New Jersey. Pages 3-17.

Macdonald, K. A., Penno, J. W., Kolver, E. S., Carter, W. A. and Lancaster, J. A., 1998. Balancing pasture and Maize silage diets for dairy cows using urea, soybean meal or fishmeal. *Proceedings of the New Zealand Society of Animal Production* **58**: 102-105.

MacRae, J. C., Buttery, P. J. and Beever, D. E. 1988. Nutrient interactions in the dairy cow. In: *Nutrition and Lactation in the Dairy Cow.* Ed. P. C. Garnsworthy. Butterworths, London. Pages 55-75.

Mackle, T. M., Parr, C. R. and Bryant, A. M. 1996. Nitrogen fertiliser effects on milk yield and composition pasture intake, nitrogen and energy partitioning, and rumen fermentation parameters of dairy cows in early lactation. *New Zealand Journal of Agricultural Research* **39**: 341-356.

Mangan, J. L. 1982. The nitrogenous constituents of fresh forages. In *Forage Protein in Ruminant Animal Production*. Eds. D. J. Thomson, D. E. Beever, and R. G. Gunn British Society of Animal Production Occasional Publication No. 6. Edinburgh, UK.

Marsh, R., Campling, R. C. and Holmes, W. 1971. A further study of a rigid grazing management system for dairy cows. *Animal Production* **13**: 441-448.

Mayne, C. S. 1991. Effects of supplementation on the performance of both growing and lactating cattle at pasture. *Occasional Symposium of the British Grasslands Society* **25**: 55-71.

Mayne, C. S. and Gordon, F. J. 1984. The effect of type of concentrate and level of concentrate feeding on milk production. *Animal Production* **39**: 65-76.

Mayne, C. S. and Wright, I. A. 1988. Herbage intake and utilisation by the grazing dairy cow. In *Nutrition and Lactation in the Dairy Cow.* Ed. P. C. Garnsworthy, Butterworths, London. Pages 280-293.

Mbanya, J. N. Anil, M. H. and Forbes, J. M. 1993. The voluntary intake of hay and silage by lactating cows in response to ruminal infusion of acetate or propionate, or both, with and without distension of the rumen by a balloon. *British Journal of Nutrition* **69**: 713-720.

McDonnell, M. L., Kolpfenstein, T. J., and Britton, R.A. 1979. Associative effects: corn grain and corn stalks. *Journal Animal Science,* **49**: Supplement 1: 267.

McGilloway, D. A. and Mayne, C. S. 1996. The importance of grass availability for the high genetic dairy cow. In: *Recent Advances in Animal Nutrition.* Eds P. C. Gairnsworthy, J. Wiseman and W. Haresign, Nottingham University Press, Nottingham. Pages 135-167.

McGrath, J. A., Penno, J. W., Macdonald, K. A., and Carter, W. A. 1998. Using Nitrogen fertiliser to increase dairy farm profitability. *Proceedings of the New Zealand Society of Animal Production* **58**: 117-120.

McLachlan, B., Orr, W. and Silver, B. 1991. Short-term responses in solids-not-fat to grain fed in addition to molasses for dairy cows grazing pastures. *Australian Journal of Experimental Agriculture* **31**: 191-194.

McMeniman, N. P. and Armstrong, D. G. 1977. Nitrogen levels in low-roughage diets for efficient rumen microbial protein production. *Animal Feed Science and Technology* **2**: 255-266.

Meijs, J. A. C. 1981. Herbage intake by grazing dairy cows. *Agricultural Research Report 909.* Centre for Agricultural Publishing and Documentation, Wageningen.

Meijs, J. A. C. and Hoekstra, J. A. 1984. Concentrate supplementation of grazing dairy cows. I. Effect of concentrate intake and herbage allowance on herbage intake. *Grass and Forage Science* **39:** 59-66.

Meijs, J. A. C. 1986. Concentrate supplementation of grazing dairy cows. 2. Effect of concentrate composition on herbage intake and milk production. *Grass and Forage Science* **41:** 229-235.

Metz, S. H. M. and van den Bergh. 1977. Regulation of fat mobilisation in adipose tissue of dairy cows in the period around parturition. *Netherlands Journal of Agricultural Science* **25**: 198-211.

Minson, D. J. 1981. The effects of feeding protected and unprotected casein on the milk production of cows grazing ryegrass. *Journal of Agricultural Science (Cambridge)* **96**:239-241.

Minson, D. J. 1990. *Forage in Ruminant Nutrition.* Academic Press, London.

Moate, P. J., Rogers, G. and Robinson, I. B. 1984a. Effect of level of silage supplement and pasture allowance on pasture intake, milk yield and milk composition of grazing cows. *Animal Production in Australia* **15**:722.

Moate, P. J., Rogers, G. and Robinson, I. B. 1984b. Lupins or oats as supplements for cows fed pasture in early lactation. *Animal Production in Australia* **15**:721.

Moate, P. J., Dalley, D. E., Martin, K. and Grainger, C. 1998. Milk production responses to turnips fed to dairy cows in mid lactation. *Australian Journal of Experimental Agriculture* **38**: 117-123.

Moate, P. J., Dalley, D. E., Roche, J. R., Grainger, C., Hannah, M. and Martin, K. 1999. Turnips and protein supplements for lactating dairy cows. *Australian Journal of Experimental Agriculture* **39**: 389-400.

Moe, P. W., Tyrell, H. F. and Flatt, W. P. 1971. Energetics of body tissue mobilisation. *Journal of Dairy Science* **54**:548.

Moisey, F. R. and Leaver, J. D. 1984. A study of two cutting strategies for the production of grass silage for dairy cows. *Research and Development in Agriculture* **1**: 47-52.

Moller, S. 1997. *An evaluation of major nutrients in dairy pasture in New Zealand and their effects on milk production and herd reproductive performance.* Ph.D. Thesis, Massey University, Palmerston North, New Zealand.

Moran, J. B. and Stockdale, C. R. 1992. Maize silage for the pasture fed cow. 1. Effect of level of silage feeding and responses to cotton seed while grazing perennial pastures in the spring. *Australian Journal of Experimental Agriculture* **32**: 279-285.

Mould, F. L., Orskov, E. R. and Mann, S. O. 1983. Associative effects of mixed feeds. 1. Effect of type and level of supplementation and the influence of rumen pH on cellulolysis in vivo and dry-matter digestion of various roughages. *Animal Feed Science and Technology* **10**: 15-30.

Mould, F. L. 1993. Self-regulation of supplemental feed intake by grazing dairy cows and its effects on animal performance. *Acta Agriculture Scandinavia* **43**: 96-100.

Mulholland, J. G., Coombe, J. B., and McManus, W. R. 1976. Effect of starch on the utilisation by sheep of a straw diet supplemented with urea and minerals. *Australian Journal of Agricultural Production Research* **27**: 139-153.

Murphy, M. R., Baldwin, R. L., and Koong, L. J. 1982. Estimation of stoichiometric parameters for rumen fermentation of roughage and concentrate diets. *Journal of Animal Science* **55**: 411-421.

Murphy, J. J., Connolly, J. F. and McNeill, G. P. 1995. Effect on cow performance and milk fat composition of feeding full fat soyabeans and rapeseeds to dairy cows at pasture. *Livestock Production Science* **44**: 13-25.

Neil, P. G. and Thomson, N. A. 1997. Effect on milk production and liveweight of feeding balanced or unbalanced supplements to cows grazing restricted summer pasture. *Proceedings of the New Zealand Society of Animal Production* **57**: 151-153.

Nordin, M., and Campling, R. C. 1976. Digestibility studies with cows given whole and rolled cereal grains. *Animal Production* **23**: 305-315.

National Research Council. 1989. *Ruminant Requirements of Dairy Cattle, 6th edition*. US National Academy of Science, Washington, D.C.

O'Brien, B., Crosse, S. and Dillon, P. 1996. Effects of offering and concentrate or silage supplement to grazing dairy cows in late lactation on animal performance and milk processability. *Irish Journal of Agriculture and Food Research* **35**:113-125.

Oldham, J. D. 1995. Protein requirements and responses: a United Kingdom perspective. In: *Breeding and Feeding the High Genetic Merit Cow*, British Society of Animal Science Occasional Publication No. 19. Pages 21-29.

Oldham, J. D. and G. C. Emmans. 1988. Prediction of responses to responses to protein and energy yielding nutrients. In *Nutrition and Lactation in the Dairy Cow*. Ed. P.C. Garnsworthy, Butterworths, London. Pages 76-96.

Oldham, J. D. and G. C. Emmans. 1989. Prediction of responses to required nutrients in dairy cows. *Journal of Dairy Science* **72:** 3212-3229.

Opatpatanakit, Y., Kellaway, R. C. and Lean, I. J. 1993. Substitution effects of feeding rolled barley grain to grazing dairy cows. *Animal Feed Science and Technology* **42:** 25-38.

Orskov, E. R., 1979a. Recent information on processing of grain for ruminants. *Livestock Production Science* **6**:335-347.

Orskov, E. R., 1979b. Recent advances in the understanding of cereal processing for ruminants. In *Recent Advances in Animal Nutrition*. Eds W. Haresign and D. Lewis. Butterworths, London. Pages 123-132.

Orskov, E. R., 1986. Starch digestion and utilisation in ruminants. *Journal Animal Science* **63**:1624-1633.

Orskov, E. R., and Fraser, C., 1975. The effects of processing of barley-based supplements on rumen pH, rate of digestion and voluntary intake of dried grass in sheep. *British Journal of Nutrition* **34**: 493-500.

Orskov, E. R., Soliman, H. S., and Macdearmid, A. 1977. Intake of hay by cattle given supplements of barley subjected to various forms of physical treatment or treatment with alkali. *Journal of Agricultural Science, (Cambridge)* **90**: 611-615.

Orskov, E. R., and Reid, G. W., 1979. The effect of proportion of concentrate and method of cereal processing on type of rumen fermentation and milk quality in Friesian cows. *Proceedings of the Nutrition Society* **38**: 131A.

Orskov, E. R., Reid, G. W., and McDonald, I. 1981. The effects of protein degradability and food intake on milk yield and composition in cows in early lactation. *British Journal of Nutrition* **45**: 547-555.

Ostergard, V. 1979. Strategies for concentrate feeding to attain optimum feeding level in high yielding dairy cows. *Copenhagen National Institute of Agricultural Science* **482**: 37-67.

Parsons, A. J., and Chapman, D. F. 1998. Principles of grass growth and pasture utilisation. In: *Grass for Dairy Cattle.* Eds. J. H. Cherney, and D. J. R. Cherney CABI Publishing, Wallingford, Oxon, UK. Pages 283-309.

Patterson, D. M., Gordon, F. J., Mayne, C. S., Porter, M. G. and Unsworth, E. F. 1995. The effect of genetic merit on nutrient utilisation in lactating dairy cows. In*: Feeding and Breeding the High Genetic Merit Dairy Cow*, British Society of Animal Production, Occasional Publication No. 19. Pages 97-98.

Patterson, D. M., McGilloway, D. A., Cushnahan, A., Mayne, C. S. and Laidlaw, A. S. 1998. Effect of fasting period on short-term intake rates of lactating dairy cows. *Animal Science* **66**: 299-305.

Penno, J. W., Bryant, A. M., Carter, W. A. and Macdonald. K. A. 1995a. Effects of fishmeal supplementation to high genetic merit cows grazing temperate spring pastures in early lactation. *Journal of Dairy Science* **78** (Supplement 1): 295.

Penno, J. W., Thomson, N. A., Bryant, A. M. 1995b. Summer milk – supplementary feeding. *Proceedings of the Ruakura Farmers' Conference* **47:** 17-24.

Penno, J. W., Macdonald, K. A. and Bryant, A. M. 1996. The economics of the No 2 Dairy systems. *Proceedings of the Ruakura Farmers' Conference* **48**: 11-19.

Phillips, C. J. C. 1993. *Cattle Behaviour*. Farming Press Books, Ipswich.

Phipps, R.H., Weller, R. F. and Bines, J. A. 1987. The influence of forage quality and concentrate level on dry matter intake and milk production of British Friesian Heifers. *Grass and Forage Science* **42**: 49-58.

Radcliffe, J. E., and Baars, J.A., and Snaydon, R.W. 1987. The productivity of temperate grasslands. *Ecosystems of the World* **17B**: 7-17.

Reeves, M., Fulkerson, W. J. and Kellaway, R. C. 1996. Production responses of dairy cows grazing well managed kikuyu (*Pennisetum clandestinum*) pastures to energy and protein supplementation. *Australian Journal of Experimental Agriculture* **36**: 763-670.

Robaina, A. C, Grainger, C., Moate, P., Taylor, J. and Stewart, J. 1998. Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* **38:** 541-549.

Robinson, I. and Rogers, G. 1983. Supplementary feeding concentrates in mid lactation. *Department of Agriculture, Victoria. Dairy Production Report, 1983*: pages 113-116.

Robinson, P. H., McQueen, R. E., and Burgess, P. L. 1991. Influence of rumen undegradable protein levels on feed intake and milk production of dairy cows. *Journal of Dairy Science* **74**:1623-1631.

Rogers, G. L., Porter, R. H. D., Clarke, T., and Stewart, J. A. 1980. Effect of protected casein supplements of pasture intake, milk yield and composition of cows in early lactation. *Australian Journal of Agricultural Research* **32**:1147-1152.

Rook, A. J., Huckle, C. A. and Wilkins, R. J. 1994a. The effects of sward height and concentrate supplementation on the performance of spring calving dairy cows grazing perennial ryegrass-white clover swards. *Animal Production* **58:** 167-172.

Rook, A. J., Huckle, C. A. and Penning, P. D. 1994b. The effects of sward height and concentrate supplementation on the ingestive behaviour of spring calving dairy cows grazing perennial ryegrass-white clover swards. *Applied Animal Behaviour Science* **40:** 101-112.

Rusdi and van Houtert., M. F. J. 1997. Responses to protected amino acids or protected protein in dairy cows grazing ryegrass pastures in early or late lactation. *Proceedings of the New Zealand Society of Animal Production* **57:**120-125.

Russell, J. B. and Hespell, R. B. 1981. Microbial rumen fermentation. *Journal of Dairy Science* **64**: 1153-1169.

Saker, A. B. and Holmes, W. 1974. The influence of supplementary feeding on the herbage intake and grazing behaviour of dry cows. *Journal of the British Grasslands Society* **29**: 141-143.

Scharp, D. W. 1983. The influences of nutrition and management on productivity in year round calving herds, with reference to the Hunter Valley of New South Wales. In: *Nutrition, Proceedings No. 63.* Post Graduate Committee in Veterinary Science, University of Sydney. Pages 407-427.

Schroeder, G. F. and Gagliostro, G. A. 2000. Fishmeal supplementation to grazing dairy cows in early lactation. *Journal of Dairy Science* **83**: 2899-2906.

Sheaffer, C. C., Seguin, P. and Cuomo, G. J. 1998. Sward characteristics and management effects on cool-season grass quality. In: *Grass for Dairy Cattle.* Eds. J. H. Cherney, and D. J. R. Cherney CABI Publishing, Wallingford, Oxon, UK. Pages 73-100.

Smith, N. E. 1988. Alteration of the efficiency of milk production in dairy cows by manipulation of the diet. In: *Nutrition and Lactation in the Dairy Cow.* Ed. P. C. Garnsworthy. Butterworths, London. Pages 216-231.

Spedding, C. R. W., Large, R. V. and Kydd, D. D. 1966. The evaluation of herbage species by grazing animals. *Proceedings of the 10th International Grasslands Congress, Helsinki.* Pages 479-483.

Stakelum, G. 1986a. Herbage intake of grazing dairy cows. 1. Effect of autumn supplementation with concentrates and herbage allowance on herbage intake. *Irish Journal of Agricultural Research* **25:** 31-40.

Stakelum, G. 1986b. Herbage intake of grazing dairy cows. 2. Effect of herbage allowance, herbage mass and concentrate feeding on the intake of cows grazing primary spring grass. *Irish Journal of Agricultural Research* **25:** 41-51.

Stakelum, G. 1986c. Herbage intake of grazing dairy cows. 3. Effect of herbage mass, herbage allowance and concentrate feeding on the herbage intake of dairy cows grazing on mid-summer pasture. *Irish Journal of Agricultural Research* **25:** 179-189.

Stakelum, 1993. Achieving high performance from dairy cows on grazed pastures. *Irish Grassland and Animal Production Association Journal* **27**: 9-18.

Standing Committee on Agriculture. 1990. *Feeding Standards for Australian Livestock, Ruminants.* SCA, CSIRO, Melbourne.

Stobbs, T.H. 1973. The effect of plant structure on the intake of tropical pastures 2. Differences in sward structure, nutritive value and bite size of animals grazing *Setaria anceps* and *Chloris gayana* at various stages of growth. *Australian Journal of Agricultural Research* **24**: 821-829.

Stobbs, T. H., Minson, D. J. and McLeod, M. N. 1977. The response of dairy cows grazing a nitrogen fertilised grass pasture to a supplement of protected casein. *Journal of Agricultural Science (Cambridge)* **89**:137-141.

Stockdale, C. R. 1985. Influence of some sward characteristics on the consumption of irrigated pastured grazed by lactating dairy cows. *Grass and Forage Science* **40:** 927-940.

Stockdale, C. R. 1995. Maize silage as a supplement for pasture-fed dairy cows in early and late lactation. *Australian Journal of Experimental Agriculture* **35:** 19-26.

Stockdale, C. R. 1996. Substitution and production responses when lactating dairy cows graze a white clover pasture supplemented with maize silage. *Australian Journal of Experimental Agriculture* **36:** 771-776.

Stockdale, C. R. 1997a. Influence of energy and protein supplements on the productivity of dairy cows grazing white clover swards in spring. *Australian Journal of Experimental Agriculture* **37**: 151-157.

Stockdale, C. R. 1997b. Supplements improve the production of dairy cows grazing either white clover or paspalum-dominant pastures in late lactation. *Australian Journal of Experimental Agriculture* **37**: 295-302.

Stockdale, C. R. 1999a. The nutritive characteristics of herbage consumed by grazing dairy cows affect milk yield responses obtained from concentrate supplementation. *Australian Journal of Experimental Agriculture* **39**: 379-387.

Stockdale, C. R. 1999b. Effect of cereal grain, lupins-cereal grain or hay supplements on the intake and performance of grazing dairy cows. *Australian Journal of Experimental Agriculture* **39**: 811-817.

Stockdale, C. R. 1999c. Effect of length of the period of supplementation with concentrates on pasture intake and performance of grazing dairy cows. *Australian Journal of Experimental Agriculture* **39**: 803-809.

Stockdale, C. R. and Trigg, T. E. 1985. Effect of pasture allowance and level of concentrate feeding on the productivity of dairy cows in late lactation. *Australian Journal of Experimental Agriculture* **25:** 739-744.

Stockdale, C. R. and Trigg, T. E. 1989. Effect of feeding levels on the responses of lactating dairy cattle to high energy supplements. *Australian Journal of Experimental Agriculture* **29:** 605-611.

Stockdale, C. R. Currie, R. and Trigg, T. E. 1990. Effects of pasture and supplement quality on the responses of lactating dairy cows to high energy supplements. *Australian Journal of Experimental Agriculture* **30**: 43-50.

Stockdale, C. R., Callaghan, A, and Trigg, T. E. 1987. Feeding high energy supplements to pasture-fed dairy cows. Effects of stage of lactation and level of supplement. *Australian Journal of Agricultural Research* **38:** 927-940.

Stockdale, C. R. and Dellow, D. W. 1995. The productivity of lactating cows grazing white clover and supplemented with maize silage. *Australian Journal of Agricultural Research* **46:** 1205-1217.

Stockdale, C. R., Dellow, D. W., Grainger, C., Dalley, D. and Moate, P. J. 1997. Supplements for dairy production in Victoria. Dairy Research and Development Corporation, Glen Iris, Melbourne.

Suksombat, W., Holmes, C. W. and Wilson, G. F. 1994. Effects of herbage allowance and a high protein supplement on performance of dairy cows grazing on autumn-winter pastures. *Proceedings of the New Zealand Society of Animal Production* **54**: 83-86.

Sutton, J. D. 1985. Digestion and the absorption of energy substrates in the lactating cow. *Journal of Dairy Science* **68**: 3376-3393.

Sutton, J. D. 1989. Altering milk composition by feeding. *Journal of Dairy Science* **71**, Supplement 1:152.

Sutton, J. D., Bines, J. A., Morant, S. V. and Napper, D. J. 1987. A comparison of starchy and fibrous concentrates for milk production, energy utilisation and hay intake by Friesian cows. *Journal of Agricultural Science (Cambridge)* **109**: 375-386.

Tait, R. M. and Beames, R. M., 1988. Processing and preserving of cereals and protein concentrates. In: *Feed Science*. Ed. E. R. Orskov. Elsevier, Amsterdam. Pages 151-175.

Theurer, C. B., 1986. Grain processing effects on starch utilisation by ruminants. *Journal of Animal Science* **63**:1649-1662.

Thomas, C. 1987. Factors affecting substitution rates in dairy cows on silage based rations. In: *Recent Advances in Animal Nutrition.* Butterworths, London. Pages 205-218.

Thomas, C., Aston, K., Daley, S. R. and Bass, J. 1986. Milk production from silage 4. The effect of the composition of the supplement. *Animal Production* **42**:315-325.

Thomson, D. J. 1982. The nitrogen supplied by and the supplementation of fresh or grazed forage. In *Forage Protein in Ruminant Animal Production.* Eds. D.J. Thomson, D.E. Beever, and R.G. Gunn British Society of Animal Production Occasional Publication No. 6. Edinburgh, UK.

Thomson, N. A., Hainsworth, R. J. Clough, J. C. and McCallum, D. A. 1997. Effect of nitrogen fertiliser and concentrate feed on dairy production. *Proceedings of the New Zealand Society of Animal Production* **57**: 172-175.

Vadiveloo, J. and Holmes, W. 1979. The effect of forage digestibility and concentrate supplementation on the nutritive value of the diet and performance of finishing cattle. *Animal Production* **29**: 121-129.

Valentine, S. C. and Bartsch, B. D. 1989. Milk production by dairy cows fed hammermilled lupin grain, hammermilled oaten grain or whole oaten grain as supplements to pasture. *Australian Journal of Experimental Agriculture* **29**: 309-313.

Valentine, S. C. and Bartsch, B. D. 1990. Milk production by dairy cows fed legume grains or barley grain, with or without urea as supplements to a cereal hay based diet. *Australian Journal of Experimental Agriculture* **30**: 7-10.

Van Soest, P. J. 1994. *Nutritional Ecology of the Ruminant*, 2nd ed., Cornell University Press, Ithaca, NY.

van Vuuren, A. M., van der Koelen, C. J. and Vroons-de Bruin, J. 1986. Influence of level and composition of concentrate supplements on rumen fermentation patterns of grazing dairy cows. *Netherlands Journal of Agricultural Science* **34**: 457-467.

Veerkamp, R.F., Simm, G. and Oldham, J.D. 1994. Effects of interaction between genotype and feeding system on milk production, feed intake, efficiency and body tissue mobilization in dairy cows. *Livestock Production Science* **39**: 229-241.

Walker, D. J., Egan, A. R., Nader, C. J., Ulyatt, M. J., and Storer, G.B. 1975. Rumen microbial protein synthesis and proportions of microbial and non-microbial nitrogen flowing to the intestines of sheep. *Australian Journal of Agricultural Research* **26**: 699-708.

Waghorn, G. C. and Barry, T. N. 1987. Pasture as a nutrient source. In *Livestock Feeding on Pasture.* Ed. A. M. Nicol. New Zealand Society of Animal Production Occasional Publication No. 10. Pages 21-37.

Wales, W. J., Doyle, P. T. and Dellow, D. W. 1998. Dry matter intake and nutrient selection by lactating dairy cows grazing irrigated pastures at different pasture allowances in summer and autumn. *Australian Journal of Experimental Agriculture* **38:** 451-460.

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

Wilkins, R. J., Gibb, M. J., Huckle, C. A. and Clements, A. J. 1994. Effect of supplementation on production by spring-calving dairy cows grazing swards of differing clover content. *Grass and Forage Science* **49**: 465-475.

Wilson, G. F. 1970. The influence of protein supplements on milk yield and composition. *Proceedings of the New Zealand Society of Animal Production.* **30**:123-127.

CHAPTER THREE

SUPPLEMENTARY FEEDING RESPONSES BY COWS IN EARLY, MID AND LATE LACTATION GRAZING LOW PASTURE ALLOWANCES IN SPRING, SUMMER, AUTUMN AND WINTER
1. PASTURE INTAKE AND SUBSTITUTION

CHAPTER 3: SUPPLEMENTARY FEEDING RESPONSES BY COWS IN EARLY, MID AND LATE LACTATION GRAZING LOW PASTURE ALLOWANCES IN SPRING, SUMMER, AUTUMN AND WINTER

1. PASTURE INTAKE AND SUBSTITUTION

3.1 Abstract

Many experiments have measured the responses of grazing dairy cows to various forms of supplementary feed, but few have studied the reasons for the large differences in responses between experiments. Two trials, each using early, mid and late lactation cows in four experimental periods (spring, summer, autumn and winter), were designed to determine the effects of stage of lactation, and season of the year, on the cows response to supplementary feeding. Two grazing trials (trial 1 in year 1; trial 2 in year 2) were conducted with groups of cows in early, mid and late lactation in spring, summer, autumn and winter, in a partially complete Latin Square arrangement. At each stage of lactation, and in each season of the year, cows were offered either a restricted pasture allowance (25 to 35 kg DM/cow/day), or a restricted pasture allowance plus supplements offered at 50 MJME/cow/day in trial 1 and 80 MJME/cow/day in trial 2. The supplements were either rolled maize grain (MG) or a mixture of feeds formulated to nutritionally balance the diet (BR). In trial 2, a fourth nutritional treatment of a generous pasture allowance (AP) was imposed on an additional group of early lactation cows during each season. Each experimental group included 8 cows. Pasture DMI was measured using the alkane faecal marker technique, and supplementary feed DMI was measured directly for each cow.

In both trials 1 and 2, offering MG and BR resulted in large increases in total DMI. At the restricted pasture allowance, increasing total ME allowance (MEA) by offering supplementary feeds increased ME intake (MEI) by 0.65 (±0.071) MJ eaten/MJ offered. This highly significant linear relationship was consistent across the

different seasons, and did not diminish at higher MEA. However, at a constant MEA, MEI was higher in spring and winter than in summer and autumn.

In trial 2, cows in early lactation had lower substitution rates (SR) than mid and late lactation cows. Although season did not affect SR, higher SR were recorded when higher pasture allowance or quality enabled the unsupplemented cows to achieve higher DMI from pasture than at other times of the year.

These results suggest that supplementary feeds have their greatest effect on total DMI during periods of greatest feed deficit, measured as the lowest pasture allowance relative to the cows' demand for feed. Stage of lactation and season of the year had only small effects on the DMI intake response of cows to increased total feed allowance. Within seasonal calving dairying systems the largest increases in total DMI per kg of supplement offered, is likely to result from offering supplements to early lactation cows grazing restricted allowances of high quality pasture.

3.2 Introduction

Grazed temperate pasture provides a low-cost source of nutrients for dairy production, but is characterised by seasonal variations in pasture growth and nutrient composition, both of which can limit animal performance. When pasture is the predominant source of feed, spring calving, conservation of surplus pasture, and strategic early drying-off are often used to closely match the feed requirements of the herd to the pattern of pasture production. Supplementary feeds can be used to increase nutrient supply during periods of inadequate pasture supply, or to achieve levels of animal performance that are higher than those achievable from pasture alone. However, feeds used as supplements are usually more expensive than pasture and should only be used when the value of the extra milk produced exceeds the cost of providing the feed.

The factors that determine the response of grazing dairy cows to supplementary feed must be understood so that the likely benefits of offering a particular supplement can be predicted. Previous research has established that offering supplementary feeds to grazing dairy cows usually reduces pasture intake (Leaver, 1985), and the extent to which the supplement increases total nutrient intake is the primary determinant of the animal response to supplements (see chapter 2). Substitution of pasture by supplements generally increases as pasture allowance increases (Grainger and Mathews, 1989), and as level of supplementary feeding increases (Meijs and Hoekstra, 1984; Bines, 1985). This suggests that the degree to which pasture alone is able to supply the current nutrient requirements of the cow determines the extent to which supplements will substitute for pasture.

It was proposed in the previous chapter that the extent to which supplements would increase the total intake of the herd would be determined by the relative feed deficit of the cows. While unquantified, the relative feed deficit was defined as the difference between the cows theoretical metabolisable energy (ME) demand to achieve her target milk yield and rate of liveweight gain, and her actual ME intake. In seasonal dairying systems, the energy and nutrient requirements of the herd are closely related to stage of lactation, and energy and nutrient supply are closely associated with season of the year. Therefore, two series of trials were conducted which aimed to determine the effect of stage of lactation and season of the year on the response of dairy cows, grazing restricted allowances of pasture, to rolled maize grain or nutritionally balancing supplementary feeds. The results are reported in 3 chapters, of which this is the first. Chapter 3 reports the pasture and supplement intake and discusses pasture substitution. Chapter 4 reports the liveweight change and milk yield responses, and Chapter 5 use these data to develop a model enabling the prediction of animal responses.

3.3 Materials and methods

3.3.1 Animals and pastures

The trials were conducted at the Dairying Research Corporation's No 3 Dairy, near Hamilton, New Zealand (latitude 37° 47' south, longitude 175°19' east, altitude 40m above sea level) between September 1996 and July 1998. Pastures were predominantly ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.)

associations on Te Rapa silty peat loam (Humic Haporthod). All pastures regularly received fertiliser providing N, P, and K at approximately 150, 50, and 60 kg/ha/year, respectively. Phosphatic fertiliser was applied as a single application in autumn, and potassic fertiliser was applied as a single application in spring to ensure maintenance of optimum soil fertility. Nitrogenous fertiliser was applied after most grazings, except during periods of summer moisture deficit.

Two years before this experiment, a herd of high genetic merit spring calving Friesian cows (n=140) were blocked on age, genetic merit, milk yield, liveweight and condition score and allocated to four groups. Each group was randomly allocated to a season of calving representing winter, spring, summer and autumn. Breeding was arranged so that the winter, spring, summer and autumn groups calved over an eight-week period starting on either 12 July, 25 October, 20 January, or 15 April, respectively (Auldist *et al.,* 1998). Cows due to calve 56 days after their groups planned start of calving were treated to induce premature calving within 42 days of the planned start of calving (Chesterton and Marchant, 1985). Approximately 20% of the cows were culled from each calving group annually. Culls were selected at the end of lactation on the basis of reproductive failure, health, age and genetic merit, and replaced with primiparous cows one month before the planned start of calving.

3.3.2 Experimental design

Trial 1 was conducted in a 3 x 3 x 4 factorial design, with three feeding treatments imposed on three groups of cows (n=8) in early, mid, and late lactation at four times of the year representing spring, summer, autumn and winter. At commencement, cows in each calving date group were blocked on age, genetic merit, milk yield, liveweight and condition score and were randomly assigned to one of three feeding treatments. After the first experimental period, cows were reassigned to subsequent feeding treatment groups for the next experimental period according to a partially complete Latin Square arrangement.

Feeding treatments were either a restricted pasture allowance (approximately 25 to 35 kg DM/cow/day), or the restricted pasture allowance plus 50 MJME/cow/day of rolled maize grain (MG), or the restricted pasture allowance plus

50 MJME/cow/day of a mixture of supplementary feeds and minerals formulated to balance the total diet, including grazed pasture (BR). Trial 1 was conducted in four periods, each of 35 days, commencing 30 September 1996, 27 January 1997, 14 April 1997 and 30 June 1997 representing spring, summer, autumn and winter, respectively. A 7 day uniformity period preceded each experimental period, during which cows were grazed together with their calving group and offered a generous pasture allowance. Measurements of milk yield, milk composition and liveweight were made at the end of each uniformity week and the resultant data was subsequently used for covariant analysis. After the conclusion of each experimental period cows in early and mid lactation were again grazed together with their calving group and offered a generous pasture allowance for 28 days to allow the measurement of carry-over effects. Cows in late lactation were dried off immediately after each 35 day experimental period and no carryover measurements were taken.

Trial 2 was conducted in a 4 x 3 x 4 partially complete factorial design, with four feeding treatments imposed on groups of cows (n=8) in early lactation and three feeding treatments imposed on groups of cows (n=8) in mid and late lactation, at four times of the year. Feeding treatments imposed on the groups of cows in early lactation were a restricted pasture allowance (approximately 25 to 35 kg DM/cow/day; Control), a generous pasture allowance (approximately 60 to 75 kg DM/cow/day; AP), the restricted pasture allowance plus 80 MJME/cow/day of rolled maize grain (MG), and the restricted pasture allowance plus 80 MJME/cow/day of a mixture of supplementary feeds and minerals formulated to balance the total diet (BR). Only the control, MG and BR feeding treatments were imposed on cows in mid and late lactation. Trial 2 was conducted in four periods of 35 days commencing 1 September 1997, 24 November 1997, 23 March 1998, and 8 June 1998. The experimental schedule and measurements were the same for trials 1 and 2.

3.3.3 Supplementary feeds

Maize grain was processed through a single roller crusher so that each kernel was broken into 3 or 4 pieces, and offered to the MG treatment group; it also formed the basis of the BR supplement. The Spartan computer programme (van de Haar *et al.*,

1992) was used to formulate the balancing ration, taking into account the chemical composition of the pasture and the predicted pasture DMI. Rations were then checked for their ability to provide sufficient ME, metabolisable protein (MP), and amino acids using the Cornell Net Carbohydrate and Protein System (CNCPS; Fox *et al.*, 1992) and the feed parameters shown in Table 3.1. CNCPS feed values for pastures were based on those used by Kolver *et al.* (1998) when validating the model for dairy cows consuming pasture based diets. The formulation objective was to provide sufficient nutrients for cows in early lactation to achieve milk yields 25% higher than those being achieved immediately before the experimental treatments were imposed. The mixtures of supplementary feed offered to cows in the BR treatment groups during trials 1 and 2 are shown in Table 3.4.

3.3.4 Feeding

Supplementary feeds were offered individually to cows in feeding stalls immediately after the morning milking. Refusals were collected and weighed. During experimental periods, all cows were grazed in their treatment groups on pastures of similar pre-grazing pasture masses. Portable electric fences were used to contain each group on the area of pasture allocated for that day, such that each group was offered the same total pasture allowance. A fresh allowance of pasture was offered every 24 hours, immediately after the morning milking.

3.3.5 Experimental measurements

3.3.5.1 Pasture allocation

Pre- and post-grazing pasture mass was estimated daily, on each area, by calibrated visual assessment. Once each week, the pasture mass of twelve quadrats (0.33 m^2), representing the range of pre- and post-grazing pasture masses present on the trial areas, were visually assessed. The quadrats were then cut to ground level with a portable shearing hand-piece. Harvested material was collected, washed to remove soil and faecal contamination, and then dried for 48 hours in an oven at 100°C. The dried material was weighed to determine the dry-weight of the pasture above ground level. Measured pasture mass was related to the visually assessed

Table 3.1: Estimated concentration of dry matter (DM), neutral detergent fibre (NDF), lignin, crude protein, soluble crude protein, non-protein nitrogen, neutral detergent fibre insoluble protein (NDFIP), acid detergent fibre insoluble protein (ADFIP), starch, fat, ash, and effective neutral detergent fibre (eNDF), rates of carbohydrate and protein degradation, and amino acid composition of feeds used when checking feed rations with the CNCPS.

Feed description	Spring Pasture	Summer Pasture	Autumn Pasture	Winter Pasture	Maize grain	Barley Straw	Pasture Hay	Fish Meal	Soybean Meal
DM (% Fresh weight)	17	24	20	17	88	91	88	90	89
NDF (% DM)	42	45	39	45	9	80	55	2	14
Lignin (% NDF)	8	8	8	8	2	14	10	0	2
Crude protein (% DM)	27	18	25	22	10	4	9	7	49
Soluble protein (% Crude protein)	80	40	80	85	11	20	25	21	20
Non-protein nitrogen (% Soluble protein)	50	40	60	60	73	95	96	0	55
NDFIP (% Crude protein)	25	25	25	25	15	75	31	1	5
ADFIP (% Crude protein)	3	3	3	3	5	65	6	1	2
Starch (% NSC)	5	5	5	5	90	100	6	90	90
Fat (% DM)	5	5	5	5	4	2	2	5	2
Ash (% DM)	8	8	8	8	2	7.0	10	25	7
eNDF (% NDF)	40	60	35	50	60	100	98	10	23
Carbohydrate A kd (%/hour)	250	250	250	250	150	300	250	300	300
Carbohydrate B1 kd (%/hour)	60	60	60	60	15	40	30	50	25
Carbohydrate B2 kd (%/hour)	12	12	12	12	5	80	3	7	6
Protein B1 kd (%/hour)	135	135	135	135	150	300	135	100	230
Protein B2 kd (%/hour)	30	30	30	30	5	12	11	1	11
Protein B3 kd (%/hour)	0.09	0.09	0.09	0.09	0.09	0.35	0.09	0.80	0.20
Methionine (% UDP)	0.67	0.67	0.67	0.67	1.12	1.33	0.67	2.84	1.01
Lysine (% UDP)	2.83	2.83	2.83	2.83	1.65	3.33	2.83	7.13	5.36
Arginine (% UDP)	2.83	2.83	2.83	2.83	1.82	4.67	2.83	7.19	6.55
Threonine (% UDP)	2.83	2.83	2.83	2.83	2.80	2.67	2.83	4.19	3.52
Leucine (% UDP)	5.49	5.49	5.49	5.49	10.73	4.67	5.49	7.01	7.23
Isoleucine(% UDP)	2.83	2.83	2.83	2.83	2.69	3.00	2.83	4.53	4.65
Valine (% UDP)	3.83	3.83	3.83	3.83	3.75	3.67	3.83	4.81	5.09
Histidine (% UDP)	1.00	1.00	1.00	1.00	2.06	3.00	1.00	2.30	2.82
Phenylalanine (% UDP)	3.50	3.50	3.50	3.50	3.65	1.00	3.50	4.33	4.94
Tryptophan (% UDP)	4.50	4.50	4.50	4.50	0.37	0.67	4.50	1.52	1.64

pasture mass by linear regression and the resultant equation used to correct the visual assessments made during that week.

3.3.5.2 Pasture intake

The pasture DMI of each cow was measured during the final week of each experimental period using the alkane faecal marker technique of Dove and Mayes (1991). During trial 1 all cows were dosed twice daily at 0730 hours and 1600 hours with gelatine capsules containing 350 mg of synthetic C_{32} alkane in a cellulose carrier from day 21 to day 32 of each experimental period. During trial 2 cows were dosed on day 21 with a Captech™ slow release alkane capsule with a known release rate of about 400mg C_{32}/day. After an equilibration period of 5 days, faecal samples (approximately 200g wet) were collected per rectum immediately before both milkings for 6 days. Each sample was dried in a ventilated oven at 60°C for 96 hours. Dried material was finely ground and sub-sampled to accumulate a composite sample for each individual cow.

Representative pasture samples were taken by hand clipping to grazing height from each area of pasture grazed, from days 26 to 32 of each experimental period to coincide with collection of faecal material. Pasture samples were immediately frozen before being freeze-dried and finely ground for subsequent alkane analysis.

Faecal and pasture alkane concentrations were measured according to the procedures of Mayes *et al.* (1986) using an automated GLC (5890A; Hewlett-Packard, Avondale, PA). Pasture intakes of each cow were calculated using the equation of Dove and Mayes (1991):

$$\text{Pasture DMI (kg/cow/day)} = \frac{F_i/F_j \times (D_j + I_s \times S_j) - I_s \times S_i}{H_i - (F_i/F_j \times H_j)}$$

Where:

F_i = Concentration of C_{33} Alkane (mg/kg DM) in faeces

F_j = Concentration of C_{32} Alkane (mg/kg DM) in faeces

D_j = Daily dose rate of C_{32} Alkane (mg/cow/day)

I_s = Supplementary feed DMI (kg/cow/day)

S_i = Concentration of C_{33} alkane (mg/kg DM) in supplementary feed

S_j = Concentration of C_{32} alkane (mg/kg DM) in supplementary feed

H_i = Concentration of C_{33} alkane (mg/kg DM) in pasture

3.3.5.3 Pasture chemical composition

Pasture samples were hand clipped to grazing height from the grazing areas of each treatment group weekly during each experimental period. Samples were oven dried at 60°C, ground and analysed by NIRS (Corson *et al.,* 1999).

3.3.6 Statistical analysis

Trials 1 and 2 were analysed separately. Residual Maximum Likelihood (REML) procedures of Genstat 5 Release 4.2b (Genstat Committee, 1997) were used for analysis of pasture, supplement and total DMI, using stage of lactation, season, feed and their interactions as fixed effects. Days-in-milk (DIM), as a deviation from the stage of lactation group mean DIM, was used as a covariate and cow was specified as a random effect. The data presented from each experimental period are the predicted means for DMI (pasture, supplement and total), adjusted for imbalance in covariates and the number of observations, of measurements from days 29 to 35 of each experimental period in trials 1 and 2. Predicted means are presented with the maximum standard error of the difference (sed) between comparable means.

Metabolisable energy substitution rate (ME SR) was calculated as the pasture ME intake of the respective control group, minus the mean pasture metabolisable energy (ME) intake of each experimental group receiving either MG or BR at the same stage of lactation and season, divided by the ME intake from the supplement. The linear model of Data Desk 6.1 (Velleman, 1997) was used sequentially to calculate expected mean ME SR for the factors stage of lactation, season, and feed separately for each trial. The relationship between pasture DMI and the dry matter substitution rate (DM SR) was determined by plotting the pasture DMI of each control group (PDMI) against the SR caused by feeding MG and BR supplements (calculated as for ME SR). The respective regression equations were calculated using Data Desk 6.1 (Velleman, 1997). The DM SR of each treatment group means of both trials were then adjusted using the PDMI as a covariate, and analysed by ANOVA using the linear model of DataDesk 6.1 (Velleman, 1997).

3.4 Results

3.4.1 Feed offered

3.4.1.1 Pasture quality

Pasture quality was high during both trials 1 and 2 (Table 3.2). The chemical composition of the pasture appeared to vary little between spring, autumn and winter. However, summer pasture had a lower concentration of crude protein (CP) and higher concentration of acid and neutral detergent fibre (ADF and NDF) than pasture in other seasons of the year. The organic matter digestibility (OMD) and ME concentration of the pasture offered in the summer period of Trial 1 was 8 to 14% lower than that offered during the other experimental periods, probably reflecting the effect of summer moisture deficit in that year.

3.4.1.2 Pasture allowance

The pasture allowances offered to each experimental group, during each experimental period of trials 1 and 2 are presented in Table 3.3. During trial 1 all groups were offered a similar pasture allowance within each experimental period. However, in trial 1 the pasture allowances offered in summer and autumn were higher than those offered during spring and winter, by about 30 and 20%, respectively. In trial 2 the pasture allowances offered to the different treatment groups were similar within experimental periods, except for the AP treatment group which, as planned, received a pasture allowance approximately two fold greater than that offered to the other groups. The pasture allowances offered during the summer, autumn and winter periods of trial 2 were similar to those in the same periods of trial 1, whereas the restricted pasture allowance offered during the spring of trial 2 was about 20% greater than that offered during the spring of trial 1.

3.4.1.3 Supplementary feeding treatments

Using the pasture parameters contained in Table 3.1, the CNCPS predicted that ME intake was the most limiting factor for cows at all stages of lactation when offered a restricted pasture allowance. Overcoming the ME limitation by offering

Table 3.2: Trials 1 and 2: Concentrations of crude protein, lipid, ash, acid detergent fibre (ADF), neutral detergent fibre (NDF), soluble carbohydrate and metabolisable energy (ME), and organic matter digestibility (OMD) of the pasture offered during each experimental period.

Period	Crude Protein (g/100g DM)	Lipid (g/100 g DM)	Ash (g/100 g DM)	ADF (g/100 g DM)	NDF (g/100 g DM)	Soluble Carbohydrate (g/100 g DM)	OMD (%)	ME (MJME/ kg DM)
Trial 1								
Spring	21.6	3.8	10.4	22.0	40.6	11.4	83.6	12.5
Summer	18.7	4.2	9.5	23.6	43.4	11.0	73.0	10.9
Autumn	25.1	4.6	10.5	18.8	37.5	12.9	85.0	12.7
Winter	25.9	4.2	10.6	16.9	33.5	16.8	85.0	12.7
Trial 2								
Spring	25.3	4.6	11.1	20.8	38.6	11.9	84.8	12.6
Summer	17.1	3.8	10.1	24.6	44.9	12.5	79.3	11.8
Autumn	23.5	4.4	11.2	23.3	42.3	10.1	79.9	11.9
Winter	24.7	4.3	11.8	23.3	42.6	10.4	83.1	12.4

Table 3.3: Trials 1 and 2: Daily pasture allowance (kg DM/cow) offered to early lactation cows in the *ad lib* pasture groups (AP), and to the early, mid and late lactation cows offered the control, maize grain and balancing ration treatments, during each experimental period.

			Stage of Lactation		
	Month	**AP**	**Early**	**Mid**	**Late**
Trial 1					
Spring	Oct 96		25	24	24
Summer	Feb 97		36	37	37
Autumn	May 97		31	31	30
Winter	Jul 97		24	24	23
Trial 2					
Spring	Sep 97	65	30	30	30
Summer	Dec 97	76	36	35	35
Autumn	April 98	76	32	32	32
Winter	June 98	62	25	24	24

rolled maize grain to the MG group at 3.7 and 6.0 kg DM/cow/day during trials 1 and 2, respectively, increased both ME and MP supply to these groups. However, overcoming the ME limitation with a maize grain supplement caused MP, or specific amino acid supply, to limit milk yield. The CNCPS suggested that the inadequate protein supply that occurred when cereal grain supplements were fed resulted from a sub-optimal rumen environment due to insufficient effective fibre (eNDF) in spring, autumn and winter, but from a low CP intake in summer.

In spring of trial 1, supplementary eNDF was provided to cows in the BR treatment groups with 1.5 kg DM/cow/day of barley straw. However, it was not possible to mix the barley straw with the other feed ingredients, and because of slow rates of consumption, it was offered at pasture. This made it difficult to measure the refusals of straw, and the amount eaten by each cow could not be determined. Therefore, chopped hay was used to provide eNDF after the spring experimental period of trial 1. In the winter experimental period of trial 1, 1.0 kg DM/cow/day of chopped pasture hay was included in the BR mixture and 2.0 kg DM of chopped hay was included in autumn of trial 1, and in spring, autumn and winter experimental periods of trial 2 (Table 3.4).

Chilean fishmeal was included in the BR supplement to increase amino acid supply in the autumn and winter of trial 1, and in spring, autumn and winter of trial 2. Soybean meal was included in the BR supplement to provide protein that was quickly degraded in the rumen, in the summer and autumn experimental periods of trial 1 and the summer of trial 2. Macro minerals were included in the BR mixture to provide adequate Mg, Ca, P and Na (Table 3.4). Vitamin or trace mineral premixes were not included in the ration.

3.4.2 Feed intake

3.4.2.1 Trial 1: Pasture and supplement DMI

The average DMI from pasture, supplementary feed, and the total DMI for each group during each experimental period of trial 1 are presented in Table 3.5, and the average pasture DMI of each group are shown in Figure 3.1. No stage of

Table 3.4: Trials 1 and 2: Mixture of supplementary feeds (kg DM/cow/day) offered to cows in the maize grain (MG) and balanced ration (BR) treatment groups and the total amount of DM and metabolisable energy (ME) offered each day.

	ME	Feed	Maize grain	Barley straw	Chopped hay	Fish meal	Soyabean meal	MgO	NaCl	CaPO	Lime flour	Total DM (kg/c/d)	Estimated ME* (MJ/c/d)
Trial 1		MG	3.7									3.7	48
Spring		BR	3.0	1.5							0.08	4.6	50
Summer		BR	2.7				1.0			0.13		3.8	49
Autumn		BR	1.7		2.0	0.5	0.5	0.03	0.03	0.10	0.04	4.9	55
Winter		BR	3.0		1.0	0.3		0.05		0.12	0.01	4.5	53
Trial 2		MG	6.0									6.0	78
Spring		BR	4.6		2.0				0.04	0.10	0.15	6.9	80
Summer		BR	4.5			0.5	1.0			0.10	0.10	6.2	79
Autumn		BR	3.9		2.0	0.5		0.01	0.03		0.14	6.6	77
Winter		BR	3.9		2.0	0.5		0.01	0.03		0.14	6.6	77

*Estimates of metabolisable energy contents of supplementary feeds taken from NRC (1989)

Table 3.5: Trial 1: Daily pasture and supplement dry-matter intake (kg/cow) of cows in early, mid and late lactation offered either a restricted pasture allowance (Control) or the restricted pasture allowance plus supplements of rolled maize grain (MG) or a balancing ration (BR), measured during the final week of each experimental period.

Stage	**Early**			**Mid**			**Late**				**Significant effects***				
Feed	Control	MG	BR	Control	MG	BR	Control	MG	BR	sed	Season	Stage	Feed	Season x Feed	Stage x Feed
Spring															
Pasture	11.2	12.2	9.1	10.6	9.3	8.1	9.9	9.8	8.9	0.92	**	**	**	NS	NS
Supplement		3.2	4.6		3.6	4.5		3.4	4.5	0.11	**	NS	**	**	NS
Total	11.2	15.4	13.7	10.6	12.8	12.7	9.9	13.2	13.5	0.95	**	**	**	NS	NS
Summer															
Pasture	9.1	9.9	8.2	12.4	10.7	11.6	10.0	9.5	9.8	0.92					
Supplement		3.7	3.8		3.7	3.8		3.7	3.8	0.11					
Total	9.1	13.5	12.0	12.4	14.4	15.5	10.0	13.2	13.6	0.95					
Autumn															
Pasture	12.0	10.6	9.8	12.1	10.2	10.8	10.7	10.1	9.6	0.92					
Supplement		3.7	4.9		3.7	4.9		3.7	4.9	0.11					
Total	12.0	14.3	14.7	12.1	13.9	15.7	10.7	13.8	14.5	0.95					
Winter															
Pasture	9.1	7.4	8.5	8.4	8.2	7.5	7.0	7.1	7.5	0.92					
Supplement		3.7	4.4		3.7	4.3		3.6	4.3	0.11					
Total	9.1	11.1	12.9	8.4	11.9	11.8	7.0	10.7	11.8	0.95					

*There were no season x stage x feed interactions (P>0.10)

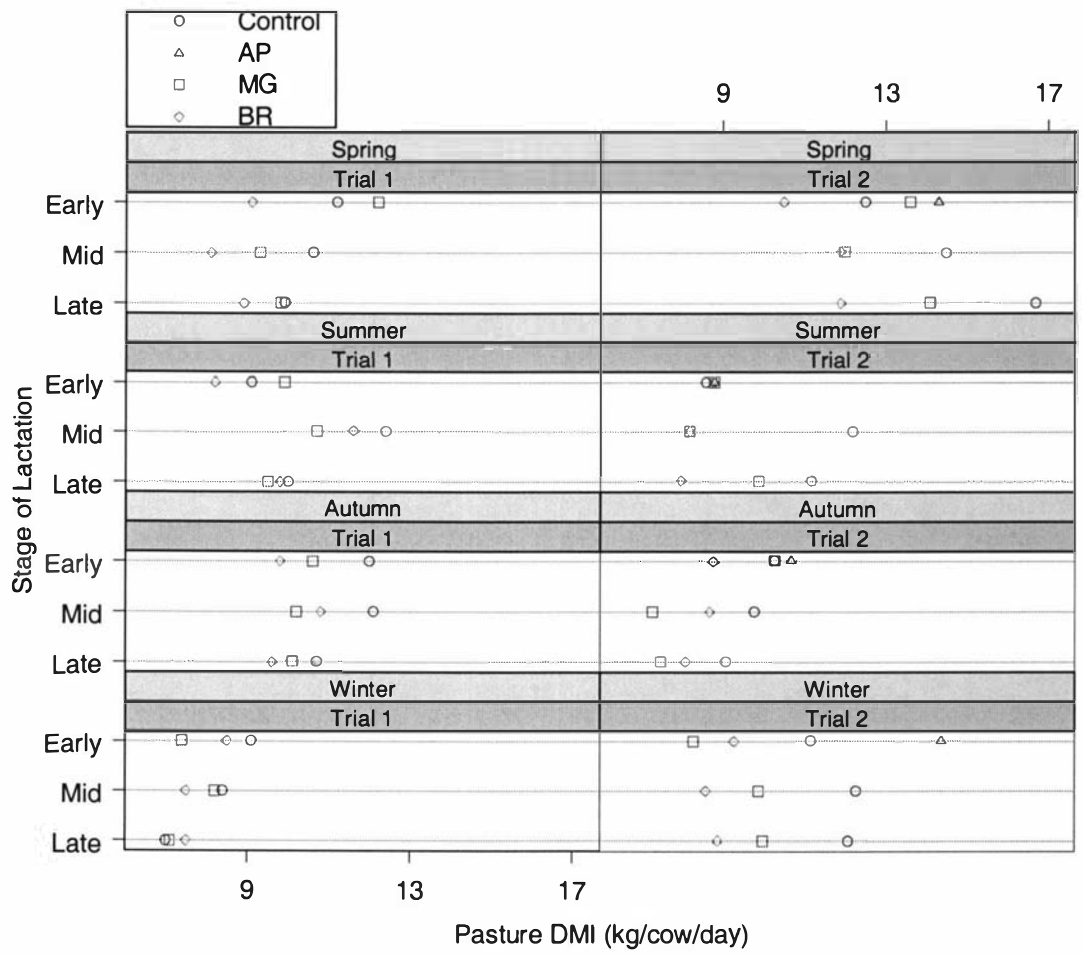


Figure 3.1: Trials 1 and 2: Average pasture dry-matter intake (DMI) of cows receiving a restricted pasture allowance (control), a generous pasture allowance (AP; trial 2 only), or a restricted pasture allowance plus either maize grain (MG) or a ration balancing (BR) supplement, measured during the final week of the spring, summer, autumn and winter experimental periods.

lactation by feed, or season by feed interactions (P>0.05) were detected for pasture DMI or total DMI.

Offering supplementary feeds increased the total DMI compared to cows offered the control diet at all stages of lactation and at all times of the year (P<0.05). Offering MG or BR increased (P<0.01) total DMI from an average of 10.2 kg DM/cow/day to 13.2 or 13.5 (±0.22) kg DM/cow/day, respectively.

The pasture DMI of cows offered the pasture only control treatment was highest (P<0.05) in autumn, and lowest (P<0.05) in winter (Figure 3.2). Offering supplements of MG and BR reduced (P<0.01) mean pasture DMI from 10.2 kg DM/cow/day to 9.6, and 9.1 (±0.22) kg DM/cow/day, respectively. In the summer and winter experimental periods there was no difference (P>0.05) between the pasture DMI of cows offered the control and supplemented treatments. In spring, cows offered the BR consumed less (P<0.05) pasture than the cows offered the control and MG diets, and in autumn cows offered both supplementary feeds ate less (P<0.05) pasture than cows offered only pasture.

Offering the MG and BR treatments reduced (P<0.05) the pasture DMI of cows in mid lactation but had no effect on the pasture DMI of cows in late lactation (Figure 3.3). In early lactation there was no difference (P>0.05) between the pasture DMI of cows offered the control and the MG treatments, however the BR supplement did reduce (P<0.05) pasture DMI. The pasture DMI of cows offered the BR supplement was similar at all stages of lactation.

3.4.2.2 Trial 2: Pasture and supplement DMI

Average DMI from pasture and supplementary feed, and total DMI for each group during each experimental period of trial 2 are presented in Table 3.6, and average pasture DMI for each group is shown in Figure 3.1. There were stage of lactation by feed interactions (P<0.05), and season by feed, and stage of lactation by season interactions (P<0.01) for pasture and total DMI. Therefore, the effect of the feeding treatments on the pasture DMI of early mid and late lactation cows are presented separately by season.

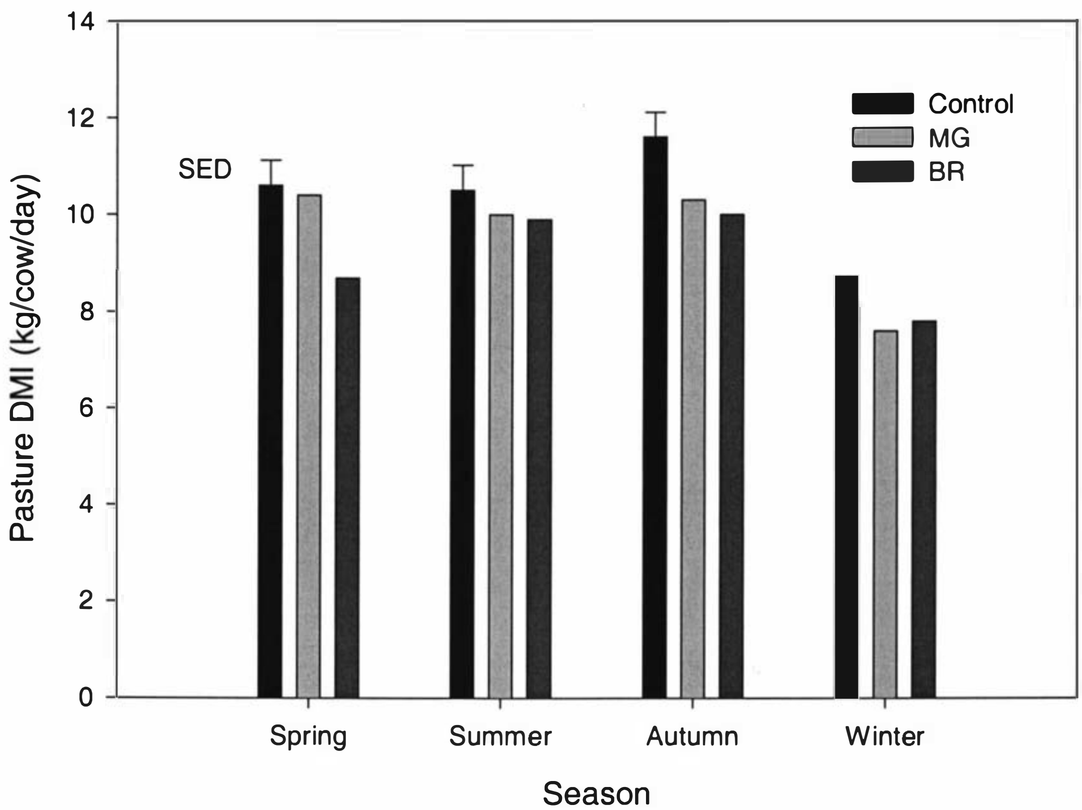


Figure 3.2: Trial 1: Average pasture dry-matter intake (DMI) of cows grazing on a restricted pasture allowance and offered no supplementary feed (control), supplements of rolled maize grain (MG) or a supplement formulated to balance the diet (BR) during the four experimental periods.

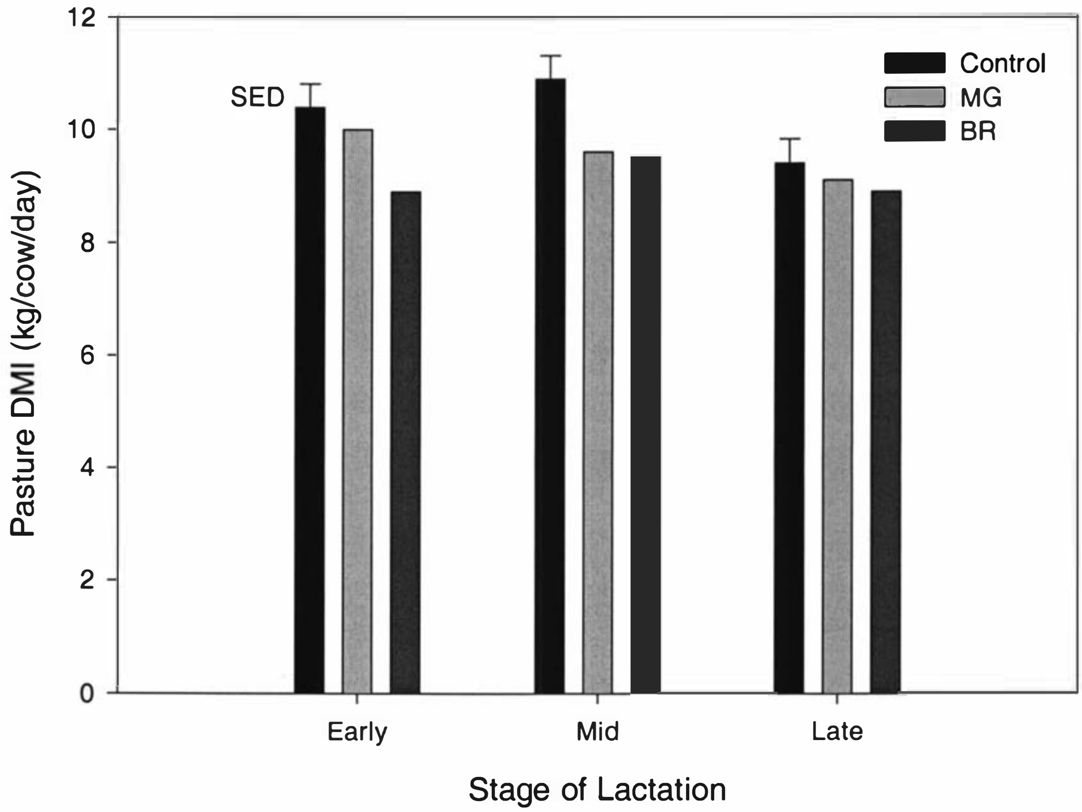


Figure 3.3: Trial 1: Average pasture dry-matter intake (DMI) of cows in early, mid and late lactation grazing on a restricted pasture allowance and offered no supplementary feed (control), or supplements of rolled maize grain (MG) or a supplement formulated to balance the diet (BR).

Table 3.6: Trial 2: Daily pasture and supplement dry-matter intake (kg/cow) of cows in early, mid and late lactation offered either a restricted pasture allowance (Control), or a generous pasture allowance (AP), or the restricted pasture allowance plus supplements of rolled maize grain (MG) or a balancing ration (BR), measured during the final week of each experimental period.

Stage	**Early**				**Mid**			**Late**				**Significant effects**[♣]				
Feed	Control	AP	MG	BR	Control	MG	BR	Control	MG	BR	sed	Season	Stage	Feed	Season x Feed	Stage x Feed
Spring																
Pasture	12.5	14.3	13.6	10.5	14.5	12.0	11.9	16.7	14.1	11.9	1.07	**	NS	**	**	**
Supplement			4.6	6.2		5.7	5.5		5.5	6.3	0.23	**	**	**	**	*
Total	12.5	14.3	18.2	16.7	14.5	17.7	17.4	16.7	19.6	18.2	1.10	**	**	**	**	*
Summer																
Pasture	8.6	8.8	8.8	8.8	12.2	8.2	8.2	11.2	9.9	8.0	1.07					
Supplement			6.0	6.1		5.8	5.8		5.8	6.2	0.23					
Total	8.6	8.8	14.8	14.9	12.2	14.0	14.0	11.2	15.7	14.2	1.10					
Autumn																
Pasture	10.3	10.7	10.3	8.8	9.8	7.3	8.7	9.1	7.5	8.1	1.07					
Supplement			6.0	6.6		6.0	6.6		5.9	6.5	0.23					
Total	10.3	10.7	16.3	15.4	9.8	13.3	15.3	9.1	13.4	14.6	1.10					
Winter																
Pasture	11.2	14.4	8.3	9.3	12.3	9.9	8.6	12.1	10.0	8.9	1.07					
Supplement			5.8	6.3		5.8	6.5		6.0	6.3	0.23					
Total	11.2	14.4	14.1	15.6	12.3	15.7	15.1	12.1	16.0	15.2	1.10					

[♣] There were no season x stage x feed interactions (P>0.05)

3.4.2.2.1 Spring

Offering MG and BR supplements reduced ($P<0.05$) the pasture DMI of mid and late lactation cows in spring, however, only the BR supplement reduced ($P<0.05$) the DMI of early lactation cows. In late lactation, cows offered the BR treatment ate 2.3 kg (±1.07) DM/cow/day less pasture ($P<0.05$) than cows offered the MG treatment.

Cows in mid and late lactation offered the pasture only control treatment had higher ($P<0.05$) pasture DMI in the spring than during the other experimental periods. The pasture DMI of early lactation cows offered the control treatment was higher ($P<0.05$) in the spring than in the summer and autumn. Similarly, the pasture DMI of early lactation cows offered the AP treatment were higher than those in the summer and autumn, but similar ($P>0.05$) to that of cows offered the AP treatment in winter. Early and late lactation cows offered the MG treatment, and mid and late lactation cows offered the BR treatment, had higher ($P<0.05$) pasture DMI in spring than during other times of the year. Season had no effect ($P>0.05$) on the pasture DMI of early lactation cows offered the BR treatment.

3.4.2.2.2 Summer

Feeding treatment had no effect ($P>0.05$) on pasture DMI of early lactation cows in summer. However, both MG and BR reduced pasture DMI of mid lactation cows, and BR reduced ($P<0.05$) pasture DMI of late lactation cows in summer.

In early lactation, cows offered the control and AP treatments had lower ($P<0.05$) pasture DMI than cows offered those treatments in autumn and winter. However, mid lactation cows offered the control treatment, and late lactation cows offered the MG treatment, had higher ($P<0.05$) pasture DMI in summer than autumn. There was no difference ($P>0.05$) between the summer and winter pasture DMI of mid and late lactation cows offered the same feeding treatments.

3.4.2.2.3 Autumn

There was no difference ($P>0.05$) between the pasture DMI of early and late lactation cows offered the different feeding treatments. Only the mid lactation cows offered the MG treatment ate less ($P<0.05$) than the control cows. Mid and late lactation cows offered the control and MG treatments ate less ($P<0.05$) pasture in autumn than in winter.

3.4.2.2.4 Winter

In winter, early lactation cows offered the AP treatment ate 3.2 (±1.07) kg DM/cow/day more ($P<0.05$) pasture than the early lactation cows offered the control treatment, and cows offered the MG treatment ate 2.9 (±1.07) kg DM/cow/day less pasture DM ($P<0.05$) than the early lactation control cows. For mid and late lactation cows, both MG and BR supplements reduced ($P<0.05$) the pasture DMI relative to cows offered the control treatment.

3.4.3 Total feed allowance and feed intake

Within each season, metabolisable energy intake (MEI) of each treatment group offered the restricted pasture allowance was directly related to the total allowance of metabolisable energy (MEA) from both pasture plus supplement (Figure 3.4). Within season, an increase of 1 MJ in MEA was associated with a 0.65 (±0.071) increase in MEI, irrespective of whether the ME was derived from pasture or supplement ($P<0.001$). While season had little effect on the rate of increase in MEI resulting from additional feed being offered, a constant MEA resulted in greater ($P<0.001$) MEI in spring and winter than in summer and autumn (Table 3.7).

3.4.4 Pasture substitution

The effects of stage of lactation, season of the year, and type of supplementary feed on SR in trials 1 and 2 are presented in Table 3.8. No interactions ($P>0.10$) were detected between stage of lactation and feed, season and feed, or stage of lactation and season for SR. Stage of lactation had no effect (>0.10) on SR in trial 1. However in trial 2, the SR of early lactation cows was lower ($P<0.01$) than those of cows in mid and late lactation.

Substitution rate increased as the pasture DMI of the respective control group increased according to the relationship SR = -0.495 (±0.163) + 0.314(±0.065) PDMI (Figure 3.5); where PDMI is the pasture DMI of the respective control group/100 kg of liveweight. Similar relationships were derived for each season and stage of

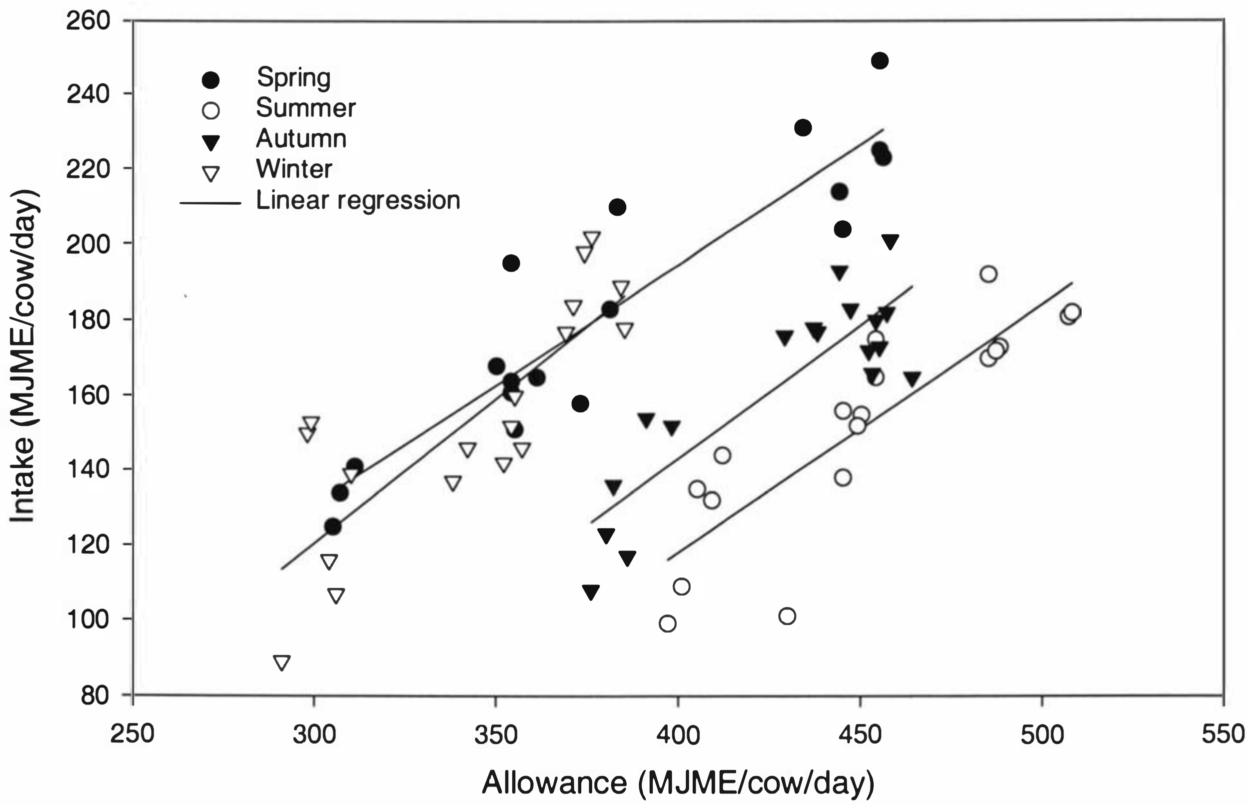


Figure 3.4: Trials 1 and 2: The relationship between the total metabolisable energy allowance (MEA) from pasture plus supplement offered to each experimental group grazing a restricted pasture allowance, and the total metabolisable energy intake (MEI) of that group (regression equations are shown in Table 3.7).

Table 3.7: Trials 1 and 2: The relationship between total allowance of metabolisable energy (MEA; MJME/cow/day) from pasture plus supplement, and total metabolisable energy intake (MEI; MJME/cow/day) in spring, summer, autumn and winter.

Dependent variable	Regression equation	R^2	rsd	P value
Spring MEI	-60 (±25.9) + 0.61(±0.067)MEA	0.85	14.7	<0.001
Summer MEI	-146 (±44.7) + 0.66(±0.089)MEA	0.74	14.9	<0.001
Autumn MEI	-146 (±43.7) + 0.71(±0.102)MEA	0.76	13.5	<0.001
Winter MEI	-112 (±46.4) + 0.78(±0.135)MEA	0.67	18.2	<0.001

Table 3.8: Trials 1 and 2: The average dry matter substitution rate (kg pasture DM/kg supplement DM) resulting from maize grain (MG) and nutritionally balancing (BR) supplements offered to cows at different stages of lactation and seasons of the year.

	Trial 1	**Trial 2**
Stage of Lactation		
Early	0.20	0.13
Mid	0.33	0.49
Late	0.09	0.41
SED	0.108	0.098
P value*	0.11	<0.01
Season		
Spring	0.22	0.37
Summer	0.15	0.34
Autumn	0.33	0.21
Winter	0.12	0.45
SED	0.124	0.113
P value*	0.35	0.24
Supplement		
MG	0.17	0.29
BR	0.24	0.39
SED	0.080	0.080
P value*	0.40	0.22

*No interactions were detected (P>0.10)

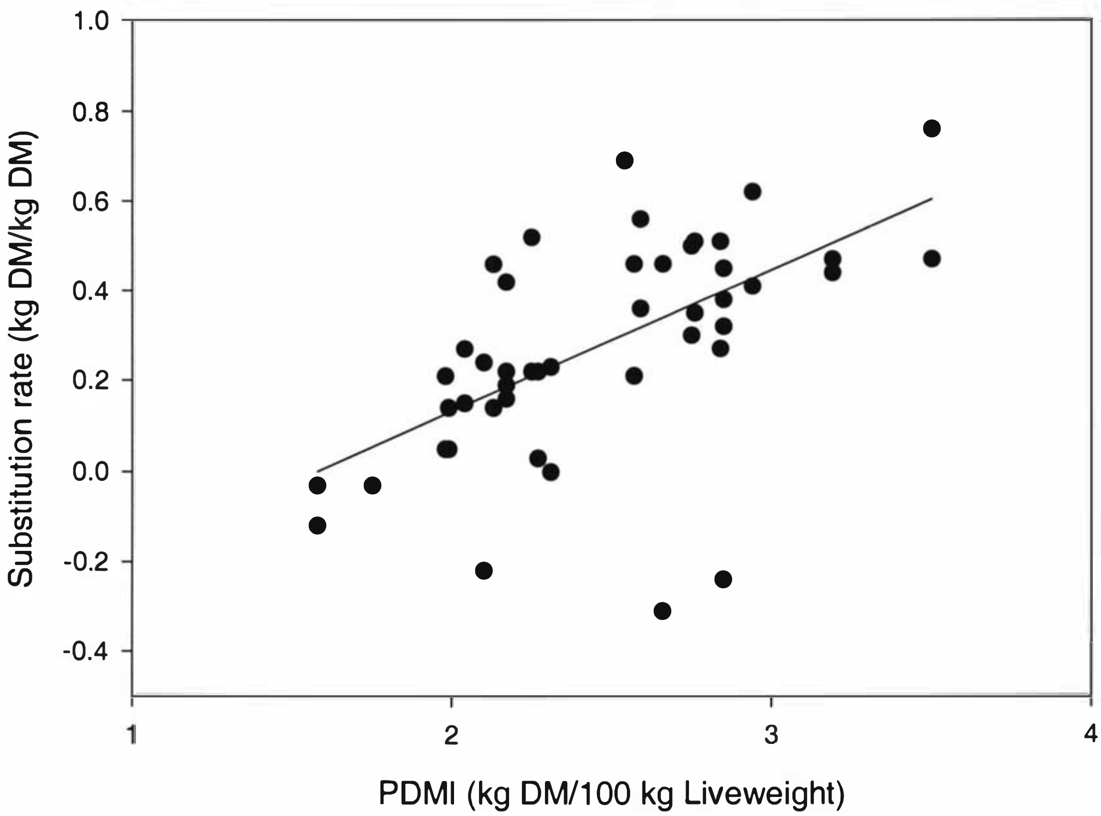


Figure 3.5: Trials 1 and 2: The relationship between the pasture intake by unsupplemented cows (PDMI; kg DM/100 kg of liveweight) and substitution rate (Individual regression equations for each season, and the pooled regression equation, are shown in Table 3.9).

lactation and are shown in Table 3.9. No interactions (P>0.10) were detected between experiment or supplement ME intake and the relationship between SR and PDMI.

Adjusted to the overall mean PDMI of the control groups (2.5 kg/100 kg liveweight), the mean SR of pasture for the supplementary feeds measured during the eight experimental periods of the two trials was 0.27 (±0.072). When adjusted for differences in PDMI between experimental periods, the SR resulting from the MG of 0.23 (±0.05) was slightly lower (P=0.10) than the SR of 0.32 ±0.05 resulting from the BR supplements. After adjustment for differences in PDMI between stages of lactation and season, substitution rates of 0.17, 0.35 and 0.29 (±0.068) were calculated for early, mid and late lactation, respectively, and 0.14, 0.34, 0.29, and 0.32 (±0.088), in the spring, summer, autumn and winter experimental periods, respectively, with the value in spring being lower (<0.05) than that in summer (Table 3.9).

3.5 Discussion

3.5.1 Pasture DMI

3.5.1.1 Pasture allowance

These trials were characterised by the low pasture DMI measured at all stages of lactation and seasons of the year (Figures 1 & 4), because the pasture allowances offered (25 to 37 kg DM/cow/day) were much lower than the 50 kg DM/cow/day required by high genetic merit cows in order to maximise pasture DMI (Wales *et al.*, 1998), with the exception of cows offered the AP treatment during trial 2. Consequently, it is likely that these low pasture allowances suppressed the differences in pasture DMI between the various treatment groups because they did not enable the cows to express their inherent feed demands.

Table 3.9: Trials 1 and 2: The relationship between the unsupplemented pasture dry matter intake per 100 kg/liveweight (PDMI) and substitution rate, and the average substitution rate (SR) adjusted for PDMI of groups in early, mid and late lactation.

	Regression equation	Mean SR♣	R^2	rsd	Prob.
Mean	-0.495 (±0.163) + 0.314(±0.065)PDMI	0.27	33.4	0.21	<0.001
Stage of Lactation					
Early lactation	-0.359 (±0.426) + 0.217(±0.173)PDMI	0.17^{a}	10.0	0.27	NS
Mid lactation	-0.211 (±0.299) + 0.238(±0.114)PDMI	0.35^{b}	23.9	0.17	0.05
Late lactation	-0.564 (±0.139) + 0.349(±0.058)PDMI	0.29^{ab}	71.8	0.13	<0.001
Season of the Year					
Spring	-0.751 (±0.604) + 0.368(±0.210)PDMI	0.14^{a}	23.5	0.29	NS
Summer	-1.344 (±0.440) + 0.722(±0.198)PDMI	0.34^{b}	57.0	0.20	0.005
Autumn	-0.334 (±0.262) + 0.256(±0.108)PDMI	0.29^{ab}	35.9	0.12	0.04
Winter	-0.644 (±0.175) + 0.394(±0.073)PDMI	0.32^{b}	74.5	0.12	0.003
Feed					
MG	-0.368 (±0.281) + 0.244(±0.113)PDMI	0.23	17.5	0.25	0.04
BR	-0.622 (±0.153) + 0.384(±0.061)PDMI	0.32	64.0	0.14	<0.001

♣ Mean SR, adjusted for the common PDMI 2.5 kg DM/100 kg/LW with differing superscript letters are significantly different from each other (P<0.05).

3.5.1.2 Stage of lactation

Stage of lactation had little effect on pasture DMI at these restricted pasture allowances. It is generally accepted that when access to feed is unrestricted, the nutritional requirements for lactation results in DMI increasing rapidly after calving to a peak 8 to 16 weeks post-partum, before steadily declining for the remainder of lactation (Bauman and Currie, 1980). This has been supported by recent studies of pasture-fed cows at different stages of lactation. When cows were offered *ad libitum* access to pasture indoors, Grainger (1990) observed DMI of 14.6 and 11.7 kg DM in early and late lactation, respectively. Likewise, Auldist *et al.* (1998) reported a steady decline in the pasture DMI of grazing cows as lactation progressed, in an experiment which included groups of early, mid and late lactation cows at four times of the year. The trials of Grainger (1990) and Auldist *et al.* (1998) both studied cows offered generous amounts of pasture. By comparison, the small and variable differences in pasture DMI associated with stage of lactation in the present work suggest that the restricted pasture allowance imposed greater relative feed restrictions on the early lactation cows than on the cows in later lactation. Again, this suggests that the feed intakes measured during these trials were predominantly determined by the availability of feed and the characteristics of that feed, rather than by the inherent feed demand of the cows.

3.5.1.3 Season of the year

Larger differences in pasture DMI existed between seasons than between stages of lactation. While there was some variation in pasture allowance offered between seasons (Table 3.3), this did not explain the differences in pasture DMI that were measured between seasons. For example, cows usually had higher pasture DMI in spring than in summer, despite the higher pasture allowances that were offered in summer. These differences between seasons have been reported before, and they probably reflect differences in the composition of the sward that are known to occur between seasons of the year (Stockdale, 1985; Holmes, 1987). At a common pasture allowance, pasture intake is often about 20% lower in summer than in spring (Holmes, 1987). Temperate pastures accumulate dead leaf and stem material at the base of the sward during spring and summer which has a marked effect on the amount of pasture DM located in the stratum below normal grazing height

(L'Huillier and Thomson, 1988), and therefore does not contribute to pasture eaten. These expected differences in pasture structure were the predominant reason for the higher pasture allowances that were deliberately offered during the summer experimental periods of trials 1 and 2.

3.5.2 Total feed intake

The total feed intake of cows in these experiments was highly responsive to supplementary feeding at all stages of lactation, and at all times of the year. Within each season, an increase of 1 MJME in MEA resulted in a linear increase in MEI of 0.65 MJ (Figure 3.5), where increased feed allowance was achieved in both trials mainly by offering the supplementary feeds (in larger amounts in trial 2) to cows offered a relatively low pasture allowance. Large increases in feed intake have been reported previously from similar studies (Chapter 2). Stockdale and Trigg (1985) reported linear increases in DMI resulting from offering increasing amounts of supplement to cows grazing pasture allowances of 15 and 26 kg DM/cow/day, with increases of 0.87 (±0.124) and 0.76 (±0.093) additional MJME eaten/extra MJME offered as concentrate. A slightly lower value (0.48 (±0.040)) can be calculated from a similar trial reported by Robaina *et al.* (1998). Responses to increasing feed allowance by offering supplement are larger than responses to increasing feed allowance by offering more pasture. In contrast to the MEI responses to supplement, increasing pasture allowances, from similar basal pasture allowances, only increased intake by 0.2 to 0.3 MJME/MJME provided from extra pasture (Calculated from Holmes, 1987; Wales *et al.,* 1998; Wales *et al.,* 1999).

The feed intake response to a change in the availability of feed depends on the factors that were limiting feed intake before the change occurred. Oldham and Emmans (1989) suggested that cows try to eat enough feed to satisfy their metabolic demands for the energy and nutrients required, in order to achieve the target levels of production determined by the cows genetic merit and nutritional status. Genetic merit determines the absolute levels of production attainable by the animal (AFRC, 1998), while the current state of the animal, including milk yield and body reserves, is determined by the annual cycle of reproduction and lactation, and by recent nutritional history (Bauman and Currie, 1980). Hence, when offered the same feed conditions, high yielding cows (McGilloway and Mayne, 1996), and cows with low body fat mass (Broster and Broster, 1998), achieve higher feed intakes. As feed supply increases the cows feed intake increases until her demand for energy and nutrients is satisfied, or until the physical or nutritional characteristics of the feed limit her feed intake. Some of the factors known to affect the feed intake of grazing dairy cows include; pasture allowance (Holmes, 1987), presentation of the sward and the mechanics of harvesting pasture (McGilloway and Mayne, 1996), feed digestibility (Minson, 1982) and rumen capacity (Anil *et al.,* 1993), and the rate of volatile fatty acid (VFA) production in the rumen (Forbes, 1995). The plethora of factors influencing DMI are integrated via the central nervous system to determine the end of feeding bouts and to control total daily feed intake (Forbes, 1995). The metabolic and physical efforts required to continue grazing are probably also integrated via the central nervous system, thereby determining the feed intake response of grazing cows to the amount and characteristics of feed made available, relative to the nutrient requirements of the cow (Chapter 2).

In keeping with the model of Oldham and Emmans (1989), as pasture availability increases, grazing dairy cows eat a decreasing proportion of the pasture on offer as their feed demand becomes increasingly satisfied. The resultant curvilinear relationship between pasture allowance and pasture DMI has been well documented (Bryant, 1980; Glassey *et al.,* 1980; Holmes, 1987; Wales *et al.*, 1998). Recent data suggest that when grazed pasture comprises a high proportion of the diet, a similar relationship exists between **total** feed allowance and **total** feed intake when pasture and supplementary feeds are considered together (Chapter 2). Nevertheless, in agreement with Stockdale and Trigg (1985) and Robaina *et al.* (1998), the present data clearly demonstrate that increasing MEA with supplements resulted in a linear increase in MEI, at a higher rate per MJME, than would be expected from the equivalent increases in MEA from pasture.

The large, linear increase in total feed intake resulting from supplementary feeding suggest that the feed intake of the cows offered the restricted pasture only control treatment was limited by the difficulty of ingesting nutrients by grazing, when compared with the relative ease with which the supplements could be consumed. The data suggest that high MEI can be achieved at low pasture allowances by offering large amounts of supplementary feed. While some reduction in pasture utilisation does occur at higher levels of supplement intake, higher levels of pasture utilisation can be achieved at a common MEI by offering restricted amounts of pasture plus supplementary feeds, than by trying to achieve high pasture intakes by offering generous pasture allowances. In early lactation, the generous pasture allowances in trial 2 resulted in these cows eating only 18% of the pasture on offer, compared with more than 30% by the cows offered restricted pasture allowances plus high levels of supplementary feed. Nevertheless, the total DMI of cows offered the generous pasture allowances were consistently lower than that of cows offered the restricted pasture allowance and supplement.

3.5.3 Pasture substitution

3.5.3.1 Unsupplemented pasture DMI

The substitution of pasture by supplements was higher during experimental periods when the allowance and quality of pasture on offer enabled cows to attain higher DMI from pasture alone (Table 3.9). Grainger and Mathews (1989) reviewed recent supplementary feeding studies and suggested that the factor with greatest influence on SR was the unsupplemented pasture intake, and that SR could be predicted using the equation SR=-0.455 + 0.315 PDMI; where PDMI is the unsupplemented pasture DMI/100 kg liveweight. When all experimental periods were analysed together, the relationship between PDMI and SR measured in this trial (SR=-0.5 + 0.314 PDMI; Table 3.9) was similar to that of Grainger and Mathews (1989) and in agreement with other recent studies (Stockdale, 1996; Wales *et al.*, 1999). Based on the average pasture DMI of cows offered to the control treatment (2.5kg/100 kg liveweight), the equation of Grainger and Mathews (1989) predicted a SR of 0.32 compared to the average actual SR of 0.27. However, in the present study, some differences in the relationship between PDMI and SR existed between stages of lactation, seasons of the year, and the two forms of supplement (Table 3.9). Used in this context, PDMI by the unsupplemented cows provides a unifying measure of the ability of the pasture on offer to meet the nutritional demand of the cows. If pasture availability, or the physical or chemical characteristics of the pasture on offer, limit the feed intake of the grazing cow relative to her feed requirements, total feed intake is likely to be highly responsive to additional supplementary feed inputs, giving rise to low SR.

Substitution can be considered as the inverse of the relationship between total feed allowance and feed intake, rather than being an independent nutritional phenomena (Opatpatanakit *et al.,* 1993; Kellaway and Porta, 1993). When supplementary feed is offered, the increase in total DMI is usually less than the amount of supplement offered. Supplementary feeds are generally eaten in preference to pasture, probably because the supplement can be ingested more rapidly and easily than pasture. The decrease in the proportion of the available pasture that is eaten is seen as a reduction in pasture DMI. Several researchers have demonstrated increases in SR as pasture allowance or the amount of supplementary feed offered is increased (Meijs and Hoekstra, 1984; Stakelum, 1986a; Stakelum, 1986b; Stakelum, 1986c; Grainger and Mathews, 1989; Stockdale, 1996; Robaina *et al*., 1998; Wales *et al.,* 1999). Increasing SR at higher feed allowances reflects the curvilinear relationship that exists between pasture allowance and intake for groups of cows, and that probably also exists between total MEA and total MEI for any feed.

3.5.3.2 Stage of lactation

In trial 2, SR was lower for early lactation cows than for mid and late lactation cows (Table 3.8). Further, after SR was adjusted for differences in PDMI and the two experiments were analysed together, SR was smaller in early lactation than in mid and late lactation (Table 3.9). At a common feed allowance, cows with higher milk yield, and therefore larger metabolic demand, generally consume a higher proportion of the feed on offer than lower producing cows (McGilloway and Mayne, 1996). Faverdin *et al.* (1991) was able to demonstrate lower SR by cows with greater potential to increase milk yield than by cows with lower yield potential. In the present study, the relative energy deficit ($MEI_{target} - MEI_{actual}$) was larger for cows in early lactation, with higher milk yields, than for late lactation cows because of the constant feed allowance offered to cows at different stages of lactation. Therefore the higher demand, and larger relative feed deficit of cows in early lactation resulted in lower SR.

3.5.3.3 Season of the year

Although there was no direct relationship between season of the year and SR (Table 3.8), lower SRs were associated with periods of lower PDMI (Figure 3.5). Further, when SR was adjusted for the higher pasture DMI of the control groups, the SR was smaller in spring than during other times of the year, because of higher pasture DMI achieved by the control cows at that time (Table 3.9).

The regression equations comparing PDMI and SR suggest that in summer, SR increased at a faster rate with increasing PDMI than at other times of the year (Table 3.9), although there was no difference between the average SR observed in summer, autumn or winter. In the summer experimental periods of both trials the early lactation cows offered the control treatment ate less pasture than mid lactation cows and little substitution of pasture for supplement occurred among early lactation cows. In the summer experimental period of trial 2, mid and late lactation cows offered the control treatment had higher pasture DMI than the early lactation cows offered the control treatment. At the same time, offering mid and late lactation cows MG and BR supplements resulted in larger SR. A possible explanation for these results is that the cows had more difficulty ingesting nutrients from summer pasture than from pasture at other times of the year, as reported by Stockdale (1985). Greater difficulty of ingesting nutrients from grazed pasture may have resulted in some cows stopping grazing after attaining lower DMI from summer pasture than at other times of the year.

A similar result has been demonstrated when very early lactation cows continuously grazed on 4, 6, or 8 cm pastures, and substituted pasture for supplement at 0.9, 0.5, and 0.1, respectively, when offered 3.4 kg DM/cow/day of concentrate (Rook *et al.,* 1994a). Offering supplements had a larger effect on the pasture DMI of cows grazing less accessible swards, even though the cows on the less accessible swards ate less pasture than those on the accessible swards. When grazing the 4cm pastures the supplemented cows reduced pasture DMI from 13.9 to 12.2 kg/cow/day by reducing grazing time from 765 to 553 minutes. By comparison, cows grazing 8 cm pasture only reduced pasture DMI from 16.8 to 16.5 kg/cow/day and grazing time from 636 to 606 minutes (Rook *et al.,* 1994b). The cows grazing on less accessible pasture appeared to stop grazing more readily when supplements were offered, resulting in higher SR of supplement for pasture, even though their total intake was relatively low.

In contrast, Stockdale (1996) and Wales *et al.* (1999) have both recently reported that SR of mid or late lactation dairy cows are increased as pasture mass increased at a constant pasture allowance. Interestingly, Rook *et al.* (1994b) also reported that by mid lactation, there was no difference in the SR of cows grazing 6 and 8 cm pastures, and the 4 cm treatment had been discontinued because of extreme weight loss among those cows. The study of Stockdale (1996) was conducted using white clover pastures, which are generally of very high quality, and are usually associated with higher DMI than pastures based on grass species (Harris *et al.*, 1997). Despite a high pasture allowance of 39 kg DM/cow/day, offering 4.4 kg DM/cow/day as maize silage resulted in a low SR of only 0.40. Wales *et al.* (1999) clearly demonstrated increasing pasture SR as both the allowance and mass of low quality irrigated summer pasture increased. The conflicting responses reported in these studies have probably arisen because different factors limited the feed intake of cows offered the pasture only treatments in the different experiments.

3.5.3.4 Type of supplement

In both trials, cows offered the BR supplement ate less pasture, and had higher SR than cows offered the MG supplement. These differences in the pasture DMI resulting from the two treatments were largest in spring. The predominant difference in composition between the two supplements during the spring experimental periods was the large amounts of relatively low quality forage that was included in the BR to provide eNDF. The differences in pasture DMI between the MG and BR groups in the spring experimental periods was 1.7 and 1.8 kg/cow/day in trials 1 and 2 which are similar to the amounts of forage included in the BR (1.5 and 2.0 kg DM/cow/day, respectively; Table 3.3). It is possible that some of the difference is due to experimental error caused by the refusals in the spring experimental periods which contained a disproportionately large amount of barley straw in trial 1, and chopped hay in trial 2. These feeds provided a high proportion of the alkane in the BR supplement, and therefore the pasture DMI of the BR groups may have been underestimated by the alkane technique. However, if all the alkane provided by the straw and hay was excluded from the DMI calculations, pasture DMI would increase by only 0.5 and 0.3 kg DM/cow/day, respectively. This would reduce the SR from 0.47 to 0.38, compared to only 0.13 from the MG in spring.

The BR treatments were designed to improve the nutritional characteristics of the whole diet and to optimise rumen digestion. Some authors have suggested that fibre based concentrates caused lower SR than cereal grain supplements (Kellaway and Porta, 1993). However, other evidence suggests that the differences in SR between concentrates based on starch or fibre are proportional to the ME concentration of the supplement (Meijs, 1986; Fisher *at al.*, 1996). Alternatively, if the BR treatment did succeed in improving rumen efficiency, the whole diet may have yielded more ME and digestible nutrients than did the diet of cows offered the MG treatment. Thus, the energy and nutrient demand of cows offered the BR treatment may have been relatively more satisfied at lower pasture DMI.

3.6 Conclusions

The objective of these studies was to determine the effect of stage of lactation and season of the year on the DMI response of grazing dairy cows to supplementary feeds. Increasing total feed allowance, by offering large amounts of high quality supplementary feed, resulted in large, linear increases in total feed intake. These increases in feed intake were larger, and SR smaller in early lactation, when the feed requirements of the cows were higher than in later lactation. The data also suggest that at higher pasture intakes, SR may be lower on high quality pastures than on low quality pastures.

However, the data clearly demonstrate that the magnitude of feed deficit has a larger effect on the DMI response of cows to supplements than either stage of lactation or season. Supplementary feeds are likely to have the greatest effect on total DMI of grazing cows during periods of most severe relative feed deficit (MEI_{target} – MEI_{actual}). The relative feed deficit is increased when cows have higher feed demand, as determined by genetic merit, stage of lactation and nutritional history, or when the amount of feed on offer is reduced. The pasture DMI that can be achieved in the absence of supplements provides an indirect estimate of relative energy deficit. During periods when the amount or quality of pasture on offer is sufficient to allow high pasture DMI by unsupplemented cows, the total feed intake response to supplements will be small. Substitution of supplements for pasture is simply the inverse of these relationships, and these data support evidence that there is a strong relationship between the unsupplemented pasture DMI and the substitution of pasture for supplements.

3.7 References

AFRC 1993. *Energy and Protein Requirements of Ruminants.* CAB International, Wallingford.

Anil, M. H., Mbanya, J. N., Symonds, H. W. and Forbes, J. M. 1993. Responses in the voluntary intake of hay or silage by lactating cows to intra ruminal infusions of sodium acetate, sodium propionate or rumen distension. *British Journal of Nutrition* **69:** 699-712.

Auldist, M. J., Walsh, B. J. and Thomson, N. A. 1998. Seasonal and lactational influences on bovine milk composition in New Zealand. *Journal of Dairy Research* **65:** 401–411.

Bauman, D. E. and Currie, W. B. 1980. Partitioning of nutrients during pregnancy and lactation. A review of mechanisms involving homeostasis and homeorhesis. *Journal of Dairy Science* **63:** 1514-1529.

Bines, J. A. 1985. Feeding systems and food intake by housed dairy cows. *Proceedings of the Nutrition Society* **44:** 355-362.

Broster, W.H. and Broster, V.J. 1998. Review Article: Body score of dairy cattle. *Journal of Dairy Research* **65:** 155-173.

Bryant, A. M. 1980. Effect of herbage allowance on dairy cow performance. *Proceedings of the New Zealand Society of Animal Production* **40:** 50-58.

Chesterton, R. N., and R. M. Marchant. 1985. Early induction of dairy cows. *Proceedings of the 2nd seminar of the Dairy Cattle Veterinarians' Society of the New Zealand Veterinary Association* **2:**52.

Corson, D. C., Waghorn, G. C., Ulyatt, M. J. and Lee, J. 1999. NIRS: Forage analysis and livestock feeding. *Proceedings of the New Zealand Grasslands Association* **61:**127-132.

Dove, H. and Mayes, R. W. 1991. The use of plant wax alkanes as marker substances in studies of the nutrition of herbivores: a review. *Australian Journal of Agricultural Research* **42:** 913-952.

Faverdin, P. Dulphy, J. P., Coulon, J. B., Verte, R., Garel, J. P., Rouel, J. and Marquis, B. 1991. Substitution of roughage by concentrates for dairy cows. *Livestock Production Science* **27:** 137-156.

Fisher, G. E. J., Dowdeswell, A. M. and Perrott, G. 1996. The effects of sward characteristics and supplement type on the herbage intake and milk production of summer calving cows. *Grass and Forage Science* **51:** 121-130.

Forbes, J. M. 1995. Voluntary intake: a limiting factor to production in high-yielding dairy cows? In *Breeding and Feeding the High Yielding Dairy Cow.* Eds. T. L. J. Lawrence, F. J. Gordon and A. Carson. Occasional Publication No. 19 of the British Society of Animal Science.

Fox, D. G., Sniffen, C. J., O'Connor, J. D., Russell, B. J. and Van Soest, P J. 1992. A Net Carbohydrate and Protein System for evaluating cattle diets. *Journal of Animal Science* **70:** 3578-3596.

Genstat Committee. 1997. Genstat for Windows Command Language Manual, Third Edition.

Glassey, C. B., Davey, A. W. F. and Holmes, C. W. 1980. The effects of herbage allowance on the dry matter intake and milk production of dairy cows. *Proceedings of the New Zealand Society of Animal Production* **40:** 59-63.

Grainger, C. 1990. Effect of stage of lactation and feeding level on milk yield response by stall-fed dairy cows to change in pasture intake. *Australian Journal of Experimental Agriculture* **30:** 495-501.

Grainger, C. and Mathews, G. L. 1989. Positive relationship between substitution rate and pasture allowance for cows receiving concentrates. *Australian Journal of Experimental Agriculture* **29:** 355-360.

Harris, S. L., Clark, D. A., Auldist, M. A., Waugh, C. D. and Laboyrie, P. G. 1997. Optimum white clover content for dairy pasture. *Proceedings of the New Zealand Grasslands Association* **59:** 29-33.

Holmes, C. W. 1987. Pastures for dairy cows. In Livestock Feeding on Pasture. Ed. A. M. Nicol. *New Zealand Society of Animal Production, Occasional Publication* **10:** 133-143.

Kellaway, R. C. and Porta, S. 1993. Feeding concentrates: supplements for dairy cows. E. Hopkins, ed. Agmedia, Melbourne, Australia.

Kolver, E. S., Muller, L. D., Barry, M. C. and Penno, J. W. 1998. Evaluation and application of the Cornell Net Carbohydrate and Protein System for dairy cows fed diets based on pasture. *Journal of Dairy Science* **81:** 2029-2039.

Leaver, J. D. 1985. Milk production from grazed temperate grassland. *Journal of Dairy Science* **52**: 313-344.

L'Huillier, P. J. L. and Thomson, N. A. 1988. Estimation of herbage mass in ryegrass/white clover dairy pastures. *Proceedings of the New Zealand Grasslands Association* **49:** 117-122.

McGilloway, D. A. and Mayne, C. S. 1996. The importance of grass availability for the high genetic merit dairy cow. In *Recent advances in animal nutrition* (ed. P.C. Garnsworthy, J. Wiseman and W. Haresign), pp. 135-169. Nottingham University Press.

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

Meijs, J. A. C. and Hoekstra, J. A. 1984. Concentrate supplementation of grazing dairy cows. I. Effect of concentrate intake and herbage allowance on herbage intake. *Grass and Forage Science* **39:** 59-66.

Meijs, J. A. C. 1986. Concentrate supplementation of grazing dairy cows. 2. Effect of concentrate composition on herbage intake and milk production. *Grass and Forage Science* **41:** 229-235.

Minson, D. J. 1982. Effects of chemical and physical composition of herbage eaten upon intake. In *Nutritional Limits to Animal Production from Pastures.* (Ed. J.B. Haker), pp. 167-182. Commonwealth Agricultural Bureaux, Farnham Royal, UK.

National Research Council. 1989. *Ruminant Requirements of Dairy Cattle, 6th edition*. US National Academy of Science, Washington, D.C.

Oldham, J. D. and Emmans, G. C. 1989. Prediction of responses to required nutrients in dairy cows. *Journal of Dairy Science* **72:** 3212-3229.

Opatpatanakit, Y., Kellaway, R. C. and Lean, I. J. 1993. Substitution effects of feeding rolled barley grain to grazing dairy cows. *Animal feed Science and Technology* **42:** 25-38.

Robaina, A. C, Grainger, C., Moate, P., Taylor, J. and Stewart, J. 1998. Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* **38:** 541-549.

Rook, A. J., Huckle, C. A. and Wilkins, R. J. 1994a. The effects of sward height and concentrate supplementation on the performance of spring calving dairy cows grazing perennial ryegrass-white clover swards. *Animal Production* **58:** 167-172.

Rook, A. J., Huckle, C. A. and Penning, P. D. 1994b. The effects of sward height and concentrate supplementation on the ingestive behaviour of spring calving dairy cows grazing perennial ryegrass-white clover swards. *Applied Animal Behaviour Science* **40:** 101-112.

Stakelum, G. 1986a. Herbage intake of grazing dairy cows. 1. Effect of autumn supplementation with concentrates and herbage allowance on herbage intake. *Irish Journal of Agricultural Research* **25:** 31-40.

Stakelum, G. 1986b. Herbage intake of grazing dairy cows. 2. Effect of herbage allowance, herbage mass and concentrate feeding on the intake of cows grazing primary spring grass. *Irish Journal of Agricultural Research* **25:** 41-51.

Stakelum, G. 1986c. Herbage intake of grazing dairy cows. 3. Effect of herbage mass, herbage allowance and concentrate feeding on the herbage intake of dairy cows grazing on mid-summer pasture. *Irish Journal of Agricultural Research* **25:** 179-189.

Stockdale, C. R. 1985. Influence of some sward characteristics on the consumption of irrigated pastured grazed by lactating dairy cows. *Grass and Forage Science* **40:** 927-940.

Stockdale, C. R. 1996. Substitution and production responses when lactating dairy cows graze a white clover pasture supplemented with maize silage. Australian *Journal of Experimental Agriculture* **36:** 771-776.

Stockdale, C. R. and Trigg, T. E. 1985. Effect of pasture allowance and level of concentrate feeding on the productivity of dairy cows in late lactation. *Australian Journal of Experimental Agriculture* **25:** 739-744.

Wales, W. J., Doyle, P. T. and Dellow, D. W. 1998. Dry matter intake and nutrient selection by lactating dairy cows grazing irrigated pastures at different pasture allowances in summer and autumn. *Australian Journal of Experimental Agriculture* **38:** 451-460.

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

van de Haar, M. H. Bucholtz, R. Beverly, R. Emery, M. Allen, C. Sniffen, and C. Black. 1992. Users manual for Spartan dairy ration evaluator/balancer. Version 2. Michigan State University Cooperative Extension Service.

Velleman, P. F. 1997. Data Desk, Version 6. Data Description, Ithaca, NY.

CHAPTER FOUR

SUPPLEMENTARY FEEDING RESPONSES BY COWS IN EARLY, MID AND LATE LACTATION GRAZING LOW PASTURE ALLOWANCES IN SPRING, SUMMER, AUTUMN AND WINTER
2. MILK YIELD AND LIVEWEIGHT CHANGE, AND SOME BLOOD AND RUMEN METABOLITES

CHAPTER 4: SUPPLEMENTARY FEEDING RESPONSES BY COWS IN EARLY, MID AND LATE LACTATION GRAZING LOW PASTURE ALLOWANCES IN SPRING, SUMMER, AUTUMN AND WINTER

2. MILK YIELD AND LIVEWEIGHT CHANGE, AND SOME BLOOD AND RUMEN METABOLITES

4.1 Abstract

Many experiments have measured the responses of grazing dairy cows to various forms of supplementary feed, but few have studied the reasons for the large differences in responses between experiments. Two trials, each using early, mid and late lactation cows in four experimental periods (spring, summer, autumn and winter), were designed to determine the effects of stage of lactation, and season of the year, on the cows response to supplementary feeding. Two grazing trials (trial 1 in year 1; trial 2 in year 2) were conducted with groups of cows in early, mid and late lactation in spring, summer, autumn and winter, in a partially complete Latin Square arrangement. At each stage of lactation, and in each season of the year, cows were offered either a restricted pasture allowance (25 to 35 kg DM/cow/day), or a restricted pasture allowance plus supplements offered at 50 MJME/cow/day in trial 1 and 80 MJME/cow/day in trial 2. The supplements were either rolled maize grain (MG) or a mixture of feeds formulated to nutritionally balance the diet (BR). In trial 2, a fourth nutritional treatment of a generous pasture allowance (AP) was imposed on an additional group of early lactation cows during each season. Each experimental group included 8 cows. Supplemented cows at each stage of lactation, and during each season of the year were compared to their respective control groups, which received only the restricted pasture allowance.

Cows offered MG supplement had lower ($P<0.05$) daily minimum pH and concentrations of ammonia in rumen fluid, lower ($P<0.05$) serum concentrations of non-esterified fatty acids (NEFA) and urea, than cows offered the pasture only control during most seasons of trials 1 and 2, indicating improved energy nutrition and reduced crude protein (CP) intake. Cows offered the BR supplement also had lower ($P<0.05$) serum concentrations of NEFA and beta hydroxy butyrate (BOH) in all experimental periods of Trial 1. Cows offered the BR treatment had lower ($P<0.05$) serum urea concentrations than cows offered the control treatment in the spring and autumn of trial 1 and in the spring of trial 2, but had higher ($P<0.05$) serum urea concentrations than the control cows in the summer of trial 2.

During Trial 1, there were no interactions ($P>0.10$) between the effects of stage of lactation and those of supplementary feeding on milksolids yield. However, there were significant interactions ($P<0.05$) between the effects of season and those of feed for milksolids yield. Immediate responses to the MG (50 MJME/cow/day) were 169, 279, 195 and 251 (±37.1) g MS/cow/day in spring, summer, autumn and winter, respectively, while those to BR (50 MJME/cow/day) were 107, 250, 192, 289 (±37.1) g MS/cow/day. Early and mid lactation cows which had been offered the MG and BR treatments continued to produce 73 and 100 (±22.7) g MS/cow/day, respectively, more ($P<0.05$) than the control cows during the four week carryover period following the termination of supplementary feeding.

During trial 2 there were significant interactions ($P<0.05$) between the effects of stage of lactation and those of feed, and between the effects of season and those of feed ($P<0.01$) for milksolids yield. Responses from MG and BR (80 MJME/cow/day) ranged from –13 to 322, and –60 to 255 (±93.6) g MS/cow/day, respectively. There were also significant interactions ($P<0.01$) between the effects of season and those of feed on milksolids yield during the carryover period of trial 2. During spring neither of the supplements had a subsequent effect ($P>0.05$) on the milksolids yields of cows measured during the four week carryover period after supplementary feeding. In summer and autumn, cows that had been offered the BR supplement had higher ($P<0.05$) milksolids yield than cows that had been offered the control treatment, but not the MG treatment ($P>0.05$). In the winter of trial 2, cows which had been fed both the MG and BR supplements produced higher ($P<0.05$) milksolids yields during the carryover period.

As in many previous studies, offering supplements to cows grazing restricted allowances of pasture generally increased milksolids yield. Nevertheless, stage of lactation had little effect on the immediate responses in milksolids yield or liveweight change to supplementary feeds. Differences between the types of supplement were small, and generally occurred only in periods of inadequate protein concentration in the diet of cows offered pasture plus MG. There was some variation in responses between seasons, with the smallest responses being observed in the spring of both trials. These differences were closely associated with the level of performance achieved by cows grazing the pasture only control treatments. Milksolids responses to supplementary feeds were largest during seasons of the year when the quantity and quality of pasture on offer resulted in the lowest milksolids yield from the control herd.

4.2 Introduction

Many researchers have measured the milk yield response of grazing dairy cows to various forms of supplementary feed. Leaver *et al.* (1968) reviewed several supplementary feeding trials and concluded that the increase in milk yield was likely to be small and uneconomic when cows were grazing generous amounts of pasture. However, over the last 30 years the use of supplementary feeding has become an important component of pasture-based dairy farming. Yet, both the literature (Chapter 2) and farmer experience suggests that the milk yield response to supplementary feeds is extremely variable. In order for farmers to make sound supplementary feeding decisions the reasons for this variability must be understood.

It is well established that much of the variation in milk yield response to supplementary feeding is caused by variations in the total dry matter intake (DMI) response of grazing cows to supplements (Chapter 3). However, indoor experiments have demonstrated that when supplements do increase total DMI, short-term milk yield responses remain variable (e.g. Stockdale and Trigg, 1989). Not all the additional energy and nutrients consumed are partitioned directly into extra milk production. Rather, the cow uses varying proportions of the additional energy for increased milk yield and increased reserves of body fat and protein. Some the factors affecting energy partitioning are the stage of lactation of the cow (Broster and Thomas, 1981), the current milk yield of the cow relative to her target milk yield (Oldham and Emmans, 1989) and the mixture of nutrients provided by the pasture and supplements relative to the nutrient requirements of the cow (AFRC, 1998).

It has often been assumed that cows in early lactation partition a higher proportion of extra energy and nutrients toward milk production and less toward liveweight gain than cows in late lactation (Broster and Thomas, 1981). For example, Stockdale *et al.* (1987) and Stockdale and Trigg (1989) demonstrated that at several levels of pasture DMI, the immediate milk yield response by stall fed cows to concentrates was greater in early lactation than in late lactation. Even if this is true, in the long-term energy stored as body reserves as a result of supplementary feeding will probably result in increased milk yield at some time after the period of supplementary feeding. While these potential carryover effects have often been discussed, they have seldom been measured in experiments (Kellaway and Porta, 1993). Partitioning of energy between milk yield and body reserves, and subsequent carryover effects, may explain the results of recent farmlet trials that have suggested that the milk yield response to supplementary feeding was small in spring (early lactation) and improved as the season progressed (Penno *et. al.,* 1995a). However, larger responses to supplements from mid and late lactation cows in summer and autumn than from early lactation cows in spring have also been reported recently from short-term grazing experiments (Stockdale, 1999).

It was concluded from the previous chapter that the relative feed deficit of the cow ($MEI_{target} - MEI_{actual}$), had a large effect on the DMI response of grazing cows to supplementary feeds. It was also demonstrated that the specific mixture of nutrients provided by the supplements had little affect on the DMI response to supplementary feeding. However, both the relative feed deficit imposed on the cow, and the specific nutrients provided by the supplement, may affect the animals short and long-term milk yield response to supplementary feeds. Therefore, this chapter reports the effects of stage of lactation and season of the year on the immediate and carryover milk yield and liveweight responses of dairy cows, grazing restricted amounts of pasture, to rolled maize grain or nutritionally balancing supplementary feeds, from the experiments described in chapter 3. To help interpret these responses, data on some blood and rumen metabolites are also reported.

4.3 Materials and methods

4.3.1 Experimental design

Details of the site, cows, experimental design, and feeding treatments have been described in chapter 3. Two supplementary feeding experiments were conducted with cows in early, mid and late lactation at four times of the year. In trial 1 (year 1), cows at each stage of lactation were grazed on a restricted allowance of pasture (approximately 25 – 35 kg DM/cow/day) and offered pasture only or supplementary feeding treatments of 50 MJME/cow as either rolled maize grain, or as a nutrient balancing ration. In trial 2 (year 2) the same supplementary feeding treatments were offered but at 80 MJME/cow/day, and a fourth treatment group of early lactation cows offered a generous pasture allowance (approximately 60 to 75 kg DM/cow/day) was included during each of the four experimental periods. Each experimental period comprised a seven day uniformity period, followed by a 35 day supplementary feeding period. After each supplementary feeding period, cows were grazed together in their stage of lactation group and offered a generous pasture allowance for a further 28 days to allow any carryover effects to be measured. The average days in milk (DIM), yields of milk, milkfat and protein, and liveweight of the early mid and late lactation cows measured during the uniformity weeks of trial 1 and trial 2 are presented in Table 4.1 and Table 4.2, respectively.

Table 4.1: Stage of lactation and mean yield of milk, milkfat, protein and mean liveweight of each group measured during the uniformity week of trial 1, immediately before supplementary feeding treatments were imposed.

Season		**Spring**			**Summer**			**Autumn**			**Winter**		**Sed**
Stage of lactation	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	
Days in milk	61	142	249	74	180	264	74	151	257	53	153	234	6.5
Milk yield (kg/cow/day)	21.5	15.7	12.4	20.8	17.2	14.5	14.8	13.9	12.0	18.0	13.9	12.8	1.00
Milkfat yield (g/cow/day)	854	631	586	854	777	696	775	615	555	762	638	588	41.4
Milk protein yield (g/cow/day)	722	543	461	658	607	549	489	485	411	613	512	486	31.4
Liveweight (kg)	425	412	398	451	487	493	428	435	471	400	411	435	12.9

Table 4.2: Stage of lactation and mean yield of milk, milkfat, protein and mean liveweight of each group measured during the uniformity week of trial 2, immediately before supplementary feeding treatments were imposed.

Season	**Spring**			**Summer**			**Autumn**			**Winter**			**Sed**
Stage of lactation	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	Early	Mid	Late	
Days in milk	21	113	215	33	107	197	81	148	224	73	136	223	12.2
Milk yield (kg/cow/day)	20.7	15.0	14.5	22.0	18.2	14.1	16.1	11.4	9.8	13.6	12.7	9.7	1.05
Milkfat yield (g/cow/day)	856	657	692	1072	849	645	713	513	473	574	546	451	46.2
Milk protein yield (g/cow/day)	667	516	515	743	592	478	486	362	342	452	434	354	34.3
Liveweight (kg)	443	437	430	473	453	483	421	419	441	408	405	418	13.5

4.3.2 Measurements

4.3.2.1 Milk volume and composition, and liveweight

Milk volume and composition of all cows were measured by weekly herd test, using Tru-test™ in-line milk meters to take a representative sub-sample of 2.5% of the total milk yield of each cow. Milk volumes were read from the meter flask and recorded after the milking machine had been removed from each cow. Following stirring by bubbling air through the flask, a 30 ml aliquot was taken and delivered to the DRC Milk Laboratory and analyzed for fat and protein concentrations by calibrated Fossomatic milk-o-scan (Foss Electric, Hillerod, Denmark).

The liveweight of each cow was measured, by calibrated Tru-test™ electronic scales, immediately after the morning milking on day 7 of the uniformity period, on day 35 of the experimental period and on day 28 of the post experimental carryover period.

4.3.2.2 Rumen and blood metabolites

One cow fitted with a rumen cannulae was allocated to each treatment group, such that a cannulated cow in early, mid and late lactation was included in each feeding treatment. Rumen fluid samples were collected at 0, 1, 2, 3, 5, 7, 9, 11, 15, and 21 hours after supplementary feeds were offered on day 31 of each experimental period. On each occasion, about 1 *l* of rumen contents was taken from the mid-ventral area and strained though a muslin cloth to collect 100 ml of rumen fluid. Rumen fluid pH was determined within 15 minutes of collection using a calibrated glass electrode (PW9420, Philips, England), before samples were acidified to pH 2.0 with 50% sulphuric acid and centrifuged at 2800 rpm for 10 minutes. The supernatant was frozen at -18°C and stored until analysis for ammonia nitrogen (N) concentration according to the method of Chaney and Marbach (1962) by Alpha-Scientific, Hamilton.

Blood samples were taken from each cow by tail-vein using 10 ml evacuated plain glass tubes at approximately 1400 hours on day 33 of each experimental period and immediately delivered to Ruakura Animal Health Laboratory for analysis. After being allowed to clot at room temperature for 60 - 90 minutes, samples were centrifuged at 2800 rpm for 15 minutes. Aspirated serum was immediately assayed for concentrations of albumin, beta hydroxy butyrate (BOH), non-esterified fatty acids (NEFA), glucose and urea using a Hitachi 717 auto-analyser.

4.3.3 Statistical analysis

The results from trials 1 and 2 were analysed separately. Trellis graphs of production and liveweight through time, conditioned on stage of lactation, season and feed, were examined (Appendix 1). Residual Maximum Likelihood (REML) procedures of Genstat 5 Release 4.2b (Genstat Committee, 1997) were used for analysis of milk and liveweight variables, with fixed effects being stage of lactation, season, feed and their interactions. In addition, appropriate covariates from the uniformity week and random effects were specified for each particular variable. For milk and milk components over various periods, stage of lactation, season/week, feed and their interactions were specified as fixed effects; the uniformity production at week -2 as a deviation from the stage by season mean was used as a covariate and cow/season/week were specified as random effects. Rumen pH and ammonia concentrations were compared separately at each sample time and standard errors of the difference calculated using Data Desk 6.1 (Velleman, 1997).

Milk yield data presented for the experimental periods are the predicted means, adjusted for imbalance in covariates and the number of observations, of three herd tests measured from days 15 to 35 of each experimental period in trial 1, and from two herd tests from days 22 to 35 of each experimental period in trial 2. Milk yield data presented from the carryover response are the predicted means of four herd tests taken during the 28 days after each experimental period of trials 1 and 2. Predicted means are presented with the maximum standard error of the difference (sed) between comparable means.

4.4 Results

4.4.1 Results of Trial 1

4.4.1.1 Trial 1: Rumen pH and ammonia concentration

The diurnal patterns in the pH of rumen fluid sampled from cows receiving the three feeding treatments in the final week of each experimental period are shown in Figure 4.1. Rumen fluid pH fluctuated between pH 5.8 and 7.2. In spring, rumen pH declined more rapidly after feeding than during other experimental periods, and remained below pH 6.0 for longer ($P<0.05$) than during other seasons. In the spring experimental period, rumen pH of cows offered the MG treatment was lower ($P<0.10$) than that of cows in the other treatments three hours after the supplements had been offered. In winter, the rumen pH of cows offered the MG remained lower ($P<0.05$) than that of cows on the other treatments for most of the day.

Rumen ammonia concentrations peaked 4 to 9 hours after feeding, and were higher in the spring and autumn than during the summer and winter (Figure 4.2). The cows offered the MG treatment had lower ($P<0.05$) rumen ammonia concentrations than cows offered the control treatment for some periods of the day in spring, summer and autumn.

4.4.1.2 Trial 1: Blood metabolites

The main effects of season of the year and feeding treatments on the concentration of blood metabolites, averaged across stage of lactation, are presented in Table 4.3. There were significant interactions between the effects of stage of lactation and those of feed ($P<0.05$) for NEFA, and between the effect of season and those of feed ($P<0.05$) for all serum metabolites, other than albumin. Serum glucose concentrations were higher ($P<0.01$) during winter than during spring, summer and autumn and were lower ($P<0.05$) during spring than during summer and autumn. During winter cows offered the BR supplement had lower serum glucose than cows offered the control treatment. Early lactation cows offered the control treatment during winter had higher ($P<0.05$) serum glucose concentrations than the other

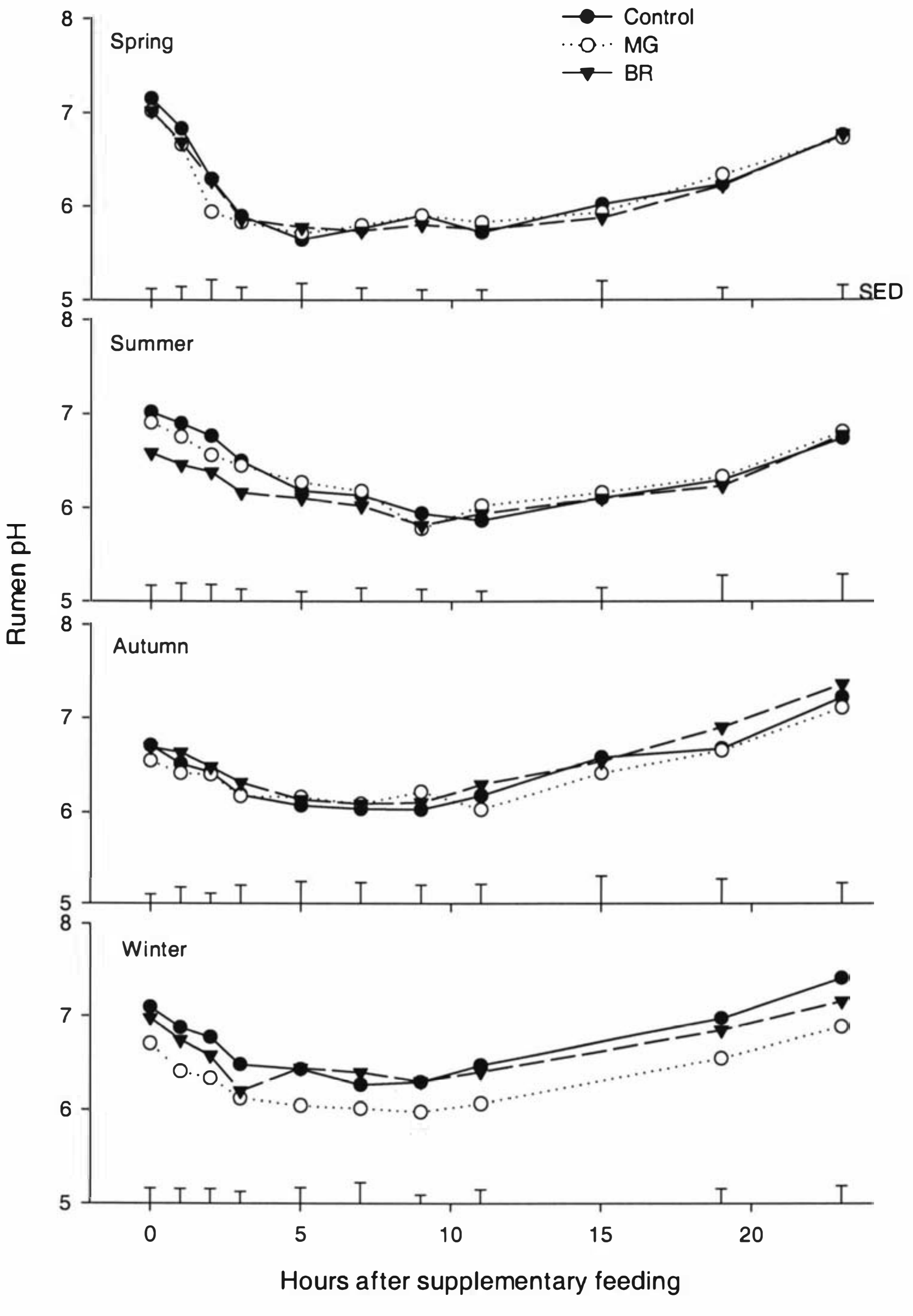


Figure 4.1: Trial 1: Rumen fluid pH of cows receiving nutritional treatments of a restricted pasture allowance (Control), a restricted pasture allowance and 50 MJME/cow/day of rolled maize grain (MG) or a mixture of supplements formulated to balance the diet (BR) during the spring, summer, autumn and winter experimental periods.

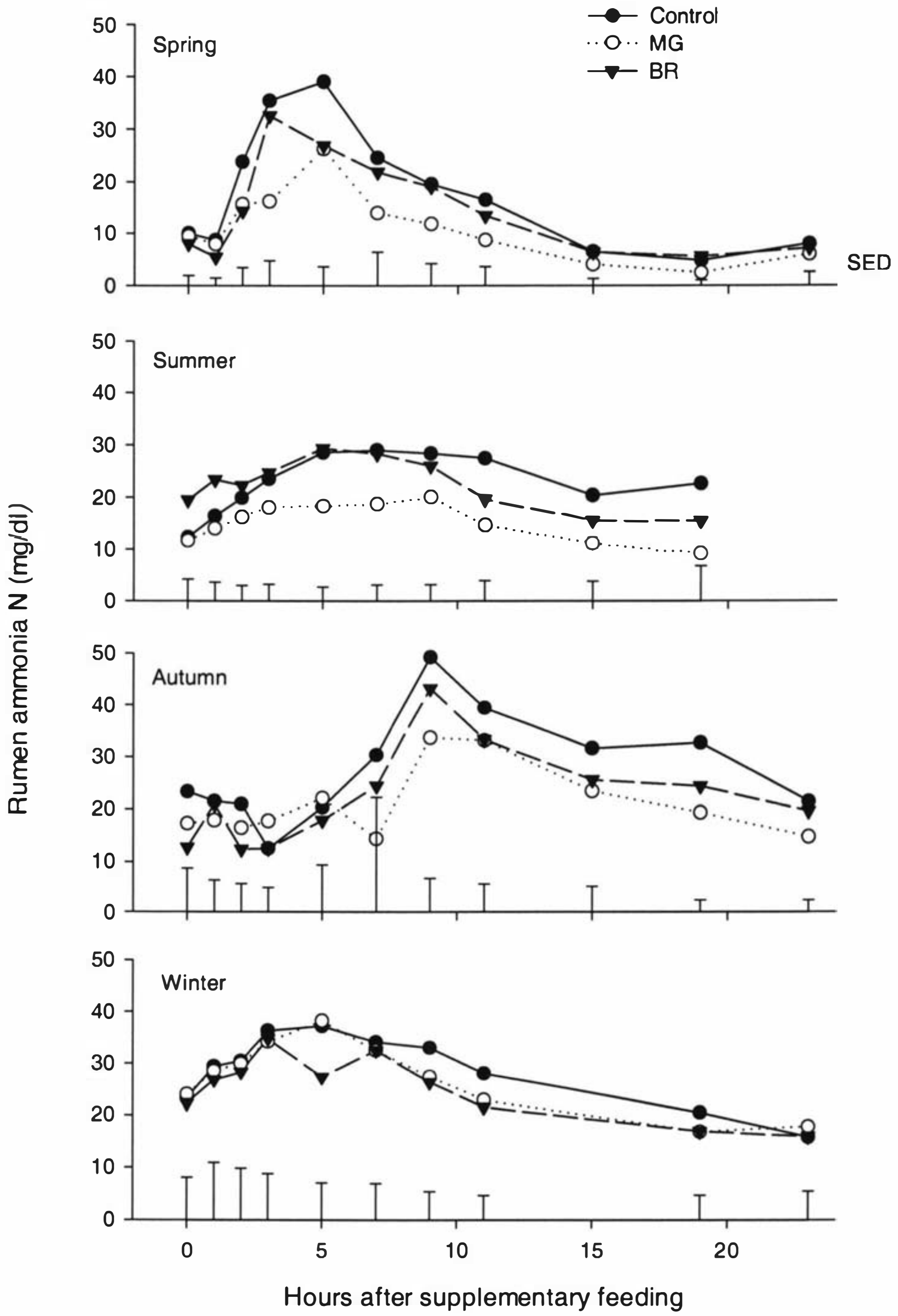


Figure 4.2: Trial 1: Concentration of ammonia nitrogen (N) in rumen fluid of cows receiving nutritional treatments of a restricted pasture allowance (Control), a restricted pasture allowance and 50 MJME/cow/day of rolled maize grain (MG) or a mixture of supplements formulated to balance the diet (BR) during the spring, summer, autumn and winter experimental periods.

Table 4.3: Trial 1: Average concentrations of albumin, beta hydroxy butyrate (BOH), non- esterified fatty acids (NEFA), glucose and urea measured in blood plasma sampled from cows in early, mid and late lactation (n=24), offered a restricted pasture allowance (Control) or a restricted pasture allowance and supplementary feeds of 50 MJME/cow/day as rolled maize grain or a nutritional balancing ration (BR) in spring, summer, autumn and winter.

Experimental period	Feeding treatment	Glucose (mmol/l)	NEFA♣ (mmol/l)	BOH♣ (mmol/l)	Albumin (g/l)	Urea (mmol/l)
Spring	Control	2.67[ab]	0.038[a]	0.99[a]	30.3[ab]	6.07[a]
	MG	2.49[a]	0.034[a]	0.83[b]	30.4[ab]	4.65[b]
	BR	2.52[a]	0.036[a]	0.83[b]	30.6[ab]	4.99[b]
Summer	Control	2.86[b]	0.073[b]	0.91[a]	30.6[ab]	6.08[a]
	MG	2.78[b]	0.051[c]	0.91[a]	30.4[ab]	4.77[b]
	BR	2.79[b]	0.048[c]	0.94[a]	30.4[ab]	6.38[a]
Autumn	Control	2.61[a]	0.057[c]	1.02[a]	30.9[a]	9.87[c]
	MG	2.80[ab]	0.049[c]	0.93[a]	30.3[ab]	7.79[d]
	BR	2.81[ab]	0.049[c]	1.00[a]	30.9[a]	9.32[e]
Winter	Control	3.41[c]	0.083[b]	0.93[a]	30.5[ab]	9.10[e]
	MG	3.28[cd]	0.036[a]	1.03[a]	29.8[b]	7.18[f]
	BR	3.17[d]	0.039[a]	0.92[a]	30.4[ab]	8.21[d]
sed		0.100	1.20♥	1.12♥	0.49	0.23

Means with different superscript letters are significantly different ($P<0.05$).

♣Calculated from natural log transformed data.

♥Minimum significant ratio calculated from natural log transformed standard error of the difference.

groups of cows in winter, and late lactation cows offered MG had lower (P<0.05) serum glucose concentration than the other groups of cows in spring.

Average serum NEFA concentrations were 0.012 to 0.020 mmol/l lower (P<0.01) in the spring than during other experimental periods, and were highest (P<0.05) among early lactation cows and lowest (P<0.05) among mid lactation cows. Cows receiving the supplementary feeding treatments had serum NEFA concentrations that were lower (P<0.05) than for cows receiving the pasture only control feeding treatment in summer and winter. In spring, average serum BOH concentrations were lower (P<0.05) among cows receiving the supplementary feeds than cows in the control treatment groups.

Average serum urea concentrations of cows on the control treatment were higher (P<0.01) than for cows offered the MG supplements in all seasons, and higher (P<0.01) than those of cows offered the BR supplements during spring and autumn. Serum urea concentrations of cows on the control treatment and offered MG supplements were highest (P<0.01) in autumn and lowest (P<0.01) in spring.

4.4.1.3 Trial 1: Milksolids yield measured during the experimental period

Average daily yield of milk and milk constituents of each group measured during the final three weeks of each experimental period of trial 1 are presented in Table 4.4, and milksolids yields are shown in Figure 4.3. There were no significant interactions (P>0.10) between the effects of stage of lactation and those of supplementary feed for milksolids yield. However, there were significant interactions (P<0.05) between the effects of season and those of feed for yields of milk, milkfat, milk protein and milksolids. Offering MG and BR supplements increased (P<0.05) milksolids yield in all seasons (Figure 4.4), with no difference (P>0.05) between MG and BR treatments. The milksolids yield of cows offered the control treatment were higher (P<0.05) in spring than in winter, with summer and autumn being intermediate (P<0.05). Offering MG in spring resulted in higher (P<0.05) milksolids yields than in summer, autumn and winter, whereas the milksolids yield of cows offered BR did not vary with season (P<0.05).

Table 4.4: Trial 1 experimental period: Mean values for yields of milk, milkfat and protein, for concentrations of milkfat and protein, and for the rate of liveweight change measured during each experimental period.

Stage	Early			Mid			Late				Significance♣				
Feed	Control	MG	BR	Control	MG	BR	Control	MG	BR	sed	Season	Stage	Feed	Season x Feed	Stage x Feed
Spring															
Milk yield (kg/cow/day)	17.4	19.9	18.3	13.2	15.7	15.2	11.5	12.8	11.9	0.80	**	**	**	**	NS
Milkfat yield (g/cow/day)	714	820	754	561	658	670	565	596	568	42.2	**	**	**	*	NS
Milk protein yield (g/cow/day)	544	651	609	440	548	524	420	482	440	27.9	**	**	**	**	NS
Milkfat concentration (g/kg)	41.6	42.0	41.1	43.9	42.0	44.2	50.0	47.0	49.0	2.07	**	**	**	*	NS
Milk protein concentration (g/kg)	31.4	32.9	33.6	33.7	35.2	34.8	36.8	37.7	37.4	0.83	**	**	**	NS	**
Liveweight change (g/cow/day)	83	164	495	1221	1533	1195	237	1436	1347	294	**	**	**	**	NS
Summer															
Milk yield (kg/cow/day)	12.3	16.3	15.7	12.4	15.0	15.7	7.2	11.0	10.2						
Milkfat yield (g/cow/day)	522	720	656	573	681	718	393	537	511						
Milk protein yield (g/cow/day)	374	514	495	415	524	538	280	413	386						
Milkfat concentration (g/kg)	44.2	43.8	42.5	46.7	46.1	46.4	55.9	50.9	51.9						
Milk protein concentration (g/kg)	31.1	31.8	31.6	33.9	35.3	34.4	39.1	38.5	38.5						
Liveweight change (g/cow/day)	-929	-710	-1014	-205	46	-336	-163	126	33						
Autumn															
Milk yield (kg/cow/day)	12.4	14.1	13.7	11.7	13.2	13.9	10.0	14.1	13.2						
Milkfat yield (g/cow/day)	594	669	661	579	628	667	495	611	621						
Milk protein yield (g/cow/day)	400	515	486	416	488	503	364	524	490						
Milkfat concentration (g/kg)	48.9	48.2	47.8	49.5	48.2	48.6	51.4	44.3	48.8						
Milk protein concentration (g/kg)	32.5	36.8	35.3	35.7	37.2	36.6	37.7	37.5	37.8						
Liveweight change (g/cow/day)	74	223	311	676	407	319	821	1197	736						
Winter															
Milk yield (kg/cow/day)	10.9	14.3	15.5	9.4	11.9	13.5	8.1	11.9	11.6						
Milkfat yield (g/cow/day)	537	637	684	476	559	622	430	589	542						
Milk protein yield (g/cow/day)	353	494	519	334	446	479	311	464	451						
Milkfat concentration (g/kg)	49.7	44.4	44.4	51.6	47.0	46.9	55.4	51.5	47.5						
Milk protein concentration (g/kg)	32.4	34.6	33.9	35.9	38.0	35.9	39.1	39.8	39.0						
Liveweight change (g/cow/day)	-890	-612	-350	-266	50	548	-498	-350	86						

♣There were no season x stage x feed interactions ($P>0.05$).

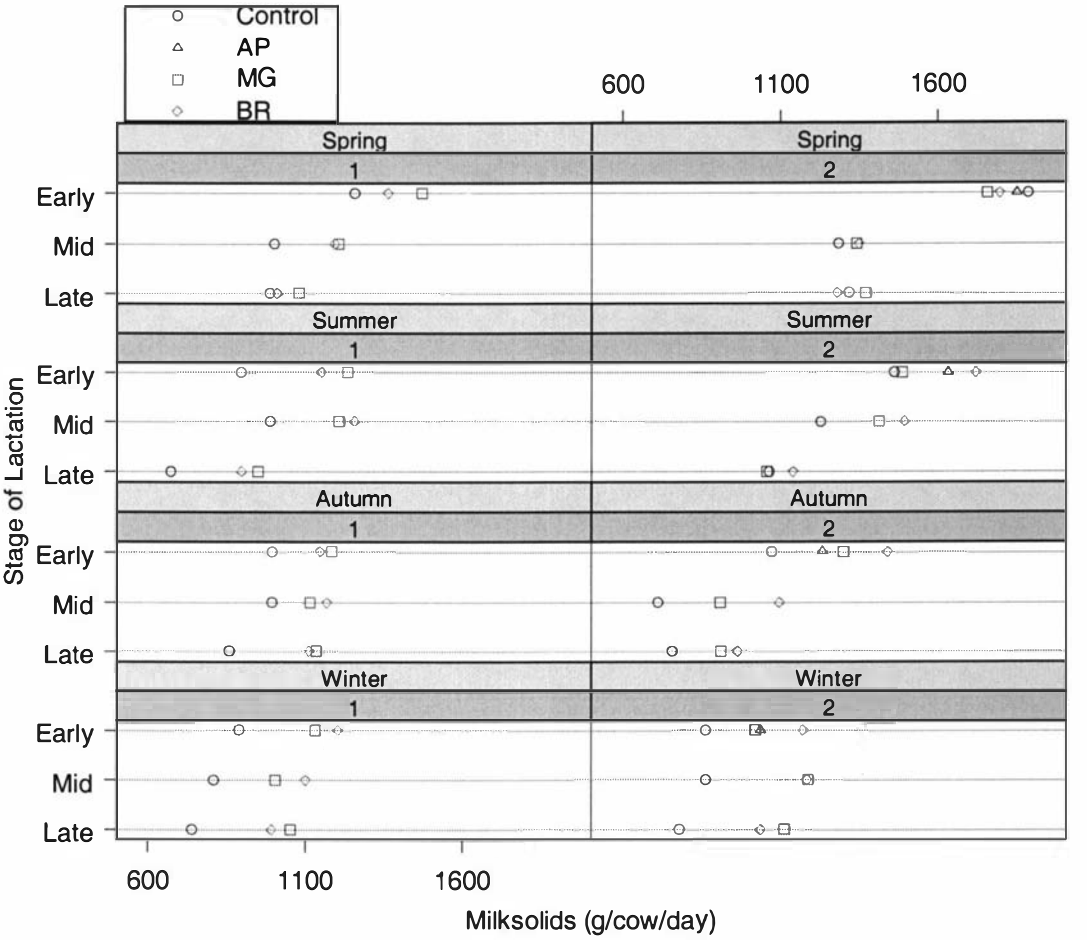


Figure 4.3: Trials 1 and 2, immediate effects: Average milksolids yield of early, mid and late lactation cows offered feeding treatments of a restricted pasture allowance (Control), a generous pasture allowance (AP; trial 2 only), or a restricted pasture allowance and supplements of rolled maize grain (MG) or a nutritional balancing ration (BR) measured during the spring, summer, autumn and winter.

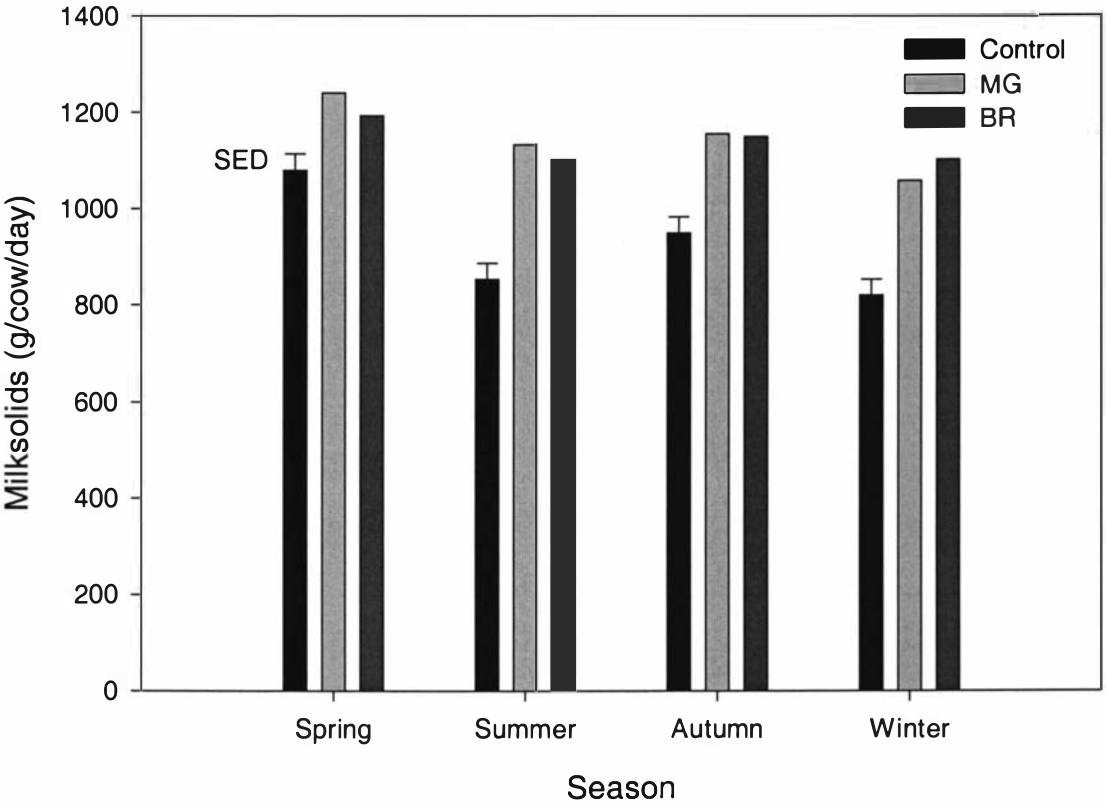


Figure 4.4: Trial 1: Average milksolids yields of cows offered nutritional treatments of a restricted pasture allowance (Control), or the restricted pasture allowance and supplementary feeds of either rolled maize grain (MG) or a nutritional balancing ration (BR) measured during the final three weeks of the spring, summer, autumn and winter experimental periods.

The increase in MS yield of cows offered the MG supplements relative to cows offered the control treatment (response) was 111 and 82 (±37.1) g MS/cow/day larger ($P<0.05$) during the summer and winter experimental periods than during the spring experimental period. In the summer and autumn, the responses of the cows to the BR supplement were143 (±37.1) and 85 (±37.1) g MS/cow/day greater ($P<0.05$) than during the spring experimental period, respectively. During the winter experimental period the response of cows offered the BR supplement was 182 and 97 (±37.1) g MS/cow/day larger ($P<0.05$) than during the spring and autumn experimental periods, respectively.

4.4.1.4 Trial 1: Concentration of milkfat and milk protein

There was no significant interaction ($P>0.10$) between the effects of stage of lactation and those of feeding treatment on milkfat concentration. However, there was an interaction ($P<0.05$) between the effects of season and those of feed for milkfat concentration. Offering MG supplements reduced ($P<0.05$) milkfat concentration relative to the control treatment in autumn, and in winter both MG and BR supplements reduced ($P<0.05$) milkfat concentrations. Milkfat concentration in the milk of cows offered the control treatment was lowest ($P<0.05$) in spring and highest ($P<0.05$) in winter. Cows offered MG had lower ($P<0.05$) milkfat concentrations in spring than during the other seasons, and BR resulted in lower ($P<0.05$) milkfat concentrations in spring than autumn.

There was an interaction ($P<0.01$) between the effects of stage of lactation and type of feed for milk protein concentration. However, the effect of feed on milk protein concentration was not different ($P>0.10$) in the different seasons. In early lactation MG and BR supplements increased protein concentration, whereas in mid lactation only MG increased milk protein concentration. In late lactation there was no difference ($P>0.05$) between the milk protein concentrations resulting from the two forms of supplementary feed.

4.4.1.5 Trial 1: Milksolids yield measured during the carryover period

Average daily yield of milk and milk constituents of early and mid lactation cows measured during the four week carryover period of trial 1 are presented in

Table 4.5, and average milksolids yields are shown in Figure 4.5. No interactions ($P>0.05$) were detected during the carryover period. Early lactation cows that had been offered the MG and BR supplements in early lactation continued to produce 119 and 114 (±32.3) g MS/cow/day, respectively, more ($P<0.05$) than the control cows for the four weeks following supplementary feeding. For early lactation cows, twenty eight days after the MG and BR feeding treatments had ceased, the milksolids yield of cows on these treatments remained 98 and 103 (±41.2) g MS/cow/day, respectively, higher ($P<0.05$) than that of the control cows. Mid lactation cows that had been offered the BR produced 87 (±32.3) g MS/cow/day more ($P<0.05$) than the control cows for the four weeks following the experimental periods, but were not producing significantly more ($P>0.05$) by the fourth week. Cows that had been offered the MG supplements produced 98, 97 and 101 (±47.4) g MS/cow/day more ($P<0.05$) than control cows in the spring, summer, and winter carryover periods, respectively. In the spring and winter carryover period, cows that had been offered the BR supplements produced 150 and 145 (±47.4) g/cow/day more ($P<0.05$) than the control cows throughout the carryover period.

During the carryover period, early and mid lactation cows that had been offered the supplementary feeding treatments produced milk with higher ($P<0.05$) concentration of milkfat and milk protein than cows that had been offered the control treatment (Table 4.5). Supplements of MG and BR increased ($P<0.05$) milkfat concentrations from 48.0g/kg to 49.7 and 50.1 (±0.87), and milk protein concentrations from 33.0 g/kg to 34.2 and 34.6 (±0.43) g/kg, respectively, compared with milk from cows that had been offered the control treatment. However, by the fourth week of the carryover period there were no differences ($P>0.05$) between the milkfat and protein concentrations of milk produced by cows that had been offered the different feeding treatments.

4.4.1.6 Trial 1: Rate of liveweight change

Average liveweight change of each group measured during the experimental periods of trial 1 are presented in Table 4.4, and the average liveweight at the end of each experimental period are shown in Figure 4.6. Stage of lactation did not change

Table 4.5: Trial 1 carryover period: Mean values for yield of milk, milkfat and protein, for concentration of milkfat and protein and for rate of liveweight change of cows in early and mid lactation during each carryover period, when all cows were offered a generous pasture allowance and no supplements.

Stage	**Early**			**Mid**				**Significance**[♣]				
Preceding Feed treatment	Control	MG	BR	Control	MG	BR	Sed	Season	Stage	Feed	Season x Feed	Stage x Feed
Spring												
Milk yield (kg/cow/day)	17.1	17.5	17.4	14.0	14.2	15.1	0.76	**	**	*	NS	NS
Milkfat yield (g/cow/day)	791	897	859	665	719	797	47.2	**	**	**	NS	NS
Milk protein yield (g/cow/day)	569	597	627	509	519	551	26.0	**	**	**	NS	NS
Milkfat concentration (g/kg)	47.2	52.3	49.4	48.9	51.4	53.5	2.78	**	**	*	NS	NS
Milk protein concentration (g/kg)	33.6	34.4	36.2	36.7	36.9	36.8	0.92	**	**	NS	*	NS
Liveweight change (g/cow/day)	732	465	448	1132	1012	749	244.9	NS	**	NS	*	NS
Summer												
Milk yield (kg/cow/day)	12.4	13.7	13.1	10.4	11.3	10.9						
Milkfat yield (g/cow/day)	561	657	603	504	536	545						
Milk protein yield (g/cow/day)	398	437	428	352	378	358						
Milkfat concentration (g/kg)	46.3	47.9	46.8	49.8	48.6	50.6						
Milk protein concentration (g/kg)	32.9	32.3	32.8	34.9	33.8	33.4						
Liveweight change (g/cow/day)	-96	-399	53	-6	-161	-4						
Autumn												
Milk yield (kg/cow/day)	11.8	12.0	11.5	9.6	9.1	9.7						
Milkfat yield (g/cow/day)	550	590	577	509	445	535						
Milk protein yield (g/cow/day)	377	421	399	341	316	347						
Milkfat concentration (g/kg)	47.2	49.6	50.3	53.3	51.9	57.0						
Milk protein concentration (g/kg)	32.0	35.1	34.6	35.9	35.3	36.1						
Liveweight change (g/cow/day)	98	351	49	-198	-89	-373						
Winter												
Milk yield (kg/cow/day)	13.3	13.7	15.1	12.1	13.0	13.7						
Milkfat yield (g/cow/day)	556	633	665	589	638	646						
Milk protein yield (g/cow/day)	446	479	516	444	478	486						
Milkfat concentration (g/kg)	41.6	46.5	44.9	49.5	49.1	48.1						
Milk protein concentration (g/kg)	33.5	34.9	34.7	36.8	37.3	35.7						
Liveweight change (g/cow/day)	1783	1796	1555	1501	1562	1064						

[♣]There were no season x stage x feed interactions (P>0.50).

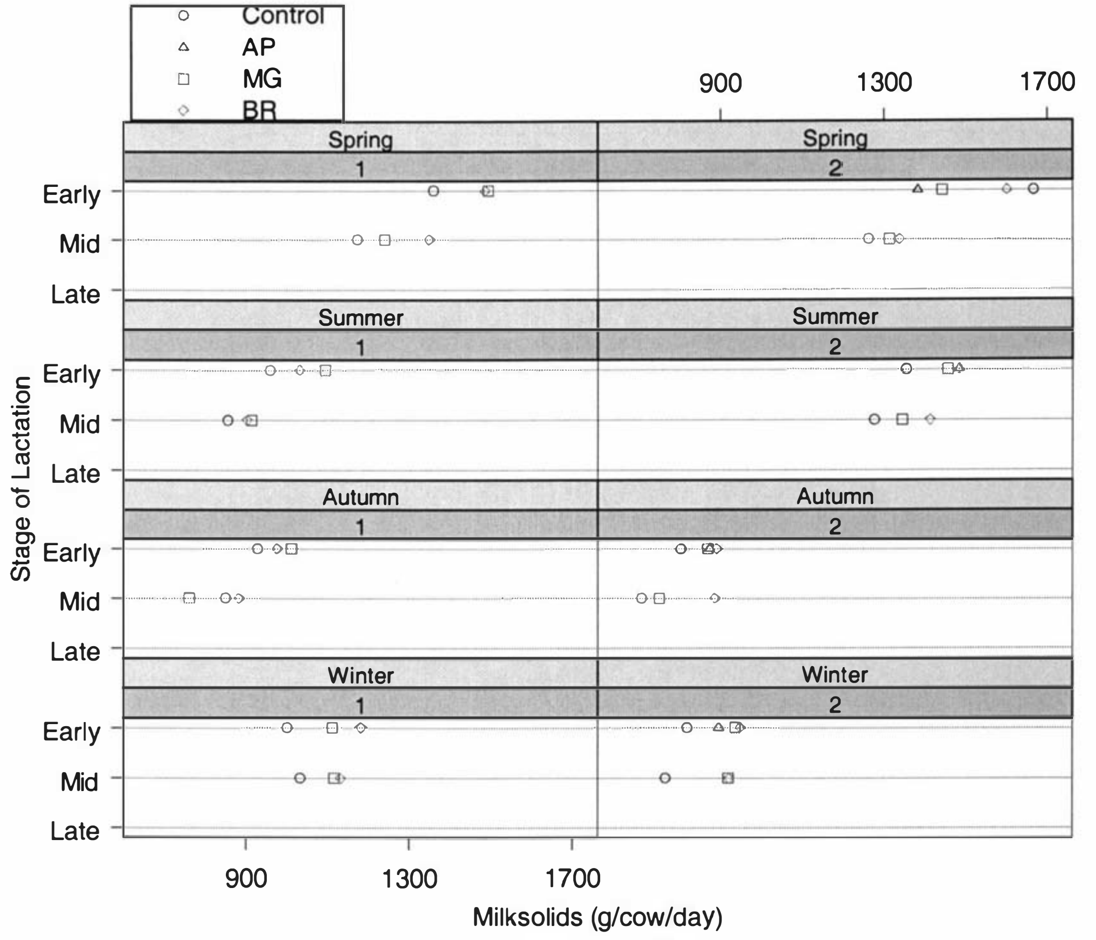


Figure 4.5: Trials 1 and 2, carryover effects: Average milksolids yield of early and mid lactation cows offered feeding treatment of a restricted pasture allowance (Control), a generous pasture allowance (AP; trial 2 only), or a restricted pasture allowance and supplements of rolled maize grain (MG) or a nutritional balancing ration (BR) measured during the spring, summer, autumn and winter carryover periods (milksolids yield of late lactation groups were not measured during the carry over periods).

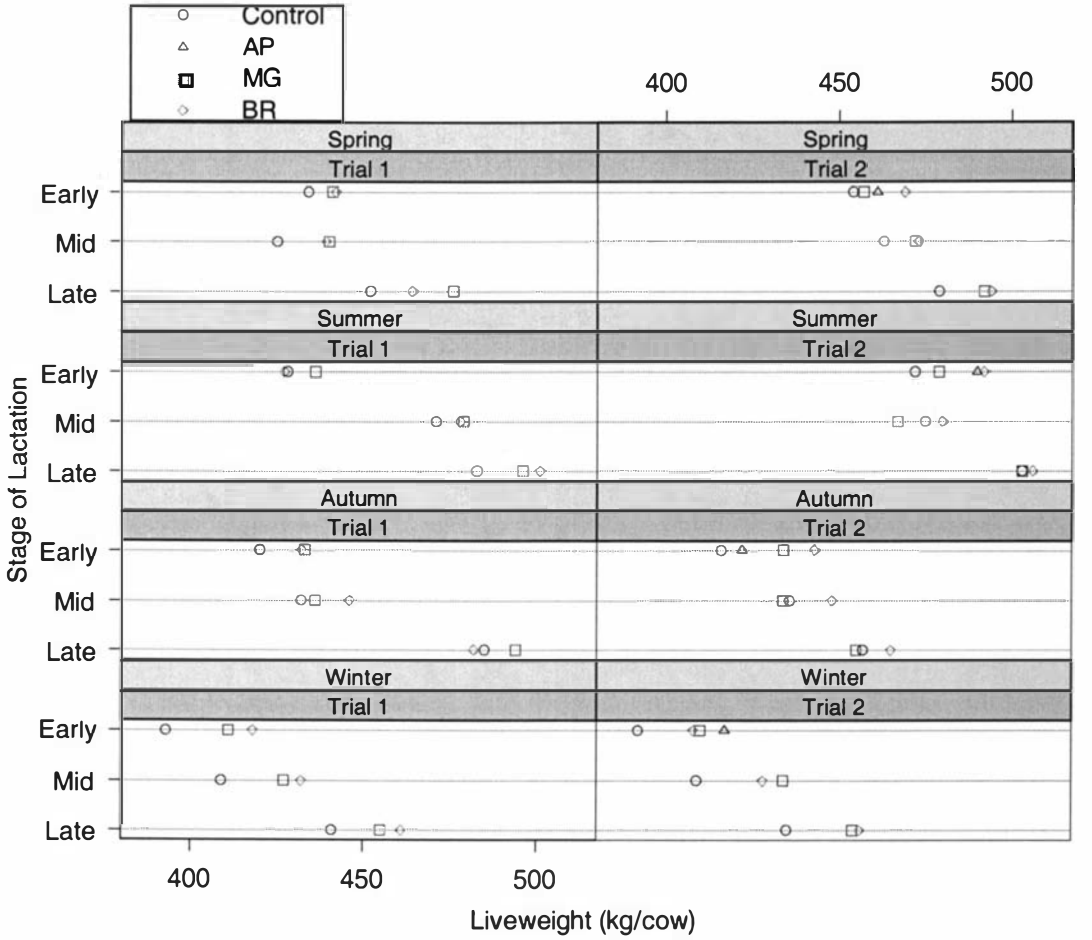


Figure 4.6: Trials 1 and 2: Average liveweight of early, mid and late lactation cows offered feeding treatments of a restricted pasture allowance (Control), a generous pasture allowance (AP; trial 2 only), or a restricted pasture allowance and supplements of rolled maize grain (MG) or a nutritional balancing ration (BR) measured at the conclusion of the spring, summer, autumn and winter experimental periods.

(P>0.10) the effect of feed on the rate of liveweight change during trial 1. However, there was a significant interaction (P<0.01) between season and feed for liveweight gain. Cows offered the control treatment gained less (P<0.05) weight in spring than the MG and BR cows and in winter lost more (P<0.05) than the MG cows, while BR cows actually gained weight (P<0.05). Control and MG cows gained weight in spring and autumn and lost weight in summer and winter, whereas cows offered the BR treatment only lost weight in summer (Figure 4.7).

4.4.2 Results of Trial 2

4.4.2.1 Trial 2: Rumen pH and ammonia concentration

The diurnal patterns in rumen pH measured during the final week of each experimental period of trial 2 are shown in Figure 4.8. Rumen pH fluctuated between 7.4 and 5.5, with a similar pattern to that observed in trial 1. In the spring, summer and autumn experimental periods, cows offered the MG supplements had lower (P<0.05) rumen pH than cows offered the control treatment 2 to 3 hours after feeding. Five hours after being offered fresh pasture, the early lactation cows offered the AP diet had higher (P<0.05) rumen pH than the early lactation cows offered the control treatment, a difference which persisted for the rest of the day.

Ammonia concentration in rumen fluid is shown in Figure 4.9. Ammonia concentration peaked 4 to 7 hours after feeding. During the spring, autumn and winter experimental periods, rumen ammonia concentrations of cows offered the control treatment were higher (P<0.05) than those of cows offered the MG treatment for much of the day. The difference between ammonia concentrations of the control and MG cows were largest in autumn, and in the summer experimental period the different feeding treatments resulted in few differences in rumen ammonia concentrations.

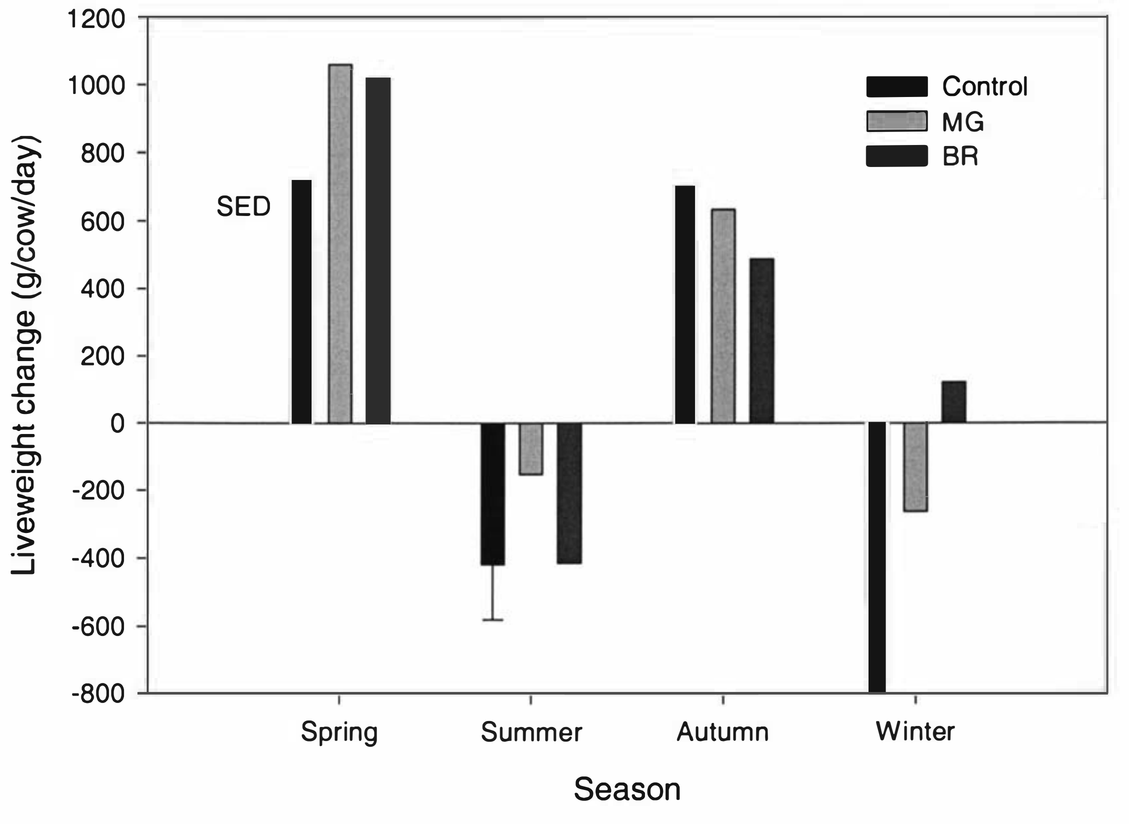


Figure 4.7: Trial 1: Average rate of liveweight change of cows offered nutritional treatments of a restricted pasture allowance (Control), or a restricted pasture allowance and supplementary feeds of either rolled maize grain (MG) or a nutritional balancing ration (BR) measured during the spring, summer, autumn and winter experimental periods.

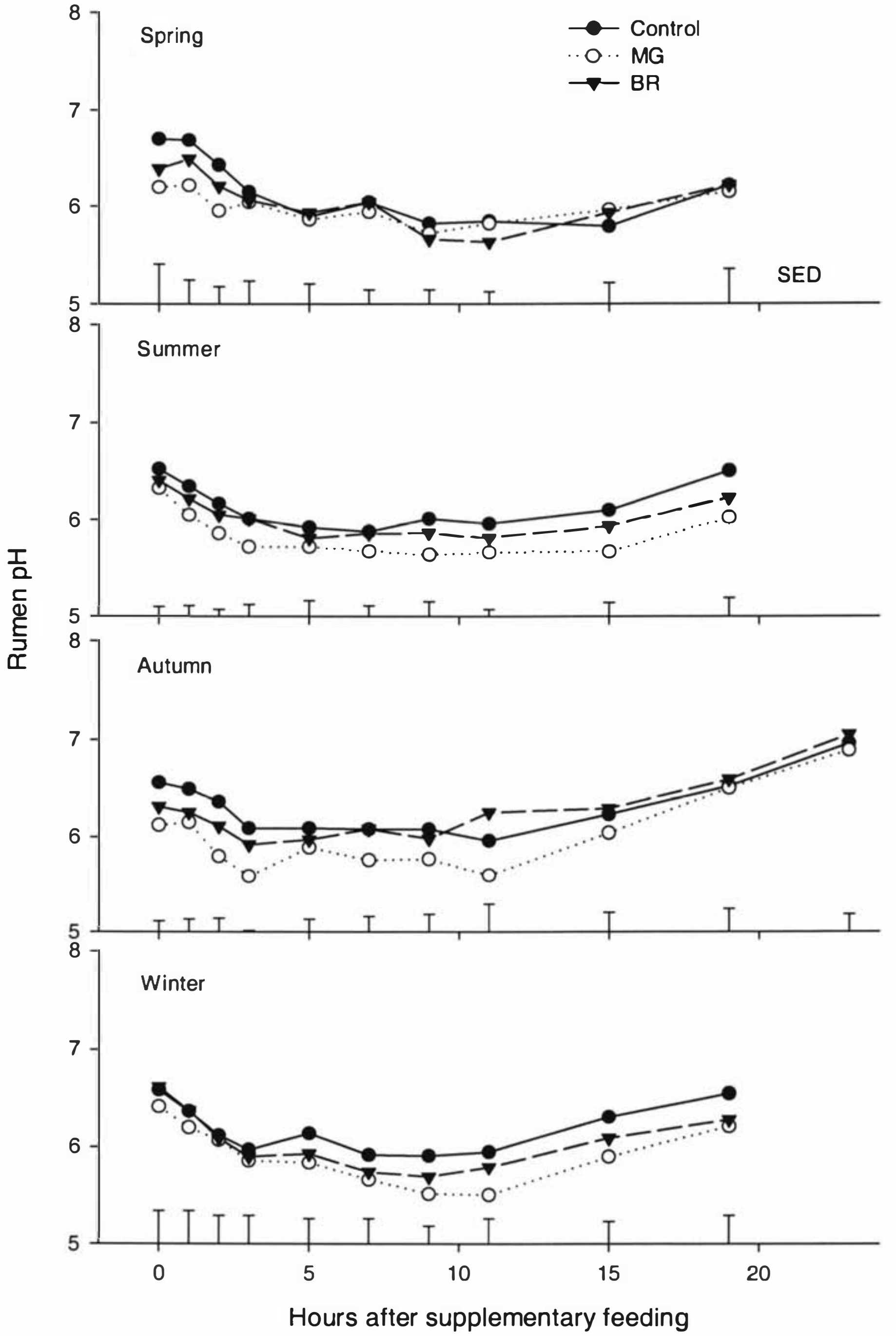


Figure 4.8: Trial 2: Rumen fluid pH of cows receiving nutritional treatments of a restricted pasture allowance (Control), or a restricted pasture allowance and 80 MJME/cow/day of rolled maize grain (MG) or a mixture of supplements formulated to balance the diet (BR) during the spring, summer, autumn and winter experimental periods.

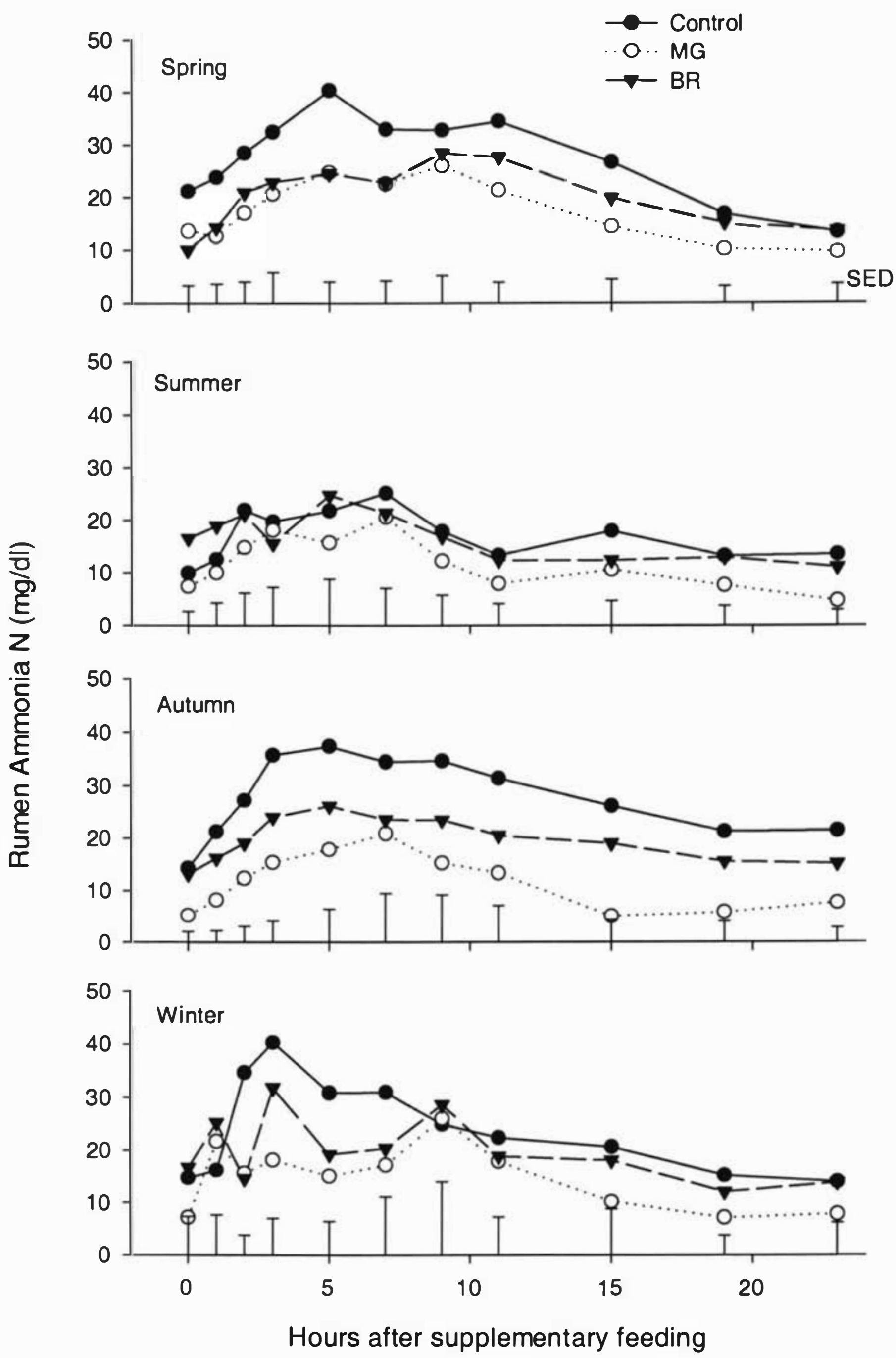


Figure 4.9: Trial 2: Concentration of ammonia nitrogen (N) in rumen fluid of cows receiving nutritional treatments of a restricted pasture allowance (Control), or a restricted pasture allowance and 80 MJME/cow/day of rolled maize grain (MG) or a mixture of supplements formulated to balance the diet (BR) during the spring, summer, autumn and winter experimental periods.

4.4.2.2 Trial 2: Blood metabolites measured during the experimental period

The main effects of season of the year and feeding treatments on the concentration of blood metabolites, averaged across stage of lactation, are presented in Table 4.6. There were no significant interactions (P>0.30) between the effects of stage of lactation and those of feed for serum glucose, BOH, urea or albumin concentrations. However, there were significant interactions between the effects of season and those of feed (P<0.05) for all serum metabolites, other than albumin. Cows offered the control diet had highest (P<0.05) serum glucose during winter, whereas cows offered the BR supplement had highest (P<0.05) serum glucose during spring. Cows offered the MG and BR treatments had higher (P<0.05) glucose concentrations than cows offered the control treatment during spring and autumn. During summer cows offered the BR treatment had lower (P<0.05) serum glucose than cows offered the control and MG treatments.

There were also significant interactions (P<0.05) between the effects of stage of lactation and those of feed for serum NEFA concentrations. Mid and late lactation cows offered the MG and BR supplements had lower (P<0.05) serum NEFA concentrations than early lactation cows, whereas stage of lactation had no effect (P>0.05) on the serum NEFA concentration of cows offered the control treatment. Cows offered the control treatment had higher (P<0.05) NEFA concentrations than cows offered the MG in summer, and than cows offered the MG and BR treatments in winter.

Cows offered the control treatment had higher (P<0.05) serum BOH concentrations during summer than at other seasons of the year. Cows offered the BR treatment had lowest (P<0.05) BOH during spring, whereas cows offered the MG had lowest (P<0.05) BOH during the winter experimental period.

Among early lactation cows, serum albumin concentrations of cows offered the AP treatment were not different (P>0.05) from cows offered the control and BR treatments.

Table 4.6: Trial 2: Average concentrations of albumin, beta hydroxy butyrate (BOH), non- esterified fatty acids (NEFA), glucose and urea measured in blood plasma sampled from cows in early, mid and late lactation (n=24), offered a restricted pasture allowance (Control) or a restricted pasture allowance and supplementary feeds of 80 MJME/cow/day as rolled maize grain or a nutritional balancing ration (BR) in spring, summer, autumn and winter.

Experimental period	**Feeding treatment**	**Glucose (mmol/l)**	**NEFA♣ (mmol/l)**	**BOH♣ (mmol/l)**	**Albumin (g/l)**	**Urea (mmol/l)**
Spring	Control	3.18^{a}	0.053^{ab}	0.88^{a}	30.2^{a}	9.21^{a}
	MG	3.54^{bf}	0.046^{ac}	0.76^{ab}	29.6^{ab}	6.39^{b}
	BR	3.69^{b}	0.045^{ac}	0.71^{b}	29.4^{ab}	6.24^{b}
Summer	Control	2.10^{c}	0.076^{b}	1.06^{c}	29.9^{a}	5.73^{bf}
	MG	2.20^{c}	0.049^{abc}	0.84^{ab}	28.4^{b}	3.42^{c}
	BR	1.79^{d}	0.055^{abc}	0.95^{ac}	30.0^{a}	7.22^{d}
Autumn	Control	2.22^{b}	0.041^{ac}	0.78^{ab}	28.9^{ab}	7.89^{e}
	MG	2.79^{e}	0.042^{ac}	0.68^{b}	28.2^{b}	3.75^{c}
	BR	2.62^{e}	0.044^{ac}	0.82^{ab}	29.0^{ab}	6.22^{b}
Winter	Control	3.47^{f}	0.067^{ab}	0.74^{b}	31.0^{a}	9.52^{a}
	MG	3.49^{f}	0.038^{c}	0.63^{d}	30.1^{a}	5.09^{f}
	BR	3.41^{f}	0.045^{ac}	0.89^{ac}	30.5^{a}	7.53^{d}
sed		0.106	1.65♥	1.18♥	0.64	0.298

Means with different superscript letters are significantly different (P<0.05).

♣Calculated from natural log transformed data.

♥Minimum significant ratio calculated from natural log transformed standard error of the difference.

Cows offered the control and MG treatments had higher ($P<0.05$) serum urea concentrations in spring and winter than in summer and autumn. The MG treatment resulted in lower ($P<0.05$) serum urea concentrations than the control treatment in all seasons. Cows offered the BR treatment had lower ($P<0.05$) serum urea than cows offered the control treatment in spring, but higher ($P<0.05$) serum urea concentrations than the control and MG treatments in summer. Serum urea concentrations of cows offered the BR treatment in the autumn and winter were intermediate ($P<0.05$) between the control and MG treatments.

4.4.2.3 Trial 2: Milksolids yield

Average daily yield of milk and milk constituents of each group measured during the final two weeks of each experimental period of trial 2 are presented in Table 4.7. The average milksolids yields of early, mid and late lactation cows offered the three feeding treatments in spring, summer, autumn and winter, are shown in Figure 4.3. There were significant interactions ($P<0.05$) between the effects of stage of lactation and those of feed, and between the effects of season and those of feed ($P<0.01$) for yields of milk, milkfat, milk protein and milksolids. Therefore, data from each experimental period are presented separately.

4.4.2.3.1 Spring

Offering MG and BR supplements or the AP treatment had no effect ($P>0.05$) on milksolids yield at any stage of lactation in the spring of trial 2. Cows at all stages of lactation and on all feeding treatments had higher ($P<0.05$) milksolids yields during spring than during autumn and winter. Early and late lactation cows offered the control, AP and MG feeding treatment had higher milksolids yield in spring than summer. There was no difference ($P>0.05$) between the milksolids yield of mid lactation cows offered any feeding treatments during spring or summer, or cows at each stage of lactation offered the BR supplement in spring and summer.

4.4.2.3.2 Summer

The AP and BR feeding treatments increased ($P<0.05$) the milksolids yields of early lactation cows in summer. Offering MG and BR increased ($P<0.05$) milksolids yield in mid lactation, but had no effect ($P>0.05$) in late lactation. Milksolids yield of cows offered the control and BR treatments decreased ($P<0.05$) with increasing

Table 4.7: Trial 2 experimental period: Mean values for yields of milk, milkfat and protein, for concentration of milkfat and protein and for rate of liveweight change measured each experimental period.

Stage	**Early**				**Mid**			**Late**				**Significance**♣				
Feed	Control	AP	MG	BR	Control	MG	BR	Control	MG	BR	sed	Season	Stage	Feed	Season x Feed	Stage x Feed
Spring																
Milk yield (kg/cow/day)	24.0	23.0	23.4	22.9	15.8	16.5	17.0	15.0	15.9	14.5	1.12	**	**	**	**	*
Milkfat yield (g/cow/day)	1135	1069	1021	994	706	718	716	757	746	711	53.2	**	**	**	**	*
Milk protein yield (g/cow/day)	754	783	737	804	579	624	634	562	625	571	37.0	**	**	**	**	*
Milkfat concentration (g/kg)	48.7	46.8	44.7	43.0	44.2	44.0	42.2	50.7	46.9	49.6	2.29	**	**	**	NS	NS
Milk protein concentration (g/kg)	32.1	33.9	32.4	34.4	36.2	38.1	38.0	37.5	39.2	39.7	1.20	**	**	**	NS	NS
Liveweight change (g/cow/day)	250	717	305	597	854	1038	415	381	834	1123	312.4	**	**	**	NS	NS
Summer																
Milk yield (kg/cow/day)	19.1	22.1	19.7	23.1	15.6	17.1	18.3	12.0	12.9	13.1						
Milkfat yield (g/cow/day)	883	951	847	1004	716	828	857	619	592	635						
Milk protein yield (g/cow/day)	580	684	640	719	513	586	638	447	466	506						
Milkfat concentration (g/kg)	47.5	43.9	43.1	45.0	46.0	48.7	47.5	52.0	47.1	48.7						
Milk protein concentration (g/kg)	30.6	31.3	32.4	31.9	33.4	34.3	35.2	37.5	37.0	38.4						
Liveweight change (g/cow/day)	-665	-100	-228	-215	337	281	267	-363	-134	43						
Autumn																
Milk yield (kg/cow/day)	14.6	16.1	16.8	19.5	8.7	10.8	13.5	8.1	10.1	11.1						
Milkfat yield (g/cow/day)	634	732	755	826	417	505	628	449	510	540						
Milk protein yield (g/cow/day)	441	503	547	615	296	405	470	311	402	425						
Milkfat concentration (g/kg)	43.4	44.4	44.6	43.4	50.5	46.7	47.6	57.8	51.3	49.4						
Milk protein concentration (g/kg)	30.1	30.9	32.4	32.1	35.4	38.0	35.1	39.7	39.9	39.8						
Liveweight change (g/cow/day)	-368	-14	351	428	28	520	442	693	594	1059						
Winter																
Milk yield (kg/cow/day)	11.6	13.6	13.7	15.2	10.3	15.3	15.3	9.1	12.7	12.3						
Milkfat yield (g/cow/day)	514	580	552	668	515	635	669	448	620	575						
Milk protein yield (g/cow/day)	351	458	470	504	349	554	517	334	494	462						
Milkfat concentration (g/kg)	44.1	42.0	40.5	44.1	50.8	42.3	44.6	50.3	49.7	47.3						
Milk protein concentration (g/kg)	31.5	33.4	34.3	33.3	34.4	36.4	34.2	36.6	39.4	38.6						
Liveweight change (g/cow/day)	502	1690	976	1120	146	382	681	1217	1569	1526						

♣There were no season x stage x feed interactions ($P>0.05$), other than for milkfat concentration ($P<0.05$).

stage of lactation. Although the milksolids yields of late lactation cows offered the MG treatment were lower (P<0.05) than early lactation cows, the yields of early and mid lactation cows were similar (P>0.05).

Early and mid lactation cows had higher milksolids yields during summer than cows at the same stage of lactation and feeding treatment during autumn and winter. Late lactation cows offered the control treatment had higher (P<0.05) milksolids yield in summer than in autumn and winter, but the milksolids yield of late lactation cows offered the MG and BR supplements was similar (P>0.05) in summer, autumn and winter.

4.4.2.3.3 Autumn

In autumn, offering AP, MG and BR feeding treatments to early lactation cows increased (P<0.05) milksolids yield, and the yield of cows offered the BR treatment was higher (P<0.05) than cows offered the AP treatment. Both the MG and BR supplements increased (P<0.05) the milksolids yield of mid lactation cows, whereas only BR increased (P<0.05) the milksolids yield of late lactation cows. Early lactation cows had higher milksolids yields than mid and late lactation cows, however, there was no difference (P<0.05) between the milksolids yields of mid and late lactation cows.

Early lactation cows in autumn had higher (P<0.05) milksolids yields than early lactation cows in winter. However, mid lactation cows offered the MG and BR feeding treatments had lower milksolids yields than mid lactation cows in winter. There was no difference (P>0.05) between the milksolids yields of late lactation cows in autumn and winter.

4.4.2.3.4 Winter

In winter, only the BR treatment increased (P<0.05) the milksolids yield of the early lactation cows, however, both the MG and BR treatments increased (P<0.05) milksolids yield of mid and late lactation cows. Stage of lactation did not affect (P>0.05) the milksolids yield of cows offered any of the feeding treatments.

4.4.2.4 Trial 2: Milkfat and milk protein concentration

The effect of feeding treatment on the milkfat and milk protein concentrations of milk was not affected (P>0.10) by stage of lactation or season of the year during trial 2. Average milkfat concentration increased (P<0.01) from 44.3 to 46.3 and 50.1 (±0.56) g/kg and milk protein concentrations increased (P<0.01) from 32.3 to 35.7 and 38.6 (±0.28) g/kg in milk produced by early, mid and late lactation cows, respectively.

Milkfat concentrations were 2.45 (±0.72) g/kg lower during the autumn than during the spring experimental periods, and milk protein concentrations were 1.9, 1.3 and 1.0 (±0.37) g/kg lower during summer than spring, autumn and winter experimental periods respectively. Supplementary feeding treatments of MG and BR reduced (P<0.001) milkfat concentration from 48.8 to 45.8 and 46.1 (±0.57) g/kg and increased (P<0.001) milk protein concentrations from 34.6 to 36.1 and 35.9 (±0.29) g/kg, respectively. The milk produced by early lactation cows offered the AP treatment had a similar (P>0.05) milkfat concentration and a higher (P<0.05) milk protein concentration than the milk produced by early lactation cows offered the control treatment.

4.4.2.5 Trial 2: Milksolids yield measured during the carryover period

The average yield of milk and milk constituents of each of the early and mid lactation groups measured during the 4 weeks immediately after supplementary feeding are presented in Table 4.8, and the average milksolids yields are shown in Figure 4.5. There were no significant interactions (P>0.25) between the effects of stage of lactation and those of feed for milksolids yield measured during the carryover period. However, there was a season by feed interaction (P<0.01) for milksolids. During the carryover period of trial 2, there was no difference (P>0.05)

Table 4.8: Trial 2 carryover period: Mean values for yield of milk, milkfat and protein, and for concentrations of milkfat and protein of cows in early and mid lactation during each carryover period, when all cows were offered a generous pasture allowance and no supplements.

Stage	**Early**				**Mid**			**Significance***					
Preceding Feed treatment	Control	AP	MG	BR	Control	MG	BR	Sed	Season	Stage	Feed	Season x Feed	Stage x Feed
Spring													
Milk yield (kg/cow/day)	22.4	18.2	20.2	20.2	15.9	16.0	16.2	1.19	**	**	**	**	NS
Milkfat yield (g/cow/day)	966	789	836	904	699	728	749	55.4	**	**	**	*	NS
Milk protein yield (g/cow/day)	692	595	610	691	565	581	587	35.0	**	**	**	**	NS
Milkfat concentration (g/kg)	44.4	43.7	42.0	45.2	44.2	46.4	47.5	3.03	**	**	NS	NS	NS
Milk protein concentration (g/kg)	31.4	32.6	30.7	33.9	35.4	36.5	36.9	1.51	**	**	NS	NS	NS
Summer													
Milk yield (kg/cow/day)	18.8	21.0	19.3	20.7	16.7	16.3	17.3						
Milkfat yield (g/cow/day)	797	842	836	840	732	785	820						
Milk protein yield (g/cow/day)	564	639	621	641	540	554	593						
Milkfat concentration (g/kg)	42.9	40.0	44.4	41.7	44.9	48.2	48.4						
Milk protein concentration (g/kg)	30.6	30.7	31.5	31.6	32.6	34.3	34.1						
Autumn													
Milk yield (kg/cow/day)	10.2	11.6	11.0	11.8	8.2	9.0	10.5						
Milkfat yield (g/cow/day)	495	530	530	534	423	437	524						
Milk protein yield (g/cow/day)	312	344	338	361	289	306	366						
Milkfat concentration (g/kg)	47.7	46.6	47.7	47.8	54.4	52.4	50.6						
Milk protein concentration (g/kg)	30.5	29.9	29.9	31.3	36.6	35.7	34.8						
Winter													
Milk yield (kg/cow/day)	11.3	11.8	11.8	12.3	9.7	11.1	11.9						
Milkfat yield (g/cow/day)	487	522	563	560	447	539	530						
Milk protein yield (g/cow/day)	333	375	378	388	320	378	392						
Milkfat concentration (g/kg)	42.2	43.8	45.6	46.2	47.4	48.5	45.1						
Milk protein concentration (g/kg)	31.0	31.7	32.5	32.0	33.4	34.2	33.2						

*There were no season x stage x feed interactions (P>0.10).

between the milksolids yield of cows that had been offered the three forms of supplement in spring. During the summer and autumn, cows that had been offered the BR supplement had higher ($P<0.05$) milksolids production than cows that had been offered the control treatment, but not the MG treatment ($P>0.05$). In winter, both the MG and BR supplements increased ($P<0.05$) milksolids yield during the four weeks following supplementary feeding.

4.4.2.6 Trial 2: Rate of liveweight change measured during the experimental period

The average liveweights at the end of each experimental period are shown in Figure 4.6. No interactions ($P>0.10$) were detected for liveweight gain. If cows offered the AP treatment are excluded, early lactation cows in trial 2 gained less ($P<0.05$) liveweight than late lactation cows. Offering the MG and BR treatments increased ($P<0.05$) liveweight gain from 181 g/cow/day to 540, and 631 ($\pm$82.2) g/cow/day, respectively. Early lactation cows offered the AP, MG and BR treatments gained 641, 426 and 555 ($\pm$148.2) g/cow/day, respectively, more ($P<0.05$) liveweight than early lactation cows offered the control treatment. Mid lactation cows offered the MG and BR treatments gained 408 and 302 ($\pm$144.2) g/cow/day more ($P<0.05$) liveweight, and late lactation cows offered the BR treatment gained 465 ($\pm$144.2) g/cow/day more ($P<0.05$) liveweight than cows in their respective control groups.

The liveweight change of cows in the spring, summer, autumn and winter experimental periods of trial 2 averaged 548, -93, 427 and 916 ($\pm$98.9) g/cow/day, respectively. Both the MG and BR treatments resulted in cows gaining more ($P<0.05$) liveweight than cows offered the control treatment in spring, autumn and winter.

4.5 Discussion

The milk yields recorded during these series of experiments were generally low, consistent with the low pasture allowances and DMI reported in Chapter 3. However, milk yields were generally higher in the spring and summer periods of trial 2 than during the equivelent periods in trial 1. These differences must have resulted from differences in the feeding levels imposed during these periods as the milk yields immediately before the treatments were imposed were similar (Tables 4.1 and 4.2). The pasture allowance was higher in the spring of trial 2 than during the spring of trial 1, and the digestibility of the pasture offered during the summer of trial 2 was higher than that of the pasture offered during the summer of trial 1. It was suggested in the previous chapter that higher pasture allowance and quality was associated with higher pasture substitution rates, therefore lower milk yield responses to supplementary feeding would be expected during the spring and summer periods of trial 2.

Offering MG and BR supplementary feeds increased the milksolids yield of dairy cows grazing restricted amounts of pasture in all experimental periods of trial 1. In trial 2, BR supplements increased milksolids yield in the summer, autumn and winter, and MG supplements increased milksolids yield in the autumn and winter. Supplements of MG increased liveweight gain (or reduced the rate of liveweight loss) in the spring, summer and autumn periods of trial 1, and in the spring and summer periods of trial 2. Supplements of BR increased liveweight gain in the spring and winter of trial 1 and during all experimental periods of trial 2. These results are consistent with numerous other studies that have shown that offering supplementary feeds to cows grazing restricted amounts of pasture almost invariably results in increased milk yield and increased liveweight (Kellaway and Porta, 1993). Nevertheless, the primary purpose of the present studies was to determine the effects of stage of lactation and season of the year on the magnitude of these responses.

4.5.1 Effects of stage of lactation

When the effects of stage of lactation were separated from those of season of the year, stage of lactation had no effect on the immediate responses in milksolids yield or in liveweight gain. These results confirm some recent studies that have demonstrated large increases in milk yield when supplements have been offered to late lactation cows (Stockdale and Dellow, 1995; Robaina *et al.,* 1998). However, they are in direct contrast to earlier indoor studies which were designed to make direct comparisons between the supplementary feeding responses of cows in early or mid lactation (Stockdale *et al.,* 1987; Stockdale and Trigg, 1989).

It is generally accepted that the partitioning of energy between milk yield and body reserves is dependent on the actual milk yield of the cow, with higher yielding cows partitioning more to milk yield and less to liveweight gain (Broster and Thomas, 1981). As lactation progresses, and milk yield decreases, cows partition a decreasing proportion of energy to milk yield and an increasing proportion to replenishing body reserves lost previously in earlier lactation (Bauman and Currie, 1980). These theories have been supported by findings that cows in early lactation are more responsive to additional feed than cows in late lactation (Stockdale and Trigg, 1989; Kellaway and Porta, 1993). However, it is also recognised that the ability of the cow to increase yield, determined by genetic merit and recent nutritional history, also has a large affect on the magnitude of the increase in yield resulting from increased intake (Oldham and Emmans, 1989). As cows approach their potential milk yield, incremental increases in intake result in diminishing increases in milk yield and increasing rates of body fat and protein accumulation (Broster and Thomas, 1981). The later models provide a logical explanation for the contrasting effects that stage of lactation has apparently had on response to supplements in different studies.

Supplementary feeding studies have generally imposed common absolute feeding treatments on cows at different stages of lactation, despite large differences in actual and potential milk yield. For example, Stockdale *et al.* (1987) compared early and late lactation cows consuming a severely restricted allocation of pasture (about 7 kg DM/cow/day) plus different amounts of concentrates, with control groups consuming only the restricted allowance of pasture. This common restricted feed allowance imposed a more severe feed restriction on the cows in early lactation than on the late lactation cows, because the early lactation cows had milksolids yields that were much higher (by about 500g MS/cow/day) than late lactation cows immediately before the treatments were imposed. The decrease in milksolids yield caused by the imposition of the restricted allowance was much larger (x 2) in the early lactation cows than in the late lactation cows (Stockdale *et al.,* 1987). Similarly, Stockdale and Trigg (1989) imposed a common feeding restriction that resulted in a decrease of 9.2 kg/cow in the daily milk yield of early lactation cows offered the control treatment, compared to a decrease of only 4.0 kg/cow/day by late lactation cows. Consequently, the responses of late lactation cows to feed restrictions were much smaller (x 0.5) than the responses of early lactation cows in both of these studies (Stockdale *et al.,* 1987; Stockdale and Trigg, 1989). Because of their stage of lactation, and recent nutritional history, the late lactation cows were closer to their potential milk yield than the early lactation cows. Thus, as feeding levels were increased with supplementary feeds, the early lactation cows partitioned a greater proportion of the additional energy toward milk yield, and a lesser proportion to liveweight gain (Stockdale *et al.,* 1987; Stockdale and Trigg, 1989). Interestingly, the most generous supplementary feeding treatments in both studies simply allowed early and late lactation cows to maintain their pre-treatment milk yields. Further, when the amount of pasture offered to the control cows was more generous, and the decrease in milk yield of the early and late lactation cows became less severe, the responses attributed to supplementary feeding also declined (Stockdale and Trigg, 1989).

Grainger (1990) reported a similar trial comparing the marginal responses of early and late lactation cows to increased pasture DMI. However, in contrast to the earlier work, the reduction in milk yield that occurred as the experimental treatments were imposed were approximately half to one-third of those reported by Stockdale *et al.* (1987) and Stockdale and Trigg (1989), and there was little difference between the early and late lactation cows in the decrease in yield. Also in contrast to the earlier work, but in agreement with the present studies, the responses of early and late lactation cows to additional feed were similar. Large increases in milk yield resulting from supplementary feeding of high yielding cows in late lactation have also recently been reported by Robaina *et al.* (1998). Late lactation cows that had suffered a large decrease in milk yield as treatments were imposed (from 20.5 to 10.6 kg milk/cow/day) demonstrated a much larger milk yield response to concentrates than late lactation cows in the following year that had not changed milk yield as treatments had been imposed (from 14.7 to 14.0 kg/cow/day; Robaina *et al.,* 1998).

The changes in milksolids yield that occurred as the control treatments were imposed during the present study were generally much smaller than those of Stockdale *et al.* (1987) and Stockdale and Trigg (1989). Further, the differences between groups at different stages of lactation, within each experimental period were also small. Thus, the potential of early and late lactation cows to increase milk yield, back to their pretreatment yield, was similar. Grazing also creates higher energetic requirements and provides the cow with opportunity to respond to the imposition of feed restrictions by grazing more intensely, to maintain pasture intake. This may buffer the different relative feed restrictions that were imposed on early and mid lactation cows during the present trials.

4.5.2 Effects of season of the year

In trial 1, the increase in milksolids yield resulting from the MG and BR treatments was smallest in spring, and largest in the summer and winter. In trial 2, offering MG and BR supplements had no effect on milksolids yield in spring and responses were largest in autumn and winter. Conversely, during trial 1 the effect of MG supplements on liveweight change was two fold greater during spring than during summer and winter, while there was no effect on liveweight change during autumn. In trial 2, season had no effect on the difference in rates of liveweight change between the nutritional treatments. These results agree with recent farm systems experiments where offering supplementary feeds in summer and autumn resulted in larger immediate milksolids responses than offering supplements in spring (Penno *et al.,* 1996). It was apparent in these earlier trials that large increases in milksolids production are closely associated with periods of low milk yields (relative to their potential) from the control cows. Again, when the control cows are placed under more severe nutritional restrictions, the potential to increase milk yield becomes greater, and these cows are likely to partition a higher proportion of additional feed energy to milk yield, rather than liveweight gain.

In both trials 1 and 2, milksolids yields of the cows offered the pasture only control diet were higher in spring than at other times of the year. In trial 1 cows offered the control diet had higher production in autumn than in summer and winter, but in trial 2, yields were higher in the summer than in the autumn and winter. Low milksolids yields in the winter experimental periods were associated with large liveweight losses at all stages of lactation in trial 1, consistent with underfeeding, but in trial 2 the low milksolids yields in winter were associated with higher rates of liveweight gain than at other times of the year.

Within this experimental design, comparisons between seasons present the most difficulty. In addition to changing pasture allowances, necessitated by changing pasture structure, pasture quality also varied between seasons (Chapter 3). Both these factors are known to have a large affect on pasture DMI and subsequent milksolids yield (Holmes, 1987). However, environmental factors associated with season of the year, other than nutrition, may also have affected milk yield (Garcia and Holmes, 1999). In particular, seasonal changes in photoperiod are known to affect feed intake and milk yield of cows at all stages of lactation (Peters *et al.,* 1981). Typically, cows under winter photoperiod produce 7 to 10% less milk than cows under summer photoperiod at the same level of nutrition (Peters *et al.,* 1981; Bilodeau *et al.,* 1989). However, the results attained in the present study are not consistent with those of Auldist *et al.* (1998) who demonstrated higher milksolids yield from early, mid and late lactation cows in summer and autumn, than in winter and spring. This suggests that the different levels of performance observed between seasons are largely a reflection of the relative levels of nutrition immediately before, and during the experimental periods. The lower level of nutrition of the control cows during summer and winter are supported by the fact that the supplementary feeding treatments reduced serum NEFA levels during these period, but had no effect during other seasons.

Recent work by Stockdale *et al.* (1997) has suggested that cows become increasingly responsive to cereal grain supplements as the metabolisable energy concentration of the pasture on offer declines. In the present experiments, metabolisable energy concentration was lower in summer than spring, autumn and winter in trial 1, and was lower in summer and autumn than in spring and winter of trial 2 (Chapter 3), but these differences are not well correlated to the magnitude of supplementary feeding responses. For example, the metabolisable energy concentration of spring and winter pastures were similar, yet supplementary feeding resulted in small responses in spring and large responses in winter. The differences in pasture quality observed by Stockdale *et al.* (1997) were much larger (8 to 12 MJME/kg DM) than the between season variation that occurred in the present studies. Nevertheless, the small changes in pasture quality that were observed may have contributed to the differences in response between seasons by increasing the magnitude of underfeeding during the summer and autumn.

4.5.3 Form of supplementary feed

Offering BR supplements resulted in larger increases in milksolids production than offering the same amount of metabolisable energy in the form of MG supplement from early lactation cows in summer, autumn and winter of trial 2, and from mid lactation cows in the autumn of trial 2. The predominant difference between the two diets during these periods was the use of rumen degradable (soybean meal) and undegradable protein (fishmeal) supplements in summer, and undegradable protein and effective fibre (chopped hay) supplements in autumn and winter (Chapter 3).

Nutritional treatments and time of the year had little effect on the longer-term protein status of the cows as indicated by serum albumin concentration. However, serum urea concentrations varied with changes in the crude protein (CP) concentration in the pasture (Chapter 3). High values for CP concentration of the pasture resulted in increased values for rumen ammonia N and blood urea concentration during the autumn and winter experimental periods of trial 1, and during the spring, autumn and winter experimental periods of trial 2, particularly among cows offered the control treatment. Offering MG and BR supplements decreased serum urea concentration, probably by reducing CP intake and increasing the supply of readily fermentable carbohydrate (Kolver *et al.*, 1998). Based on these metabolic profiles, it is likely than only the experimental groups offered the MG supplement in the summer and autumn experimental periods of trial 2 received inadequate protein nutrition. The low serum urea and albumin concentrations in the summer experimental period of trial 2 correspond with the lowest pasture CP concentration, and with rumen ammonia N concentrations that were less than 10 mg/dl for much of the day. Also during these periods the cows offered the BR supplements produced higher milksolids yields than cows offered the MG supplements.

The CP content of the total diet of cows offered the MG supplements was as low as 14% during the summer of trial 2. It is generally accepted that early lactation cows require a CP concentration in the diet of 18g/100g DM (NRC, 1989). The marginal response to extra maize silage supplements was reduced when the CP concentration of the diet was less than 14g/100g DM (Stockdale, 1995). Further, milk protein yield of mid and late lactation cows consuming diets of grazed pasture and maize silage in summer and autumn was increased when soybean supplements were substituted for maize silage on an isoenergetic basis (Macdonald *et al.,* 1998). Stockdale and Dellow (1995) demonstrated larger responses to supplements of maize silage from late lactation cows grazing clover pastures in autumn, than from early lactation cows grazing clover pastures in late spring. The different responses were attributed to condensed tannins, present in clover flowers in autumn, binding to protein in the rumen and making it unavailable to the rumen microbes, effectively creating a rumen deficiency of degradable protein (Stockdale and Dellow, 1995). Clearly, inadequate crude protein supply will limit the response in milk yield to the provision of additional dietary energy.

Although the concentration of CP in the pasture in the autumn experimental period of trial 2 was relatively high (24g/100g DM), pasture DMI averaged only 8.4 kg/cow/day compared to a MG intake of 6.0 kg DM/cow/day (Chapter 3) resulting in low rumen ammonia concentrations (Figure 4.9). Nevertheless, the total diets of cows offered the MG supplements in the autumn and winter of trial 2 were likely to have contained more than 17g CP/100g DM, which should have been adequate (NRC 1989). Offering undegradable protein supplements to cows grazing generous amounts of pasture have usually not increased milk yield (Brookes, 1984; Penno *et al.* 1995b; Rusdi and Van Houtert 1997; Stockdale *et al.,* 1997). However, responses have been measured when the amount of pasture available was restricted (Rogers *et al.,* 1980; Minson, 1981). Undegradable protein (fishmeal) can also be a more effective supplement than degradable protein (soybean meal) when used as a supplement for grazing cows consuming large amounts of maize silage (Macdonald *et al.,* 1998). Orskov *et al.* (1981) suggested that when cows were in energy deficit, undegradable protein supplements may provide amino acids which were limiting milk yield, thereby stimulating the mobilisation of body condition to provide glucose for increased milk yield. However, in the present studies, there was no difference between the rate of liveweight change of cows offered the MG and BR supplements. Nevertheless, the possibility that the fishmeal provided additional essential amino acids, to overcome a limitation on the milk yield of the control cows, cannot be discounted (Schroeder and Gagliostro, 2000).

Fibre supplements were included in the BR supplement in spring, autumn and winter in an attempt to maintain adequate rumen pH for optimum fermentation. Recent work has shown that the fermentation of fresh pasture is inhibited if rumen pH falls below 5.8 (De Veth and Kolver, 1999). When starchy concentrates are included in the diet, fermentation of pasture may be impaired if pH declines below 6.0 (Stewart, 1977). During the autumn of trial 2, rumen pH of cows offered the MG supplements was below 6.0 for much of the day, and at times was as low as 5.5. Inclusion of 2 kg DM/cow/day as chopped hay maintained rumen pH above 6.0, despite the consumption of large amounts of rolled maize grain. However, during the winter of trial 2, the same mixture of feeds resulted in higher yields of milk and milkfat from early lactation cows than MG, even though rumen pH fell below 6.0 for about half the day in both the MG and BR treatments.

Overall, the incremental benefits from providing supplements that were formulated to balance the diet of grazing cows were small when compared with maize grain supplements. These findings contradict recent suggestions that many published supplementary feeding studies have grossly underestimated potential supplementary feeding responses by ignoring the detailed nutritional requirements of the cows and the nutrient composition of the pasture (Edwards and Parker, 1994; Lean *et al.*, 1996).

4.5.4 Carryover effects

Milksolids yield remained elevated during the four weeks following supplementary feeding of MG in the spring, summer and winter of trial 1, and after the winter experimental period of trial 2. Milksolids yield also remained elevated following the supplementary feeding of BR in the spring and summer experimental periods of trial 1, and after the summer, autumn and winter of trial 2. When present, the magnitude of carryover effects was usually about half the immediate effects, and diminished over time. In the present studies these increased milksolids yields usually followed a period in which supplementary feeding caused relative increases in body weight. The extra milksolids produced after the period of supplementary feeding has often been attributed to the mobilisation of body reserves (Kellaway and Porta, 1993). However, several authors have also suggested that nutritional history can affect future milksolids yield (Broster and Broster, 1984; Oldham and Emmans, 1989). In addition to the benefits of additional body reserves that usually result from a higher level of feeding, a higher absolute milk yield may predispose the cow to higher future milksolids yield, should level of nutrition allow.

The carryover effects of supplementary feeding appear to differ both within and between seasons. Bryant and Trigg (1982) suggested that the use of supplements during spring feed deficits would not result in any significant carryover effects. However, Clark (1993) found that 65% of the additional milk production that resulted from feeding silage in spring occurred after the conclusion of the feeding period. It would appear that carryover effects can be both animal and pasture related. Within farm systems, substitution of pasture by supplements may increase the pasture allowance and DMI for some time after supplementary feeding ceases, increasing milksolids yield and contributing to carryover effects (Kellaway and Porta, 1993). The present data suggest that contribution of the cow to carryover effects is only half that reported by Clark (1993). Therefore, the contribution of higher pasture intakes after the supplementary feeding may also account for half the carryover response expected within whole farm systems.

4.6 Conclusions

It is concluded from the present studies that stage of lactation has little effect on the response of high genetic merit cows grazing restricted amounts of pasture to supplementary feeds. Likewise, formulating supplementary feeds to complement the pasture on offer is of little benefit when those supplements are primarily used to overcome a total feed energy deficit. In contrast, season of the year can affect the responses to supplementary feeding. Differences between seasons were closely associated with the level of production achieved by cows receiving the pasture only control, with responses being larger at times when the quantity and quality of pasture on offer resulted in lower milksolids yield. Perhaps these low absolute milksolids yields are the best measure of the difference between the energy required for the cows to attain their potential milksolids yield, and the actual energy intake which the amount and quality of pasture on offer allowed. Therefore, although it is difficult to define quantitatively, the concept of a potential energy deficit should be developed as a predictor of the likely response of the grazing dairy cows to supplementary feeds.

4.7 References

AFRC 1998. Response in the yield of milk constituents to the intake of nutrients by dairy cows. *Nutrition Abstracts and Reviews, Series B* **68**: 11.

Auldist, M. J., Walsh, B. J. and Thomson, N. A. 1998. Seasonal and lactational influences on bovine milk composition in New Zealand. *Journal of Dairy Research* **65:** 401–411.

Bauman, D. E. and Currie, W. B. 1980. Partitioning of nutrients during pregnancy and lactation. A review of mechanisms involving homeostasis and homeorhesis. *Journal of Dairy Science* **63:** 1514-1529.

Bilodeau, P. P., Petitclerc, D., Pierre, N. ST., Pelletier, G. and Laurent, G. J. ST. 1989. Effects of photoperiod and pair-feeding on lactation of cows fed corn or barley grain in total mixed rations. *Journal of Dairy Science* **72:** 2999-3005.

Brookes, I. M. 1984. Effects of formaldehyde-treated and untreated casein supplements on performance of dairy cows offered ryegrass-clover pastures. *New Zealand Journal of Agricultural Research* **27:** 491-493.

Broster, W. H. and Thomas, C. 1981. The influence of level and pattern of concentrate input on milk output. In *Recent advances in animal nutrition*, 1981, Ed. W. Haresign, Butterworths, London. pp. 49 – 69.

Broster, W. H. and Broster, V. J. 1984. Long term effects of plane of nutrition on the performance of the dairy cow. *Journal of Dairy Science* **51:** 149-196.

Bryant, A. M. and Trigg, T. E. 1982. The nutrition of the grazing dairy cow in early lactation. *Dairy Production from Pasture.* Eds. K. L. Macmillan and V. K. Taufa. pp 185-207. Clark and Matherson Ltd, Hamilton, NZ.

Chaney, A. L., and Marbach, E. P. 1962. Modified reagents for determination of urea and ammonia. *Clinical Chemistry* **8:** 30.

Clark, D. A. 1993. Silage for milk production. *Proceedings of the Ruakura Farmers' Conference,* **45:** 41-46.

De Veth, M. J., and Kolver, E. S. 1999. Digestion of pasture in response to ruminal pH. *Proceedings of the New Zealand Society of Animal Production* **59:**66-69.

Edwards, N. J. and Parker, W. J. 1994. Increasing per cow milk solids production in a pasture-based dairy system by manipulating the diet: a review. *Proceedings of the New Zealand Society of Animal Production* **54:** 267-273.

Garcia, S. C. and Holmes, C. W. 1999. Effects of time of calving on the productivity of pasture-based dairying systems: A review. *New Zealand Journal of Agricultural Research* **42:** 347-362.

Genstat Committee. 1997. Genstat for Windows Command Language Manual, Third Edition.

Grainger, C. 1990. Effect of stage of lactation and feeding level on milk yield response by stall-fed dairy cows to change in pasture intake. *Australian Journal of Experimental Agriculture* **30:** 495-501.

Holmes, C. W. 1987. Pastures for dairy cows. In Livestock Feeding on Pasture. Ed. A. M. Nicol. *New Zealand Society of Animal Production, Occasional Publication* **10:** 133-143.

Kellaway, R. C. and Porta S. 1993. Feeding concentrates: supplements for dairy cows. E. Hopkins, ed. Agmedia, Melbourne, Australia.

Kolver, E . S., Muller, L. D., Varga, G. A. and Cassidy, T. J. 1998. Synchronization of ruminal degradation of supplemental carbohydrate with pasture nitrogen in lactating dairy cows. *Journal of Dairy Science* **81:** 2017-2028.

Lean, I. J., Parker, W. J. and Kellaway, R. C. 1996. Improving the efficiency of pasture-based dairying. *Proceedings of the New Zealand Society of Animal Production* **56:** 270-275.

Leaver, J. D., R. C. Campling, W. Holmes. 1968. The use of supplementary feeds for grazing dairy cows. *Dairy Science Abstracts 30* **7**: 355-361.

Macdonald, K. A., Penno, J. W., Kolver, E. S., Carter, W. A. and Lancaster, J. A. 1998. Balancing pasture and maize silage diets for dairy cows using urea, soybean meal, or fishmeal. *Proceedings of the New Zealand Society of Animal Production* **58:**102-105.

Minson, D. J. 1981. The effect of feeding protected and unprotected casein on the milk production of cows grazing ryegrass. *Journal of Agricultural Science, Cambridge* **96:** 239-241.

National Research Council. 1989. *Ruminant Requirements of Dairy Cattle, 6th edition.* US National Academy of Science, Washington, D.C.

Oldham, J. D. and Emmans, G. C. 1989. Prediction of responses to required nutrients in dairy cows. *Journal of Dairy Science* **72:** 3212-3229.

Orskov, E. R., Reid, G. W. and McDonald, I. 1981. The effects of protein degradability and food intake on milk yield and composition in cows in early lactation. *British Journal of Nutrition* **45:** 547-555.

Penno, J. W., Thomson, N. A., Bryant, A. M. 1995a. Summer milk – supplementary feeding. *Proceedings of the Ruakura Farmers' Conference* **47:** 17-24.

Penno, J. W., Bryant, A. M., Carter, W. A. and Macdonald, K. A. 1995b. Effects of fishmeal supplementation to high genetic merit cows grazing temperate spring pastures in early lactation. *Journal of Dairy Science* **78** (Supplement 1): 295.

Penno, J. W., Macdonald, K. A. and Bryant, A. M. 1996. The economics of the No 2 Dairy systems. *Proceedings of the Ruakura Farmers' Conference* **48**: 11-19.

Peters, P. R., Chapin, L. T., Emery, R. S. and Tucker, H. A. 1981. Milk yield, feed intake, prolactin, growth hormone, and glucocorticoid response of cows to supplemented light. *Journal of Dairy Science* **64:** 1671-1678.

Robaina, A. C, Grainger, C., Moate, P., Taylor, J. and Stewart, J. 1998. Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* **38:** 541-549.

Rogers, G. L., Porter, R. H. D., Clarke, T. and Stewart, J. A. 1980. Effect of protected casein supplements on pasture intake, milk yield and composition of cows in early lactation. *Australian Journal of Agricultural Research* **31:** 1147-1152.

Rusdi. and van Houtert., M. F. J. 1997. Responses to protected amino acids or protected protein in dairy cows grazing ryegrass pastures in early or late lactation. *Proceedings of the New Zealand Society of Animal Production* **57:** 120-125.

Schroeder, G. F. and Gagliostro, G. A. 2000. Fishmeal supplementation to grazing dairy cows in early lactation. *Journal of Dairy Science* **83**: 2899-2906.

Stewart, C. D. 1977. Factors affecting the cellulolytic activity of rumen contents. *Applied Environmental Microbiology* **33:** 497-502.

Stockdale, C. R. 1995. Maize silage as a supplement for pasture-fed dairy cows in early and late lactation. *Australian Journal of Experimental Agriculture* **35:** 19-26.

Stockdale, C. R. 1996a. Feeding supplements and concentrates: Extra feeding responses best in summer/autumn. *The Australian Dairyfarmer May-June*: 64.

Stockdale, C. R. 1999. The nutritive characteristics of herbage consumed by grazing dairy cows affect milk yield responses obtained from concentrate supplementation. *Australian Journal of Experimental Agriculture* **39**: 379-387.

Stockdale, C. R., Callaghan, A, and Trigg, T. E. 1987. Feeding high energy supplements to pasture-fed dairy cows. Effects of stage of lactation and level of supplement. *Australian Journal of Agricultural Research* **38:** 927-940.

Stockdale, C. R. and Trigg, T. E. 1989. Effect of feeding levels on the responses of lactating dairy cattle to high energy supplements. *Australian Journal of Experimental Agriculture* **29:** 605-611.

Stockdale, C. R. and Dellow, D. W. 1995. The productivity of lactating cows grazing white clover and supplemented with maize silage. *Australian Journal of Agricultural Research* **46:** 1205-1217.

Stockdale, C. R., Dellow, D. W., Grainger, C., Dalley, D. and Moate, P. J. 1997. Supplements for dairy production in Victoria. Dairy Research and Development Corporation, Glen Iris, Melbourne.

Woodward, S. L., Auldist, M. J., Laboyrie, P. J. and Jansen, E. B. L. 1999. Effect of Lotus corniculatus and condensed tannins on milk yield and milk composition of dairy cows. *Proceedings of the New Zealand Society of Animal Production* **59**: 152-155.

Velleman, P. F. 1997. Data Desk, Version 6. Data Description, Ithaca, NY.

CHAPTER FIVE

SUPPLEMENTARY FEEDING RESPONSES BY COWS IN EARLY, MID AND LATE LACTATION GRAZING LOW PASTURE ALLOWANCES IN SPRING, SUMMER, AUTUMN AND WINTER

3. MARGINAL RESPONSES IN MILKSOLIDS YIELD AND LIVEWEIGHT

CHAPTER 5: SUPPLEMENTARY FEEDING RESPONSES BY COWS IN EARLY, MID AND LATE LACTATION GRAZING LOW PASTURE ALLOWANCES IN SPRING, SUMMER, AUTUMN AND WINTER

3: MARGINAL RESPONSES IN MILKSOLIDS YIELD AND LIVEWEIGHT

5.1 Abstract

Data derived from two trials, in which supplementary feeds were offered to cows in early, mid, and late lactation in each of spring, summer, autumn and winter, were used to calculate the marginal responses (extra milksolids (MS) or extra liveweight per unit of supplement offered) to supplements of maize grain (MG) and a nutritionally balancing ration (BR).

Responses to MG and BR were similar. Stage of lactation had no consistent effect on the immediate milksolids response to either form of supplementary feed, which ranged from 3.3 to 5.1 (±0.41) g MS/MJ metabolisable energy (ME) during trial 1, and 1.2 to 2.7 (±0.41) g MS/MJME during trial 2. Immediate milksolids responses in spring were consistently smaller than during other seasons of the year in both trials, and were negligible in trial 2. The carryover responses (measured during the four weeks following supplementary feeding) were about 50% of the immediate effects in both trials 1 and 2. In trial 1 there was no difference ($P>0.10$) between the total milksolids responses (immediate plus carryover responses) of early and mid lactation cows, whereas in trial 2 mid lactation cows demonstrated larger ($P<0.05$) total milksolids responses than early lactation cows. In trial 1 the total milksolids responses measured in

spring, summer autumn and winter were 6.4, 6.9, 3.6 and 7.5 (±1.17) g MS/MJME, respectively. During trial 2 the total milksolids responses measured in spring, summer autumn and winter were –0.1, 3.4, 3.6 and 4.7 (±0.74) g MS/MJME, respectively. There was no difference in the total milksolids response resulting from MG or BR in trial 1, whereas during trial 2 the milksolids response from MG and BR were 1.9 and 3.9 (±0.52) g MS/MJME, respectively.

Stage of lactation and season of the year accounted for little of the variation in the magnitude of the marginal milksolids response from feeding supplementary feeds. The factor that was of greatest importance was the relative feed deficit (RFD) measured by the reduction in milksolids yield (kg MS/cow/day) of the respective control groups that had occurred when the feeding treatments had been imposed. Total marginal milksolids responses were greatest when severe feed restrictions, relative to the current feed demand, resulted in large reductions in milksolids yield of the control groups. Total marginal milksolids response increased ($P<0.01$) by 0.9g MS/MJME offered as supplement per 0.1 kg MS/cow/day RFD. Total marginal milksolids responses also declined ($P<0.01$) by 0.2 g MS/MJME offered as supplement as pasture allowance increased by each 10 MJME/cow/day.

The RFD was the best predictor of milksolids response to supplementary feeds. Therefore, it is likely that cows will be most responsive to supplementary feeds during or immediately after the imposition of a severe feed restriction. High milksolids responses could be assured by using farm policy (stocking rate and calving date, grazing management or drying off date), to impose periods of severe pasture restriction, allowing the efficient use of supplementary feeds to overcome the effects of the restriction on feed intake, while saving pasture for subsequent use.

5.2 Introduction

Supplementary feeds should only be offered to grazing dairy cows when the value of any additional milk produced exceeds the total costs of purchasing, storing and feeding that supplement. Further, to gain maximum economic benefit from a predetermined quantity of supplementary feed, dairy farmers must offer the supplement to grazing cows when the largest total increase in milksolids yield is likely to result per unit of supplement. While the costs of offering the supplement and the value of milk are usually known in advance, the animal response is extremely variable (Chapter 2). The ability to accurately predict production responses to supplements would make an important contribution to dairy herd management.

In the review of pasture based supplementary feeding trials published since 1978 (Chapter 2) it was concluded that, although the average response to supplements was 58 g milk, 4.1 g milksolids, and 10.6 g liveweight/megajoule of metabolisable energy (MJME) offered, the reported data were extremely variable. These published values generally referred only to the immediate milk yield response, measured during the period of supplementary feeding. However, it is well known that the increase in body reserves and milk yield that results from an increase in feeding level often continues to affect milksolids yield for a period after the increase in feeding has finished (Broster and Broster, 1984). Additional milk that is produced after the period of supplementary feeding has been defined as the residual response or the carryover effect (Kellaway and Porta, 1993). Therefore, the immediate milk yield response reported from the majority of experiments generally underestimates the total response from supplementary feeding.

Two series of trials were conducted to determine the effect of stage of lactation and season of the year on the response of dairy cows grazing restricted amounts of pasture to rolled maize grain (MG) or nutritionally balancing (BR) supplementary feeds (Chapters 3 and 4). This chapter reports calculations made on the data from these trials to determine the immediate milksolids and liveweight gain responses, and carryover milksolids response to rolled MG and BR supplements in early mid and late lactation, and in spring, summer, autumn and winter. The data are also used to describe some variables that can be used to predict the magnitude of the responses.

5.3 Materials and methods

5.3.1 Experimental design

Details of the site, cows, experimental design, and feeding treatments have been described in Chapter 3. Two supplementary feeding experiments were conducted with cows in early, mid and late lactation at four times of the year. In trial 1, cows at each stage of lactation were grazed on a restricted allowance of pasture (approximately 25 – 40 kg DM/cow/day) and offered pasture only or supplementary feeding treatments of 50 MJME/cow as either rolled maize grain, or as a nutritionally balancing ration. In trial 2, the same supplementary feeding treatments were offered, but at 80 MJME/cow/day. Each experimental period comprised a seven day uniformity period, followed by a 35 day supplementary feeding period. After each supplementary feeding period, cows were grazed together by stage of lactation group and offered a generous pasture allowance for a further 28 days to allow the measurement of any carryover effects.

5.3.2 Calculations

Data for chemical composition of feed and dry matter intake (DMI) for each experimental period of trials 1 and 2 were presented in Chapter 3. The milk yield and liveweight change resulting from the treatments in each experimental period of trials 1 and 2 were presented in Chapter 4. Marginal responses to supplements were calculated as:

$$\frac{\text{(Mean of treatment group} \quad - \quad \text{Mean of control group)}}{\text{Mean ME intake from supplement}}$$

Immediate milksolids responses were calculated as the predicted mean daily milksolids yield of each treatment group minus the predicted mean milksolids yield of the respective control group measured during each experimental period, divided by the daily metabolisable energy intake from supplementary feed (g MS/MJME). In the same way, liveweight gain responses were calculated as the predicted mean rate of liveweight change of each treatment group minus the predicted mean rate of liveweight change of the respective control group measured over each experimental period, divided by the daily ME intake from the supplementary feed (g LW/MJME). Carryover milksolids responses were calculated as mean daily milksolids yield of each early and mid lactation treatment group minus the average milksolids yield of the respective control group measured during the four weeks after the cessation of supplementary feeding, divided by the daily ME intake from supplementary feed during the preceding experimental period. Total milksolids responses were calculated for cows in early and mid lactation in the same way.

5.3.3 Statistical analysis

The mean milksolids and liveweight gain responses, calculated as above, were analysed as a four by three by two factorial arrangement using the linear model of Data Desk 6.1 (Velleman, 1997). Non-significant interactions (P>0.05) were removed from the model. Data are presented as the predicted means with standard errors of the difference (SED) using the highest order significant interactions as the error term.

The combined data from trials 1 and 2 were subject to multiple regression analysis using Data Desk 6.1 (Velleman, 1997). The factor, relative feed deficit (RFD), was calculated as the average milksolids yield of each control group measured during the pre-experimental uniformity week minus the average milksolids yield measured during the final three weeks of each experimental period. The factor "unsupplemented milksolids yield" was the average milksolids yield of each respective control group during each respective experimental period. Combinations of factors were alternatively analysed to establish models of best fit to the calculated milksolids responses, as indicated by adjusted 100 R^2. Multiple regression equations are presented with standard errors and P values for each coefficient, adjusted 100 R^2 and a residual standard deviation (rsd).

5.4 Results

5.4.1 Immediate responses to supplementary feeds

The effect of stage of lactation and season of the year on the immediate milksolids response to MG and BR supplements during trials 1 and 2 are presented in Tables 5.1 and 5.2, respectively. In both trials there were significant interactions ($P>0.05$) between stage of lactation and feed, and between season of the year and feed in their effects on immediate milksolids response. The effects of stage of lactation, season of the year and type of supplement on the liveweight gain response during the supplementary feeding periods of trials 1 and 2 are presented in Table 5.3. No interactions were detected between stage of lactation and feed, or between season of the year and feed for immediate liveweight response.

5.4.1.1 Stage of lactation

During trial 1, early lactation cows demonstrated larger ($P<0.05$) milksolids responses to MG than mid lactation cows, whereas for cows offered BR, those in mid lactation showed larger ($P<0.05$) responses than those in late lactation (Table 5.1). During trial 2, stage of lactation had no effect ($P>0.10$) on the response to MG, however, for cows offered BR, the response of late lactation cows was smaller ($P<0.05$) than the response of mid lactation cows (Table 5.2).

In trial 1 the supplements had a greater effect ($P=0.10$) on the liveweight gain of the late lactation cows than for those in earlier lactation. However, in trial 2 the supplements resulted in early lactation cows gaining more ($P<0.05$) liveweight than the mid lactation cows (Table 5.3).

5.4.1.2 Season of the year

During trial 1, milksolids responses to the MG were smaller ($P<0.05$) in the spring and autumn than in the summer and winter, likewise, responses to the BR were lowest ($P<0.05$) in the spring and largest ($P<0.05$) in the summer and autumn. During trial 2, responses to the MG were smaller ($P<0.05$) in spring and summer than in autumn, and

Table 5.1: Trial 1: The average immediate milksolids responses (g MS/MJME) resulting from maize grain (MG) and nutritionally balancing (BR) supplements offered at 50 MJME/cow/day to cows at different stages of lactation and seasons of the year.

	MG	**BR**
Stage of Lactation		
Early	5.1	3.9
Mid	3.9	4.5
Late	4.7	3.3
SED*	0.41	0.41
P value♣	0.02	0.03
Season		
Spring	3.7	2.0
Summer	5.3	4.6
Autumn	4.1	3.4
Winter	5.2	5.6
SED*	0.47	0.47
P value♣	0.01	>0.001

Interactions ($P<0.05$) were detected between stage of lactation and feed, and between season and feed.

*SED uses the interaction between stage of lactation, season and feed as the error term.

♣P value for the largest contrast within stage of lactation or season for each feed.

Table 5.2: Trial 2: The average immediate milksolids responses (g MS/MJME) resulting from maize grain (MG) and nutritionally balancing (BR) supplements offered at 80 MJME/cow/day to cows at different stages of lactation and seasons of the year.

	MG	**BR**
Stage of Lactation		
Early	1.2	2.2
Mid	1.6	2.7
Late	1.8	1.8
SED*	0.30	0.30
P value♣	0.11	0.02
Season		
Spring	0.3	0.3
Summer	0.9	2.1
Autumn	2.0	3.3
Winter	3.1	3.3
SED*	0.35	0.35
P value♣	>0.001	>0.001

Interactions (P<0.05) were detected between stage of lactation and feed, and between season and feed.

*SED uses the interaction between stage of lactation, season and feed as the error term.

♣P value for the largest contrast within stage of lactation or season for each feed.

Table 5.3: Trials 1 and 2: The average immediate liveweight response (g/MJME) resulting from maize grain (MG) and nutritionally balancing (BR) supplements offered to cows at different stages of lactation and seasons of the year.

	Trial 1	Trial 2
Stage of Lactation		
Early	4.6	6.4
Mid	4.1	2.1
Late	10.1	4.6
SED*	3.5	1.9
P value♣	0.10	0.04
Season		
Spring	11.1	3.0
Summer	4.9	3.0
Autumn	0.3	5.9
Winter	8.9	5.7
SED*	4.00	2.17
P value♣	0.02	0.20
Supplement		
MG	6.0	3.8
BR	6.5	5.0
SED*	2.83	1.53
P value♣	0.87	0.47

No two-way interactions ($P>0.05$) were detected.

*SED uses all interactions among stage of lactation, season and feed to calculate the error term.

♣P value for the largest contrast within stage of lactation or season for each feed.

the responses in winter were larger than those in autumn. Likewise, the responses to BR in trial 2 were smallest in spring ($P<0.01$), and were larger ($P<0.05$) in autumn and winter than in summer.

During trial 1 the liveweight gain responses were larger ($P<0.05$) in spring than in autumn. In contrast, season of the year had no effect ($P>0.10$) on the liveweight gain response of cows to supplements during trial 2.

5.4.1.3 Type of supplementary feed

MG supplements resulted in larger ($P<0.05$) milksolids responses than BR supplements in early and late lactation, and during the spring of trial 1 (Table 5.1). However, during trial 2, BR resulted in larger responses ($P<0.05$) than MG, for early and mid lactation cows, and during the summer and autumn (Table 5.2). Type of supplement had no effect ($P>0.10$) on liveweight gain in trial 1 or 2 (Table 5.3).

5.4.2 Carryover responses and total milksolids responses to supplementary feeds

The effects of stage of lactation, season of the year, and type of supplement on the carryover milksolids responses of cows for four weeks immediately after supplementary feeding are presented in Table 5.4. Total milksolids responses, measured from the commencement of supplementary feeding until four weeks after supplementary feeding had finished, are presented in Table 5.5. No interactions ($P>0.05$) were detected between stage of lactation and feed, or between season of the year and feed, for carryover or total milksolids responses.

5.4.2.1 Stage of lactation

Early lactation cows demonstrated larger ($P<0.05$) carryover effects than the mid lactation cows in trial 1, but the opposite occurred ($P=0.06$) in trial 2 (Table 5.4). When the immediate and carryover responses were considered together, mid lactation cows in trial 2 had larger ($P<0.05$) total milksolids responses to supplements than early lactation cows. However, there was no difference ($P>0.10$) between the total milksolids response of early and mid lactation cows in trial 1 (Table 5.5).

Table 5.4: Trials 1 and 2: The average carryover milksolids response (g MS/MJME) measured for four weeks after maize grain (MG) and nutritionally balancing (BR) supplements had been offered to cows at different stages of lactation during four seasons of the year.

	Trial 1	Trial 2
Stage of Lactation		
Early	2.3	0.5
Mid	1.2	1.5
SED*	0.45	0.48
P value♣	0.03	0.06
Season		
Spring	2.7	-0.7
Summer	1.6	1.4
Autumn	0.3	1.2
Winter	2.4	1.9
SED*	0.64	0.68
P value♣	<0.01	0.01
Supplement		
MG	1.9	0.5
BR	1.6	1.4
SED*	0.45	0.49
P value♣	0.45	0.08

No two-way interactions (P>0.05) were detected.

*SED uses all interactions among stage of lactation, season and feed to calculate the error term.

♣P value for the largest contrast within stage of lactation or season for each feed.

Table 5.5: Trials 1 and 2: The average total milksolids response (g MS/MJME) resulting from maize grain (MG) and nutritionally balancing (BR) supplements offered to cows at different stages of lactation during four seasons of the year.

	Trial 1	Trial 2
Stage of Lactation		
Early	6.8	2.2
Mid	5.4	3.7
SED*	0.83	0.52
P value♣	0.11	0.02
Season		
Spring	6.4	-0.1
Summer	6.9	3.4
Autumn	3.6	3.6
Winter	7.5	4.7
SED*	1.17	0.74
P value♣	<0.01	<0.01
Supplement		
MG	6.1	1.9
BR	6.1	3.9
SED*	0.83	0.52
P value♣	0.96	<0.01

No two-way interactions (P>0.05) were detected.

*SED uses all interactions among stage of lactation, season and feed to calculate the error term.

♣P value for the largest contrast within stage of lactation or season for each feed.

5.4.2.2 Season of the year

In trial 1, carryover responses after the period of supplementary feeding were smaller ($P<0.05$) during autumn than during spring and winter, whereas during trial 2, carryover responses were smaller ($P<0.05$) during spring than during the other seasons of the year (Table 5.4). During trial 1, total responses were smaller ($P<0.05$) in autumn than at other seasons of the year and there was no difference ($P>0.30$) between the total milksolids response of cows in spring, summer and winter in trial 1 (Table 5.5). During trial 2, carryover responses were lower ($P<0.01$) during spring than during the other seasons, and there was no difference ($P>0.10$) in the total milksolids responses between summer, autumn and winter.

5.4.2.3 Type of supplementary feed

There was no difference ($P>0.40$) in the carryover or total milksolids responses resulting between the BR or MG in trial 1 (Tables 5.4 and 5.5). However during trial 2, there was a trend for BR to result in larger carryover ($P<0.08$), and total ($P<0.01$) milksolids responses than the MG supplement.

5.4.3 Predicting the milksolids response to supplementary feeding

Using the results of both trials, the relationship between the RFD (represented by the reduction in milksolids yield as that occurred as the control treatments were imposed) and the subsequent immediate and total milksolids responses of the respective supplemented herds are shown in Figures 5.1 and 5.2, respectively. The effects of the RFD and the absolute yield of the respective control group (unsupplemented milksolids yield measured during the experimental period), supplement intake, and stage of lactation on the immediate milksolids response to supplementary feeding are described by the multiple regression equation presented in Table 5.6. The effects of the RFD, pasture ME allowance at the time of supplementary feeding, supplement intake and the stage of lactation on the total milksolids response to supplementary feeding are described by the multiple regression equation presented in Table 5.7. The magnitude of the immediate and total milksolids responses to supplementary feeds increased ($P<0.01$)

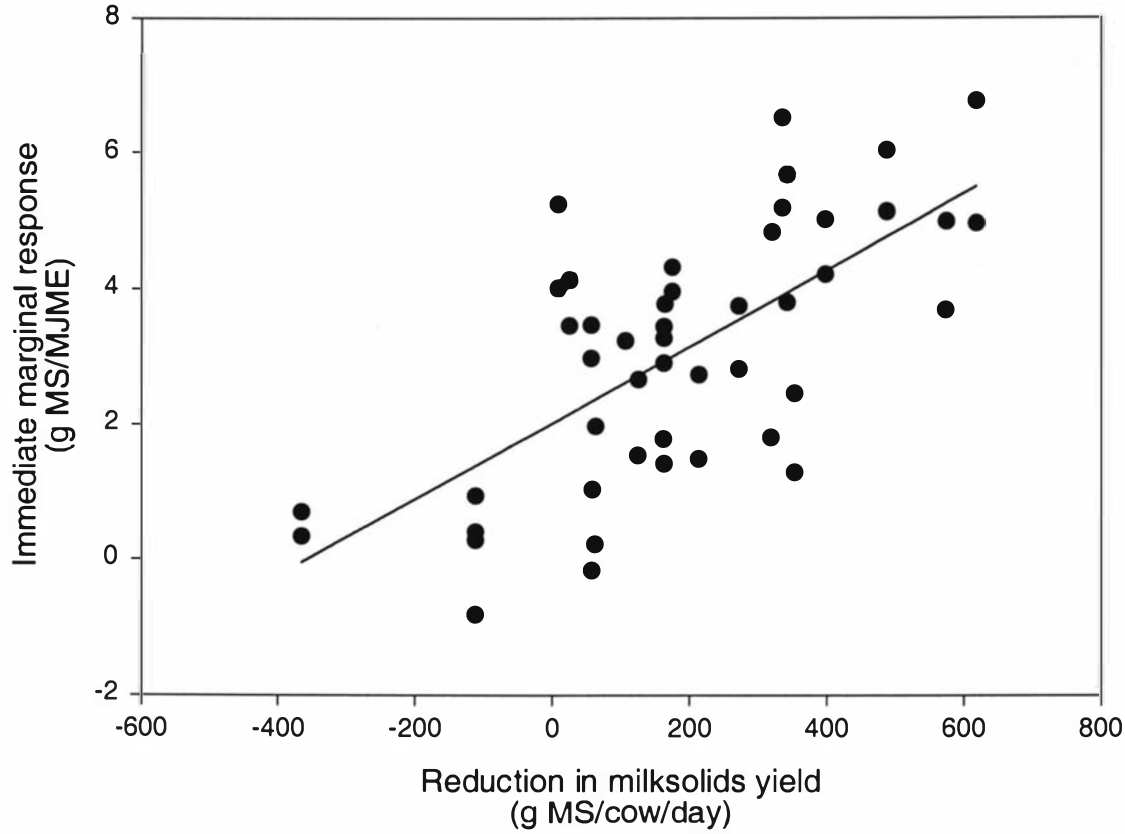


Figure 5.1: Immediate response. The effect of the decline in milksolids yield of the unsupplemented cows that occurred as restricted feeding was imposed (as a measure of the relative feed deficit) on the immediate milksolids response to supplementary feeds.

Immediate marginal response (g MS/MJME) = 2.02 (±0.26) + 0.006 (±0.0009) reduction in milksolids yield (g/cow/day); Adjusted R^2 = 0.44; r.s.d. = 1.38.

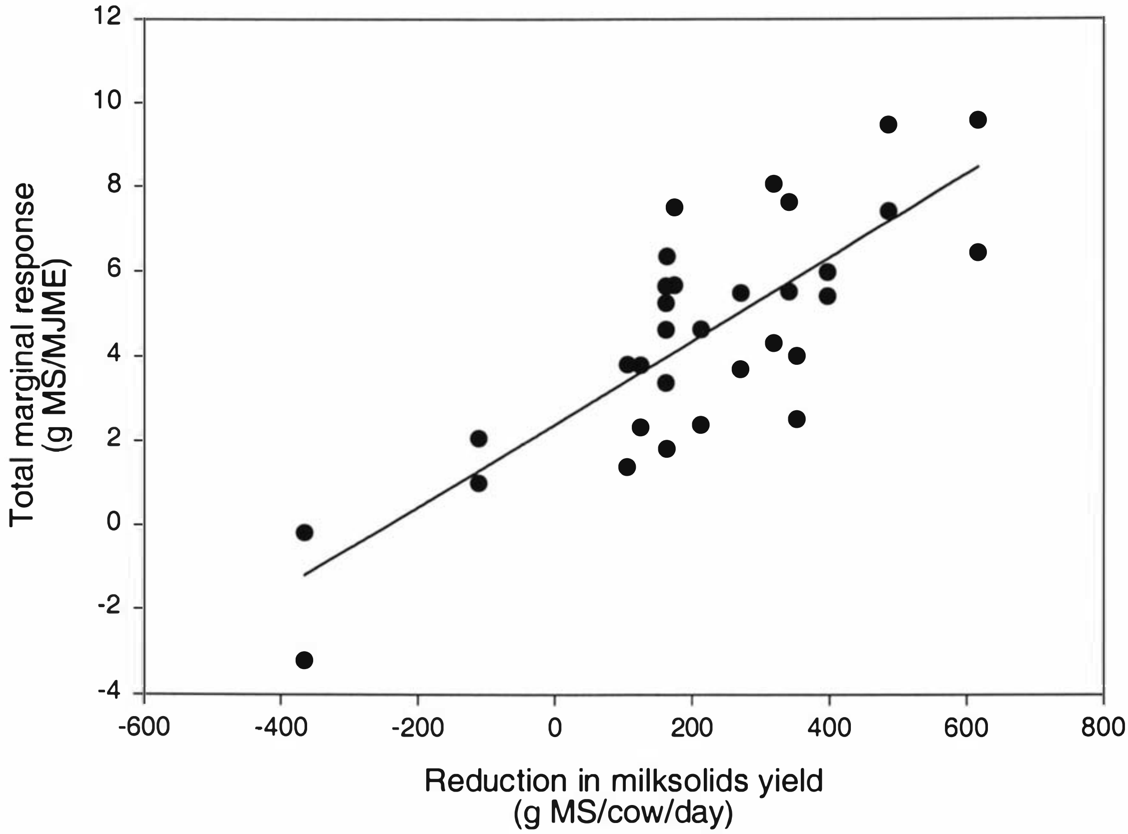


Figure 5.2: Total response. The effect of the decline in milksolids yield of the unsupplemented cows that occurred as restricted feeding was imposed (as a measure of the relative feed deficit) on the total milksolids response of early and mid lactation cows to supplementary feeds.

Total marginal response (g MS/MJME) = 2.40 (±0.41) + 0.010 (±0.001) reduction in milksolids yield (g/cow/day); Adjusted R^2 = 0.63; r.s.d. = 1.69.

Table 5.6: Immediate response. The effect of the reduction in milksolids yield of the unsupplemented cows as restricted feeding was imposed (as a measure of the relative feed deficit), the milksolids (MS) yield of the unsupplemented cows measured during the experimental period, supplement intake and stage of lactation on the immediate milksolids response to supplementary feeds (g MS/MJME).

Variable	Coefficient	SE of coefficient	P value
Constant	11.1	1.87	<0.001
Reduction in MS yield (kg/cow/day)	2.1	1.00	<0.05
Unsupplemented MS yield (kg/cow/day)	-4.1	0.99	<0.001
Supplement intake (MJME/cow/day)	-0.06	0.014	<0.001
Stage of lactation (DIM)	-0.005	0.0029	0.07

Adjusted $100R^2 = 68.8\%$; r.s.d = 1.09.

Table 5.7: Total response. The effect of the reduction in milksolids yield of the unsupplemented cows as restricted feeding was imposed (as a measure of the relative feed deficit), the pasture allowance, supplement intake and stage of lactation on the total milksolids response of early and mid lactation cows to supplementary feeds (g MS/MJME).

Variable	**Coefficient**	**SE of coefficient**	**P value**
Constant	10.2	2.30	<0.001
Reduction in MS yield (kg/cow/day)	9.1	1.18	<0.001
Pasture allowance (MJME/cow/day)	-0.02	0.006	<0.01
Supplement intake (MJME/cow/day)	-0.02	0.022	0.30
Stage of lactation (DIM)	0.007	0.005	0.17

Adjusted $100R^2$ = 79.4%; r.s.d = 1.35.

as the magnitude of the decline in milksolids yield of the unsupplemented cows that occurred when the restricted feeding was imposed, increased. The immediate and total milksolids response increased (<0.05) as the level of feeding of the unsupplemented cows decreased, as measured by unsupplemented milksolids yield (Table 5.6) or pasture allowance (Table 5.7). As the amount of supplement eaten increased the immediate milksolids response decreased (P<0.01), however, this relationship was not significant (P>0.10) for total milksolids response. Immediate milksolids responses declined slightly (P=0.07) as stage of lactation progressed (Table 5.6).

5.5 Discussion

5.5.1 Stage of lactation

While there were often differences between the milksolids and liveweight responses that resulted from offering supplements to cows at different stages of lactation, no consistent patterns emerged. Previous research has also provided conflicting evidence on the effects of stage of lactation and season on supplementary feeding response. Stockdale *et al.*, (1987) reported milksolids responses of 7.0 g MS/MJME from early and only 3.7 g MS/MJME from late lactation cows in a series of experiments conducted in spring. While Stockdale and Trigg (1989) also reported larger responses to concentrates from mid lactation than from late lactation cows in spring, this occurred only at very low pasture intakes (6.8 kg DM/cow/day). In contrast, stage of lactation had no effect on the magnitude of the immediate supplementary feeding response at pasture intakes of 9.3 and 11.7 kg DM/cow/day (Stockdale and Trigg, 1989).

5.5.2 Season of the year

The immediate milksolids responses were smallest in the spring experimental periods during both of the present trials. While in trial 1 a large liveweight response and large subsequent carryover response resulted in a total response that was similar to those measured in the other seasons, in trial 2 the total response in spring was also smaller than those measured during the other seasons. The effects of stage of lactation and of season have usually been confounded in previous experiments, because of the seasonal calving pattern of most grazing dairy herds. Nevertheless, experiments have usually not demonstrated large seasonal effects. In a series of three experiments using spring calving cows, Stakelum (1986a, 1986b, 1986c) demonstrated immediate responses of 2.2, 2.4 and 2.0 g MS/MJME in spring, summer and autumn, respectively. Stockdale and Dellow (1995) compared the response of spring calving cows to maize silage in spring, summer and autumn and demonstrated responses of 3.8, 3.6 and 5.7 g MS/MJME, respectively.

Larger responses of spring calving grazing cows to supplements of cereal grain, and mixtures of cereal grains and lupins, in summer and autumn than in spring have recently been reported (Stockdale, 1999a). In the same experiments, season had no effect on the milk yield response to supplements of hay. Stockdale (1999b) attributed the increased summer and autumn milksolids responses to the concentrate based supplements to the low quality of the pasture on offer during the summer (8.7 MJME/kg DM) and autumn (9.2MJME/kg DM), compared to the pasture offered during the spring (10.3 MJME/kg DM). While in the present data there was no association between pasture quality parameters and the magnitude of the marginal responses measured (Chapter 4), the lowest ME concentration of pasture offered was 10.9 MJ/kg DM, and concentrations were often greater than 12.0 MJME/kg DM (Chapter 3).

5.5.3 Carryover responses

The magnitude of the carryover responses measured in the present trials were generally about 50% of the immediate responses. Stakelum (1986a, 1986b, and 1986c) demonstrated carryover responses of 1.8, 3.2 and 0.4 g MS/MJME during the three weeks after supplementary feeding in spring, summer, and autumn, respectively, which on average were almost as large as the immediate responses cited above. In a full lactation study, offering cows 55 MJME/cow/day as pasture silage to dairy cows in spring, summer and autumn resulted in immediate responses of 2.4, 1.5 and 6.1 g MS/MJME, respectively, with the large autumn responses being associated with an extra 7 days-in-milk (Clark, 1993). However, by the end of the season, the total responses from spring and summer supplementary feeding had increased to 6.3 and 6.1 g MS/MJME (Clark, 1993). In addition to improved milk yield and body reserves resulting from supplementary feeding, these large carryover responses were also associated with the accumulation of extra pasture, resulting from substitution, and a subsequent increase in pasture allowance and DMI after supplementary feeding had ceased (Clark 1993). The total milksolids response of a whole farm system to supplementary feeding has been estimated to be twice the immediate response (Bryant and Trigg, 1985; Kellaway and Porta, 1993). While the data reported by Clark (1993) support these estimates, the present data suggest that the "cow factors" are likely to contribute only half of the total carryover response measured within systems experiments, with the remainder being provided by the effects of pasture substitution within the system.

5.5.4 Potential energy deficit

These results clearly demonstrate that stage of lactation and season of the year have only small, and inconsistent effects on the response of dairy cows to supplementary feed. Nevertheless, the data also demonstrates a high level of variability, with total milksolids responses ranging from –0.1 (±0.74) to 7.5 (±1.17) g MS/MJME. This suggests that other factors, of far greater importance than the changes associated with stage of lactation and season, are responsible for controlling the magnitude of milksolids response.

It has been demonstrated that the level of pasture feeding, as measured by pasture allowance, has a large influence over the extent to which cows substitute pasture for supplement. As pasture allowance is increased, pasture substitution increases such that a given amount of supplement has a smaller effect on the total intake of energy and nutrients (Grainger and Mathews, 1989; Chapter 3). Both in early and late lactation, as feeding level increases, either as additional pasture or as higher allowances of supplementary feed, the response to each incremental unit of supplement decreases in both grazing (Robaina *et al.,* 1998) and indoor studies (Stockdale and Trigg, 1989). In the present data, this effect can be seen as a reduction in the total and immediate milksolids responses with increasing pasture allowance (Table 5.7). Again, higher pasture allowance, and the higher daily milksolids yield of the control cows, also reduced the milksolids response (Table 5.6). Pasture allowances, supplementary feed intakes and milk yields were higher in trial 2 than in trial 1, which explains the lower marginal milksolids responses measured in trial 2.

As supplementary feeds are introduced, and energy intake is increased, a declining proportion of the addition feed energy is partitioned toward milk production and an increasing proportion is partitioned toward increasing body reserves (Broster and Thomas, 1981). Thus, as the amount of supplement is increased at a given pasture allowance or intake, the marginal milksolids response declines (Stockdale *et al.*, 1987, Stockdale and Trigg, 1989; Robaina *et al.,* 1998). In the present data this is demonstrated in a 0.06 g MS/MJME decline ($P<0.01$) in marginal immediate response per 1 MJ increase in supplementary feed intake (Table 5.6). However, it is interesting to note that the effect of supplementary feed intake on total marginal milksolids response was not significant ($P>0.30$). It could be assumed that although increasing supplementary feed intake reduced the immediate milksolids response, it resulted in larger deposits of body reserves at the end of the supplementary feeding period, which subsequently resulted in larger carryover effects and similar total marginal milksolids responses.

However, the factor exerting the greatest influence on the marginal milksolids response to supplementary feeds was the magnitude of the decline in milksolids yield of the unsupplemented cows that occurred as the restricted feeding was imposed. The response of the cows to the feed restriction provides an indirect measure of the RFD. The importance of the RFD, in determining the response of dairy cows to increasing feeding levels, has previously been discussed in concept (Oldham and Emmans, 1989; AFRC, 1998). The RFD refers to the current theoretical feed demand of the animal, which is determined by genetic merit and physiological state (stage of lactation, growth and reproductive cycles) modified by recent nutritional history, minus the current actual feed supply ($MEI_{target} - MEI_{actual}$). It is assumed that if sub-optimal nutrition is imposed on the cow over a long period of time, energy output will reach equilibrium and a new, lower target milk yield will be derived, thereby gradually reducing feed demand and the potential feed deficit (Oldham and Emmans, 1989; AFRC, 1998).

During the present trials, the pasture allowance offered during the experimental periods represented a restriction relative to the pasture allowance offered up to and during the uniformity week. The severity of this feed restriction varied between experimental periods and, to a lesser degree, between cows at different stages of lactation. It has been assumed that the magnitude of the decline in milksolids yield that occurred as the feeding treatments were imposed, provides a measure of the severity of the feed restriction relative to current feed demand and therefore of the potential energy deficit for that particular treatment group. Thus, Figures 5.1 and 5.2 clearly demonstrate the association between potential energy deficit and the marginal immediate and total milksolids responses. A reduction in milksolids yield (as a measure of the RFD) of 1.0 kg MS/cow/day was associated with an increases ($P<0.01$) in the total marginal milksolids response of 9 g MS/MJME of supplement (Table 5.7).

The factors considered by the multiple regression equations contained in Tables 5.6 and 5.7, calculated from some recent grazing experiments, are presented in Table 5.8. One data point from Stockdale and Trigg (1985) was excluded as the immediate milksolids response was two fold greater than any other data points in the published data (Table 5.8), and two fold greater than the immediate milksolids response in the present data set from which the models were derived. Using the data presented in Table 5.8, the model presented in Table 5.6 under-predicted ($P<0.05$) the immediate milksolids responses calculated from the published values by 0.9 ($\pm$0.29) g MS/MJME (Figure 5.3). As would be expected, the model presented in Table 5.7 generally predicted total milksolids responses which were greater than the immediate milksolids responses calculated from the published values (Figure 5.4).

Table 5.8: The factors used by the models shown in Tables 5.6 and 5.7 to predict the immediate marginal milksolids response for some recently published experiments shown in Figure 5.3, and the total marginal milksolids response shown in Figure 5.4.

Reference	**Stage of lactation (DIM)**	**Control MS yield (kg/c/d)**	**Reduction in MS yield (kg/c/d)**	**Pasture allowance (MJME/c/d)**	**Supplement intake (MJME/c/d)**	**Reported immediate response (g MS/MJME)**
Robainia *et al.*, 1998	200	1.03	0.27	421	55	4.7
	200	0.79	0.51	281	55	6.2
Stockdale, 1996	213	0.75	0.34	233	52	5.4
	213	1.15	-0.06	520	52	1.6
Grainger and Mathews, 1989	21	1.18	0.24	94	37	3.1
	21	1.52	-0.09	211	37	3.9
	21	1.72	-0.29	410	37	1.1
Stockdale and Trigg, 1985	240	0.68	0.19	140	46	6.3
	240	0.68	0.19	143	81	3.4
	240	0.78	0.09	242	23	6.9
	240	0.78	0.09	250	45	5.7
	240	0.78	0.09	247	79	4.0

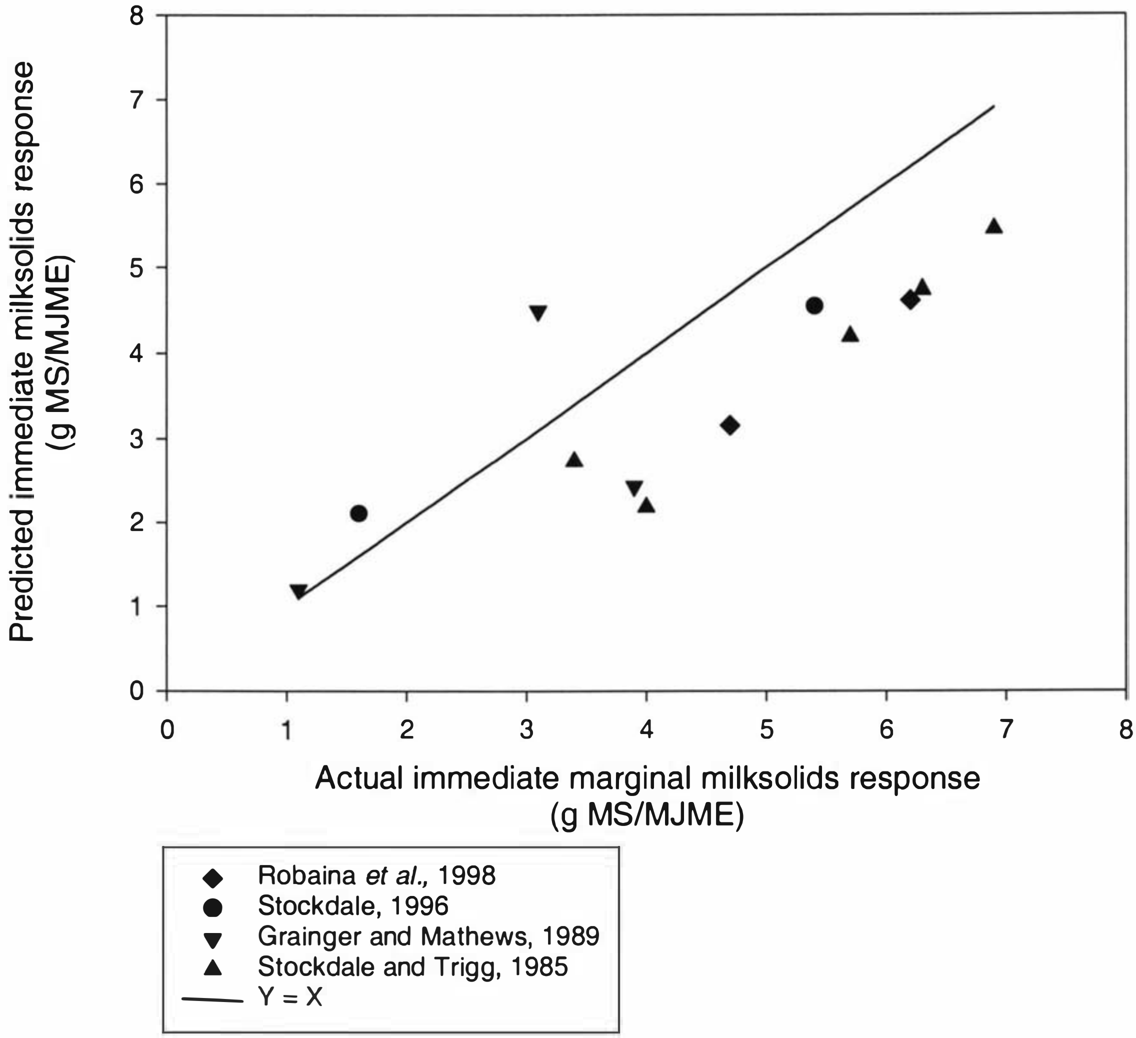


Figure 5.3: A comparison of the predicted immediate milksolids response using the model presented in Table 5.6, and the immediate milksolids response calculated from the published values of some recent experiments (Table 5.8).

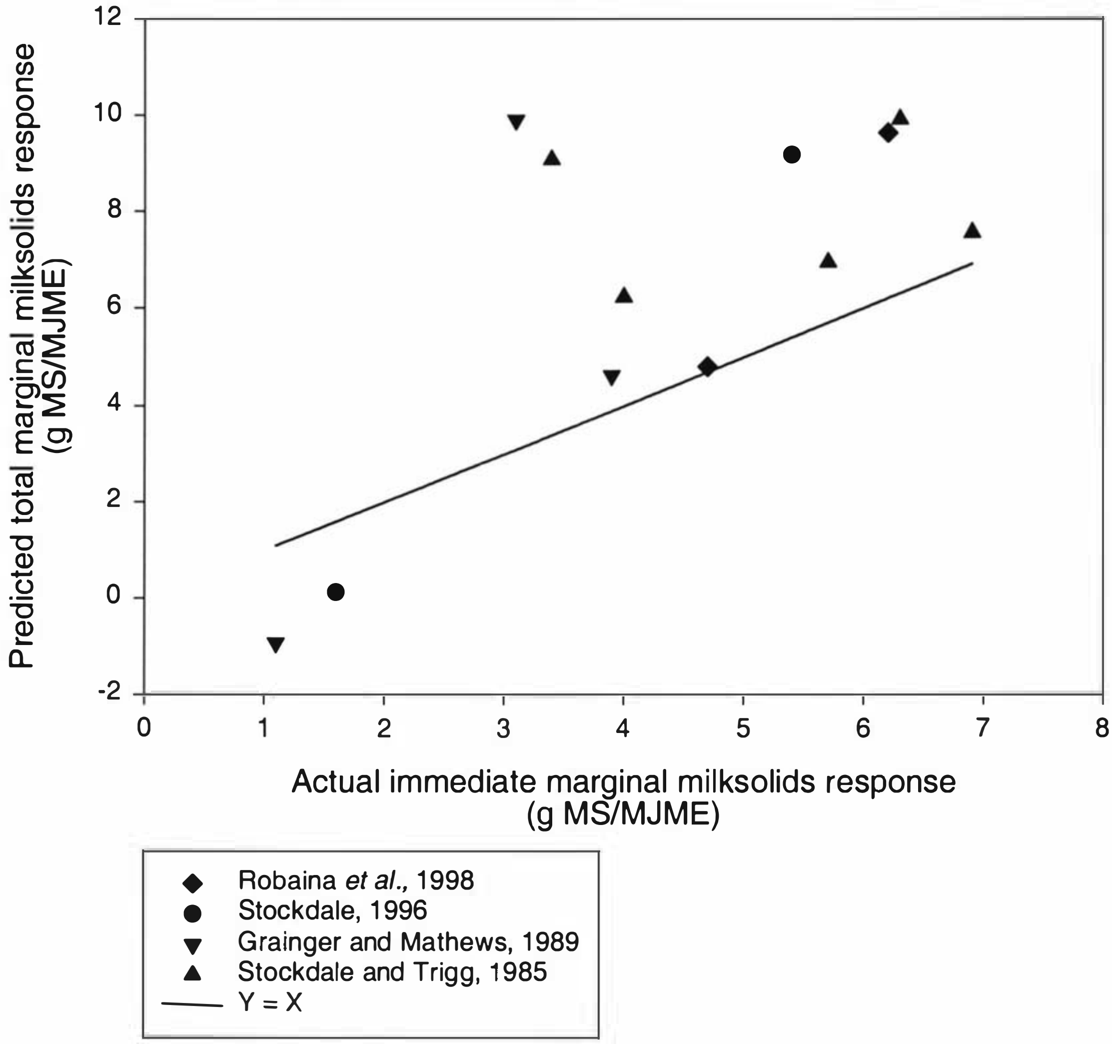


Figure 5.4: A comparison of the predicted total milksolids response using the model presented in Table 5.7, and the immediate milksolids response calculated from the published values of some recent experiments (Table 5.8).

Given the wide range of experimental techniques used, and conditions under which these experiments have been undertaken, the model of immediate milksolids yield responses closely predicted the results of the published work. This suggests that the factors included in the model, particularly the decline in milksolids yield, the unsupplemented milksolids yield, and the amount of supplement offered do account for much of the variation in published results. Insufficient data are available to test the model predicting total milksolids yield. However, it does indicate that the immediate effects published for many experiments underestimate the total response. If this model proves to be accurate, it suggests that the level of feeding provided by experimental treatments, relative to the level of feeding immediately before treatments have been imposed, is an important factor in determining the milksolids response to supplementary feeds.

5.6 Conclusions

These data suggest that the magnitude of the total milksolids response to supplementary feed can largely be predicted by the magnitude of the RFD, as represented by the decline in milksolids yield that occurs as restricted feeding is imposed, and the ME allowance from pasture and supplement. These are all factors which can be estimated by farmers in advance of supplementary feeding decisions, and they may provide the basis for prediction of the milksolids responses of grazing dairy cows to supplements. Irrespective of season of the year, and stage of lactation, the largest total milksolids responses are likely to occur during periods when cows have suffered a sudden decline in pasture allowance, and when small quantities of supplementary feed are offered.

5.7 References

AFRC 1998. *Responses in the Yield of Milk Constituents to the Intake of Nutrients by Dairy Cows.* CAB International, Wallingford.

Broster, W. H., and Broster, V. J. 1984. Long term effects of plane of nutrition on the performance of the dairy cow. *Journal of Dairy Research* **51**.149-196

Broster, W. H. and Thomas, C. 1981. The influence of level and pattern of concentrate input on milk output. In *Recent Advances in Animal Nutrition*, 1981, Ed. W. Haresign, Butterworths, London. pp. 49-69.

Bryant, A.M. and Trigg, T.E. 1985. The nutrition of the grazing dairy cow in early lactation. *Dairy Production from Pasture.* Eds. K.L. Macmillan and V.K. Taufa. pp 185-207. Clark and Matherson Ltd, Hamilton, NZ.

Clark, D. A. 1993. Silage for milk production. *Proceedings of the Ruakura Farmers' Conference* **45:** 41-46.

Grainger, C. and Mathews, G. L. 1989. Positive relationship between substitution rate and pasture allowance for cows receiving concentrates. *Australian Journal of Experimental Agriculture* **29:** 355-360.

Kellaway, R. C. and Porta S. 1993. Feeding concentrates: supplements for dairy cows. E. Hopkins, ed. Agmedia, Melbourne, Australia.

Oldham, J. D. and G. C. Emmans. 1989. Prediction of responses to required nutrients in dairy cows. *Journal of Dairy Science* **72:** 3212-3229.

Robaina, A. C, Grainger, C., Moate, P., Taylor, J. and Stewart, J. 1998. Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* **38:** 541-549.

Stakelum, G. 1986a. Herbage intake of grazing dairy cows. 1. Effect of autumn supplementation with concentrates and herbage allowance on herbage intake. *Irish Journal of Agricultural Research* **25:** 31-40.

Stakelum, G. 1986b. Herbage intake of grazing dairy cows. 2. Effect of herbage allowance, herbage mass and concentrate feeding on the intake of cows grazing primary spring grass. *Irish Journal of Agricultural Research* **25:** 41-51.

Stakelum, G. 1986c. Herbage intake of grazing dairy cows. 3. Effect of herbage mass, herbage allowance and concentrate feeding on the herbage intake of dairy cows grazing on mid-summer pasture. *Irish Journal of Agricultural Research* **25:** 179-189.

Stockdale, C. R. 1996. Substitution and production responses when lactating dairy cows graze a white clover pasture supplemented with maize silage. *Australian Journal of Experimental Agriculture* **36:** 771-776.

Stockdale, C. R. 1999a. Effects of cereal grain, lupins-cereal grain or hay supplements on the intake and performance of grazing dairy cows. *Australian Journal of Experimental Agriculture* **39:** 811-817.

Stockdale, C. R. 1999b. The nutritive characteristics of herbage consumed by grazing dairy cows affect milk yield responses attained by concentrate supplementation. *Australian Journal of Experimental Agriculture* **39:** 379-387.

Stockdale, C. R., Callaghan, A, and Trigg, T. E. 1987. Feeding high energy supplements to pasture-fed dairy cows. Effects of stage of lactation and level of supplement. *Australian Journal of Agricultural Research* **38:** 927-940.

Stockdale, C. R. and Trigg, T. E. 1985. Effect of pasture allowance and level of concentrate feeding on the productivity of dairy cows in late lactation. *Australian Journal of Experimental Agriculture* **25:** 739-744.

Stockdale, C. R. and Trigg, T. E. 1989. Effect of feeding levels on the responses of lactating dairy cattle to high energy supplements. *Australian Journal of Experimental Agriculture* **29:** 605-611.

Stockdale, C. R. and Dellow, D. W. 1995. The productivity of lactating cows grazing white clover and supplemented with maize silage. *Australian Journal of Agricultural Research* **46:** 1205-1217.

Velleman, P. F. 1997. Data Desk, Version 6. Data Description, Ithaca, NY.

CHAPTER SIX

EXTRA FEED FOR GRAZING DAIRY COWS: A COMPARISON OF MAIZE GRAIN, MAIZE SILAGE, A NUTRITIONALLY BALANCING RATION AND EXTRA PASTURE

CHAPTER 6: EXTRA FEED FOR GRAZING DAIRY COWS: A COMPARISON OF MAIZE GRAIN, MAIZE SILAGE, A NUTRITIONALLY BALANCING RATION AND EXTRA PASTURE

6.1 Abstract

Five farmlet systems were developed with the objective of increasing the production efficiency of seasonal-calving dairy farming systems by integrating large quantities of supplementary feed with grazed pasture. An experiment was conducted using these farmlet systems to measure the long-term effects of different forms of supplementary feed on cow performance. Four of five farmlets (5.67 ha) were stocked with 25 high genetic merit Friesian cows (4.41 cows/ha) and one farmlet was stocked with 19 cows (3.35 cows/ha) calving between 12 July and 31 August in each year, for three complete years. Herds on the higher stocked (HS) farmlets were offered either no supplementary feed from off farm sources (Control), or supplementary feeds of rolled maize grain (MG), or whole maize crop silage (WCS), or a nutritionally balancing ration (BR). The herd grazing the lower stocked farmlet (LS) was offered supplementary feed of pasture silage that had been conserved on that farmlet from surplus spring pasture. Supplementary feeds were offered when the post-grazing pasture mass decreased below a minimum value thought to impair pasture re-growth, or when the cows were apparently eating less than 15 kg DM/cow/day from pasture alone.

Pasture growth ranged from 17.1 to 20.8 t DM/ha/year and was greatest during year 1 and least during year 3. The high stocking rate and early calving date of the supplemented herds resulted in low pasture allowances at most times of the year, requiring the use of 1.1 to 1.7 t DM/cow/year as supplementary feed. While some pasture substitution may have occurred, there was no difference between the annual pasture dry matter intake (DMI) of the supplemented and control herds. However, LS herd ate about 1000 kg DM/cow/year more than the control HS herd. Feeding treatments of MG, WCS, BR and LS increased annual milksolids (MS) yield from

269 (Control herd) to 400, 363, 408 and 361 (±15.8) kg/cow, respectively. Differences in total dry matter and metabolisable energy intake per cow explained most of the differences in MS yield per cow between the five farmlets. Marginal responses from the MG, WCS, BR, and LS treatments averaged 7.3, 7.6, 7.8, and 6.6g MS/MJME over the three years of the experiment, although responses to BR were considerably larger in years 2 and 3 than in year 1. Cows in the HS supplementary feeding herds and the LS herd calved in fatter condition and maintained higher DMI in early spring, and had shorter post partum anoestrous interval and a lower incidence of anoestrous than those in the HS control herd.

6.2 Introduction

As part of an export-based industry with little Government protection, New Zealand dairy farmers are directly exposed to world commodity markets and receive one of the lowest farm gate milk prices in the developed world. As a consequence, low cost production systems based on grazed pasture have been developed. These systems can achieve production costs of less than half the farm gate price, and can be highly profitable (LIC,1999). However, when pasture is the only source of feed, annual pasture yield of 16 – 18t DM/ha constrains milksolids (MS) production to around 1200 kg/ha on the most efficient farms (Penno, 1998). A key challenge for these farmers is to increase productivity and profitability. One possibility is by integrating supplementary feeds into pasture-based farming systems.

Currently, most herds are calved seasonally in an attempt to synchronise the feed requirements of the cows within the herd, and match the feed requirements of the herd to the pattern of pasture production. Cows are mated and culled to achieve a calving spread of about 8 weeks in the late winter and early spring. The herd is generally milked for about 250 days before being dried-off as pasture growth slows in the late autumn. To achieve high levels of pasture utilisation and, therefore, high annual MS production per hectare, high stocking rates (2.5 to 3.5 cows/ha) are employed such that the feed requirements of the herd exceed pasture supply for much of the year. Nevertheless, despite the cost advantages, it is well recognized that high stocking rates, and the growth, availability and nutritional characteristics of pasture limit milk yield per cow to levels well below that achieved by dairy industries in other countries (Muller, 1993; Penno, 1998; Kolver and Muller, 1998).

For many years, dairy farmers have offered small amounts of supplementary feed to the grazing herd in an attempt to overcome periods of pasture deficit or to increase milk yields beyond the yield achievable from pasture alone. This practice has become common despite considerable evidence to show that the response of grazing dairy cows to supplementary feed is generally small and uneconomic (Leaver *et al.,* 1968; Kellaway and Porta, 1993). Some would argue that the practice of supplementary feeding persists because research has underestimated the total increase in milk production that results from supplementary feeding (Lean *et al.,* 1996). It is certainly true that the complex interactions between the animals, pastures and supplementary feeds require a long-term experimental approach to provide an accurate estimate of the total effect of supplementary feeds on the output of the whole farm system. Most supplementary feeding trials have been short in duration (3 – 6 weeks) and usually have not measured any of the carryover effects that may occur after the period of supplementary feeding. There have been few multiple lactation studies into the long-term effects of plane of nutrition (Broster *et al.,* 1993), and almost none have investigated the long-term effects of supplementary feeding in a grazing system.

The primary aim of supplementary feeding must be to increase the total energy and nutrient intake of the herd. The farm system must ensure that the uncontrolled substitution of supplementary feed for pasture is minimised, because a high proportion of ungrazed leaf material will senesce and decay before the subsequent grazing (Parsons and Chapman, 1998). Substitution increases as pasture allowance increases (Grainger and Mathews, 1989). Therefore, supplementary feeding should not occur when generous allowances are available, but should be offered in association with reduced pasture allowance; This will ensure that high total dry matter intake (DMI) is maintained together with reduced pasture DMI, to avoid the accumulation of excessive post-grazing pasture mass. Maximum responses will only occur if any increase in body reserves resulting from supplementary feeds also contribute to future increases in milk yield. For these reasons, it is likely that stocking rate is an important variable determining the responsiveness of the farm system to supplementary feeds, through its effects on total feed demand per hectare. The stocking rate should be high enough to ensure that the herd eats a high proportion of the pasture grown in spring, without the need for excessive pasture conservation. This would allow the use of imported supplementary feed to extend lactation by allowing early calving and delayed drying off, a strategy which has recently been shown to result in large milk yield responses (Clark, 1993; Pinares and Holmes, 1996). Improved responses to supplementary feeds may also occur if the supplements are specifically formulated to provide nutrients that are not provided by the pasture in sufficient quantities to meet the requirements of the cow (Edwards and Parker, 1994).

This chapter reports research designed to determine the long-term response of high stocked seasonal pasture-based dairying farm systems to supplementary feeds. Complete farmlet systems were used to measure the response to supplements of either rolled maize grain (MG), whole crop maize silage (WCS) or a nutritionally balancing supplementary feed (BR) on the annual milk yield of grazing dairy cows over three complete lactations. The performances of these three farmlet systems were compared with two other systems, which received no imported supplementary feed. One of the unsupplemented farmlets was at the same high stocking rate as the supplemented systems to allow the marginal response to each type of supplement to be calculated. The second of these two unsupplemented farmlets was at a lower stocking rate, in order to provide extra pasture per cow, so that the marginal response to extra pasture could also be measured.

6.3 Materials and methods

6.3.1 Experimental site, cows and management

6.3.1.1 Farmlets

Five farmlets, each 5.67 ha, were established in June 1995 and maintained for three complete seasons at the Dairying Research Corporation's No 2 Dairy, Hamilton, New Zealand (latitude 37° 47' South, longitude 175°19' East, altitude 40m above sea level). Each farmlet comprised fourteen paddocks (0.405ha) allocated to balance soil types (Horotiu silt loam (Umbric Vitrandept), Hamilton clay loam (Typic Haplohumult), and Te Rapa silty peat loam (Humic Haporthod)) and previous experimental treatments. Pastures were predominantly rye-grass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) associations. All paddocks regularly received fertiliser providing N, K, and P at approximately 200, 60, and 50 kg/ha/year, respectively, to ensure maintenance of soil nutrient status. Phosphatic fertiliser was applied in autumn and potassic fertiliser was applied in spring. Nitrogenous fertiliser was applied after each grazing, except during periods of summer moisture deficit.

6.3.1.2 Herds and management

Twenty multiparous and five primiparous high genetic merit Friesian dairy cows were allocated to four farmlets, and fifteen multiparous and four primiparous high genetic merit Friesian dairy cows were allocated to one farmlet on 1 June 1995. Cows were allocated to provide herds balanced for age, genetic merit, calving date, liveweight and condition score, and previous treatments. The lower stocking rate (LS) of 3.35 cows/ha was calculated as that required to maximise MS production per ha when no supplementary feed is offered (Penno, 1998). The higher stocking rate (HS) of 4.41 cows/ha was chosen to ensure that the herds could consume all of the pasture grown in spring, that pasture deficits were created for most of the rest of the year, and that large quantities of supplementary feeds were required. The planned start of calving of all herds was 13 July in 1995, and 11 July in 1996 and 1997, and every cow calved before 1 September each season. Cows due to calve after 1 September were treated to artificially induce premature calving before 14 August according to the procedure of Chesterton and Marchant (1985). Tail paint was applied 5 weeks before the planned start of mating. Seven days before the planned start of mating any cows that had not been detected in oestrus, as indicated by undisturbed tail paint, were subjected to veterinary examination by rectal palpation. Cows confirmed as anoestrous were treated to induce oestrus according to the procedures of Macmillan (1995), and were subsequently artificially inseminated within seven days of the planned start of mating. Cows observed in oestrus within the first 42 days after the planned start of mating were artificially inseminated with semen from high genetic merit Friesian sires. Hereford bulls were run with each herd from day 43 to day 84 after the planned start of mating. Cows were contained on the farmlets for the duration of the trial. During each season, five cows were culled from each of the higher stocked herds and four from the lower stocked herd on the basis of reproductive failure, health, age and genetic merit, and were replaced with primiparous cows on 1 June.

6.3.1.3 Grazing management

All herds were managed according to the decision rules of Macdonald and Penno (1998) with the objective of maximizing total annual MS yield from each farmlet. Each herd was rotationally grazed throughout the year by using portable electric fences to offer an area of fresh pasture every morning. Grazing intervals ranged from 112 days during the winter, to 21 days in early spring resulting in the allocation of 0.05 to 0.27 ha/day. Any temporary surplus of spring pasture was harvested and conserved as wrapped bale silage. Bales were stored separately for each farmlet before being offered as required to the herd on the farmlet from which the silage had been harvested.

6.3.2 Supplementary feeding

6.3.2.1 Treatments

Each of the high stocked farmlets was randomly assigned to one of four supplementary feeding treatments as follows: 1) no purchased supplementary feed (control); (2) rolled maize grain offered as required (MG); 3) whole maize crop silage offered as required (WCS); or 4), a nutritionally balancing ration offered as required (BR). The lower stocked farmlet (LS) received only pasture silage conserved on that farmlet. Supplements were offered when; 1) the lactating herd was restricted to a pasture drymatter intake (DMI) of less than 15 kg DM/cow/day, or 2) to prevent the herd from grazing below a post-grazing pasture mass of 1500, 1750, and 2000 kg DM/ha, in September, October, and November, respectively (Macdonald and Penno, 1998). Sufficient supplement was offered to achieve a total DMI of at least 15 kg DM/cow/day (approximately 3% liveweight).

6.3.2.2 Supplementary feeds and ration formulation

Maize grain was purchased as whole grain and processed daily through a single roller crusher so that each kernel was broken into three or four pieces. The rolled maize grain was offered to cows individually in the farm dairy during milking either as a single meal when less than 4 kg DM/cow/day was offered, or as two equal sized meals offered at both milkings when more than 4 kg DM/cow/day was offered. Maize silage was purchased each autumn and stored in long narrow bunkers. Fresh maize silage was offered to the herd at pasture immediately after morning milking in a portable feed trough of sufficient size to allow access by all cows.

The nutritionally balancing ration was formulated using the Spartan ration balancing program (van de Haar *et al.,* 1992) based on the current chemical composition of pasture and the predicted pasture DMI. Rations were then checked for metabolisable energy, metabolisable protein, and amino acid supply using the Cornell Net Carbohydrate and Protein System (CNCPS; Fox *et al.,* 1992). The objective of the balanced ration was to provide a level of nutrition sufficient for milk yields 25% higher than the milk yields being achieved at the time of ration formulation. However, in accordance with the rules outlined above, the ration was offered only during periods of pasture deficit. No attempt was made to balance the diet of the herd during periods of plentiful pasture supply. Ingredients were thoroughly mixed and offered in the same way as the maize silage.

6.3.3 Experimental measurements

6.3.3.1 Pasture

Pasture mass on every paddock was estimated weekly by calibrated visual assessment. Immediately before and after these estimates, the pasture mass of twelve quadrats (0.3 m^2), representing the full range of pasture mass present on the farmlets, were visually assessed. The quadrats were then cut to ground level with a portable shearing hand-piece. Harvested material was collected, washed to remove soil and fecal contamination, and then dried for 24 hours in an oven at 100°C. The dried material was weighed to determine the dry-weight of the pasture above ground level. The relationship between measured and estimated pasture mass was calculated by regression analysis and the resultant equation used to adjust the visual estimate.

Pasture growth rate was calculated as the mean increase in pasture mass on paddocks that had not been grazed since the previous estimate. On three occasions each week, the average pre- and post-grazing pasture mass was also estimated visually for each herd. The quantity of pasture dry matter eaten per cow each day was calculated from the difference between the pre- and post grazing pasture mass. All bales of pasture silage were weighed and sampled to measure DM concentration at the time of harvest and again at the time of feeding.

6.3.3.2 Animal performance

The volume and composition of milk from each cow were measured by herd test at two consecutive milkings each week. Tru-test™ in-line milk meters were used to take a representative sub-sample of 2.2% of the total milk yield of each cow. After the milking machine had been removed from each cow, volumes were read from the meter flask and recorded. The sample was then passed through a splitter, which took a further representative sub-sample. The two consecutive sub-samples for each cow were separately analysed for fat and protein concentrations.

Liveweight and condition score of each cow were determined immediately after the morning milking weekly throughout the experiment. Liveweight was measured using calibrated Tru-test™ electronic scales. Condition scores were visually estimated by an experienced assessor using a 1 – 10 scale (1 = very thin, 10 = very fat; Scott and Smeaton, 1980)

6.3.3.3 Sample analysis

Milk samples were analysed by calibrated Fossomatic milk-o-scan (Foss Electric, Hillerod, Denmark) at the DRC Milk Laboratory. Pasture samples were hand clipped to grazing height weekly from the grazing areas of each treatment group during year 1 of the experiment, but only from the BR farmlet in years 2 and 3. Samples were oven dried at 60°C, ground and analysed by NIRS (Ulyatt *et al.*, 1995). Samples of the maize silage and maize grain supplements were taken monthly during periods of supplementary feeding. Samples were analysed by wet chemistry for total nitrogen content, crude fat, neutral detergent fiber (NDF), acid detergent fiber (ADF), soluble carbohydrate, *in vitro* digestibility and mineral content.

6.3.4 Statistical analysis

The basic experimental unit is the farmlet system, and therefore the trial is unreplicated in design (Johnstone, 1979). However, large resources of land and cows would have been required to undertake a study of this nature with adequate replication of each farmlet system. Therefore, every effort was made to ensure no differences existed between the farmlets, herds and management, other than the imposition of the treatments being tested. Given the efforts to minimise any between herd random error, it was assumed that the variance between animals within herds provided an adequate estimate of error variance. Nevertheless, when interpreting the data, the limitations of the statistical analysis must be recognised.

Data for milk yield and composition, liveweight and body condition score were analysed using the mixed model procedure of SAS version 6.12 (SAS, 1995) with treatment and year as fixed effects. Least squares means are presented with standard errors of the difference (SED) based on analysis of variance using a total of eight herds which were part of the trial, however, data from only five of these herds are reported in this chapter. Pasture and reproductive performance measures are presented as treatment means. Regression analysis were performed using Data Desk 6.1 (Velleman, 1997).

6.4 Results

6.4.1 Feed supply

6.4.1.1 Pasture production

Data for seasonal and annual net herbage accumulation rates are presented in Tables 6.1 and 6.2. The farmlets produced about 19.0t DM/ha/yr over the three years of the trial. The proportions of the annual pasture growth that was measured in winter, spring, summer and autumn were 13%, 41%, 29%, and 17%, respectively. Differences in total annual pasture yield between farmlets were most marked in the first year, when the supplemented and LS farmlets produced 1.8t DM/ha more than the control farmlet. In year 3, the BR farmlet produced about 1.3t DM/ha/year more

Table 6.1: The amount of pasture grown and the chemical composition of the maize grain, maize silage and pasture offered during the three years of the experiment in winter (1 June to 31 August), spring (1 September to 30 November), summer (1 December to 28 February) and autumn (1 March to 31 May).

Nutrient	Winter pasture[t]	Spring pasture[t]	Summer pasture[t]	Autumn pasture[t]	Maize grain*	Maize silage*
Pasture grown (t DM/ha)	2.5	7.7	5.6	3.2		
DM, g/100g of fresh weight	17.7	17.0	22.0	16.7	87.7	37.1
CP, g/100g DM	20.2	22.7	20.4	23.8	8.4	6.6
Fat, g/100g DM	4.2	3.8	3.9	4.5	3.3	3.3
ADF, g/100g DM	20.7	22.5	24.8	22.0	2.8	26.9
NDF, g/100g DM	41.7	43.3	46.4	41.6	9.5	48.2
Nonstructural carbohydrates, g/100g DM	14.4	12.2	10.1	11.0	79.1	37.6
In vitro digestibility, g/100g DM	79.7	78.3	75.5	78.5		
Metabolisable energy, MJME/kg DM	12.4	12.2	11.6	12.0		
Ca, g/100g DM	0.4	0.4	0.5	0.5	0.8	0.9
P, g/100g DM	0.4	0.4	0.3	0.4	2.4	0.3
Mg, g/100g DM	0.2	0.2	0.2	0.2	0.9	0.6
S, g/100g DM	0.3	0.3	0.2	0.3	0.8	0.3
K, g/100g DM	3.0	3.3	2.8	3.1	0.3	0.3
Mn, ppm	61	74	60	69	47	36
Cu, ppm	6.6	6.3	7.4	7.4	1.2	3.5
Zn, ppm	55	35	97	85	176	22

* Analysed by wet chemistry

[t] Analysed by near infrared reflectance spectroscopy

Table 6.2: Annual pasture growth per hectare, and dry matter (DM) and metabolisable energy (ME) intake per cow for each year of the experiment.

Farmlet	**Control**	**Maize Grain**	**Maize Silage**	**Balanced Ration**	**LS Pasture**
Year 1					
Pasture grown (kg DM/ha)	18800	20700	20500	20800	20400
Pasture DMI (kg /cow)	4158	4286	4167	4193	5295
Pasture silage DMI (kg /cow	12	174	81	152	151
Maize grain DMI (kg /cow)		900			
Maize silage DMI (kg /cow)			1040		
Balanced ration DMI (kg /cow)				1105	
Total DMI (kg /cow)	4170	5360	5288	5450	5450
Total ME intake (MJ/cow)	49298	63157	60339	63954	63803
Year 2					
Pasture grown (kg DM/ha)	18600	18800	19900	19400	18500
Pasture DMI (kg /cow)	3715	3663	3663	3783	4830
Pasture silage DMI (kg /cow	204	288	259	185	294
Maize grain DMI (kg /cow)		1738			
Maize silage DMI (kg /cow)			1305		
Balanced ration DMI (kg /cow)				1569	
Total DMI (kg /cow)	3919	5689	5227	5537	5124
Total ME intake (MJ/cow)	48031	69988	61396	67747	62801
Year 3					
Pasture grown (kg DM/ha)	17400	17300	17100	18500	15700
Pasture DMI (kg /cow)	3659	3753	3576	3643	4408
Pasture silage DMI (kg /cow		67	58	36	165
Maize grain DMI (kg /cow)		1349			
Maize silage DMI (kg /cow)			1058		
Balanced ration DMI (kg /cow)				1480	
Total DMI (kg /cow)	3659	5169	4692	5159	4573
Total ME intake (MJ/cow)	44243	62883	54712	62438	56754
Average of three years					
Pasture grown (kg DM/ha)	18300	18900	19200	19600	18200
Pasture DMI (kg /cow)	3844	3901	3802	3873	4844
Pasture silage DMI (kg /cow	108	176	133	124	203
Maize grain DMI (kg /cow)		1329			
Maize silage DMI (kg /cow)			1134		
Balanced ration DMI (kg /cow)				1385	
Total DMI (kg /cow)	3916	5406	5069	5382	5049
Total ME intake (MJ/cow)	47191	65343	58816	64713	61119

pasture than the other high stocked farmlets, and 2.9 t DM/ha more than the LS farmlet (Table 6.2). Over the three years of the trial, the three supplemented farmlets grew about 1 t DM/ha/year more pasture than the two unsupplemented farmlets.

6.4.1.2 Pasture and supplement chemical composition

The quality and nutritional value of the pasture on offer was relatively high throughout the year (Table 6.1). Crude protein (CP) content ranged from 20.2g/100g DM in winter to 23.8g/100g DM in autumn, and NDF content ranged from 46.4g/100g DM in summer to 41.6g/100g DM in autumn. Although the chemical composition was typical of New Zealand pastures (Moller, 1997), crude protein was generally higher, and NDF content was generally lower than internationally published values for pasture (NRC, 1989). The diet of the control herd contained excess CP, NDF, and K and insufficient non-structural carbohydrate and Ca when compared to the nutrient content of diets for dairy cows recommended by the NRC (1989).

6.4.1.3 Composition of balanced ration

The BR supplement was based on maize grain and maize silage, which usually comprised 75% to 85% of the ration (Table 6.3). Tallow was included at 2% to 5% of DM to increase the energy density of the ration. Soybean meal was used as a source of rumen degradable protein throughout the experiment. Undegradable protein (UDP) was provided by copra, blood meal and meat and bone meal in year 1, and by fishmeal in years 2 and 3, based on least cost and availability. Minerals were provided from limestone flour, dicalcium-phosphate, sodium chloride and magnesium oxide as required. No mineral or vitamin premixes were included.

6.4.1.4 Pasture and supplementary feed intake

The annual quantities of DM eaten per cow as pasture, conserved pasture silage, and supplementary feed for years 1, 2, and 3 are presented in Table 6.2. Annual pasture DMI of the high stocked herds was similar between treatments within the different years, and between years. However, in each year of the experiment the annual pasture DMI of the LS herd was about 1000 kg/cow greater than that of the higher stocked herds.

Table 6.3: Composition of the balanced ration supplement offered during the three seasons of the experiment (% total supplement DM).

Ingredient	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1995/96 Season												
Maize grain			8.0	13.4	16.4			24.7	54.3	38.0	44.9	28.6
Maize silage		100	73.4	46.9	45.1			43.3	19.4	38.0	46.7	48.5
Tallow			2.4	7.1	7.3			6.0	4.9	8.7	4.6	3.9
Blood meal			2.4	7.1	2.1			6.0	4.9	2.2		
Meat and bone meal					10.4							
Copra			13.7	23.4	6.9							
Soybean meal					9.3			17.9	14.5	6.7		
Limestone				1.1	2.1							
Dicalcium phosphate				1.1	0.40			2.0	1.9	5.0	2.9	2.5
Sodium chloride										1.3	0.91	0.78
Magnesium oxide								0.29	0.25	0.27	0.24	0.17
1996/97 Season												
Maize grain		47.5	65.6	43.9	32.0			52.4	50.3	37.4	39.3	40.7
Maize silage		47.5		18.5	32.0			26.2	24.5	36.1	39.3	43.4
Tallow		0.5	2.8	2.3	3.2				1.3	1.3	2.9	2.8
Chilean fishmeal		0.1	6.0	5.8	8.0			5.7	3.2	3.4	6.0	5.6
Soybean meal		3.5	18.0	15.3	23.9			14.1	19.1	20.1	10.3	5.6
Long hay			5.0	14.2	0.9							
Limestone		0.39	1.3					0.20	0.89	0.93	0.73	0.56
Dicalcium phosphate		0.27	0.89								0.63	0.56
Sodium chloride		0.14	0.44					1.1	0.51	0.53	0.68	0.56
Magnesium oxide								0.29	0.25	0.27	0.24	0.17
1997/98 Season												
Maize grain		63.1	45.2	44.6				19.4	17.2	17.2	17.2	17.3
Maize silage		17.7	39.4	34.7				53.4	49.3	49.3	49.2	49.3
Tallow		4.6	3.7	5.0				4.1	3.7	3.7	3.7	3.7
Chilean fishmeal		11.1	8.8	11.9				4.1	3.7	3.7	3.7	3.7
Soybean meal								17.4	24.6	24.6	24.7	24.3
Long hay		1.8										
Limestone			1.5	2.0				0.39	0.62	0.62	0.63	0.68
Dicalcium phosphate		1.8	1.5	2.0				0.56	0.37	0.37	0.38	0.39
Sodium chloride								0.60	0.49	0.49	0.51	0.55

Pasture allowances for each herd are shown in Figure 6.1. The monthly pasture and supplementary DMI for each herd during each year are presented in Tables 6.4, 6.5 and 6.6. The lower stocking rate resulted in the LS herd being consistently offered a higher pasture allowance than the higher stocked herds, which subsequently resulted in higher pasture DMI throughout the year. There was little difference between the higher stocked herds in the amount of pasture consumed during spring, despite higher pasture allowances for the supplemented herds. Subsequently, in the absence of supplementary feeds, the feed demand of the control herd was reduced to match lower pasture growth in summer. This was achieved by a 20% decrease in stocking rate when low pasture DMI and declining body condition made it necessary to remove the cull cows on 31 January, 20 December, and 16 January in years 1, 2 and 3 respectively. This reduced stocking rate caused an increase in pasture allowance, resulting in the pasture herbage DMI of the remaining cows being up to 4.3 kg/cow/day greater than for the other three HS herds during February.

Supplement DMI ranged from 1.8 to 8.7 kg/cow/day in spring, and 1.2 to 8.1 kg/cow/day in the summer/autumn. The WCS herd often consumed less supplement than the MG and BR herds, particularly during periods of higher supplement requirement when the amount offered to the WCS herd had to be reduced because of excessive refusals. The quantity of supplementary feed offered to all herds was lowest in year 1, which was the year with greatest annual pasture yield. The protocol ensured that more supplement was offered in years 2 and 3, to compensate for the lower pasture production (Table 6.2).

6.4.2 Animal performance

6.4.2.1 Milk production

Supplementary feeding and the lower stocking rate resulted in large increases in annual yields of milk, and milk constituents per cow (Table 6.7). Over the three lactations, offering supplements of MG, WCS and BR, and the LS treatment, increased ($P<0.05$) the yield of MS from 269 to 400, 363 and 408, and 361 (± 15.8) kg/cow/year, respectively. In year 1, there were no differences ($P>0.05$) in the yields of milk, milkfat, milk protein or MS between the cows offered the three

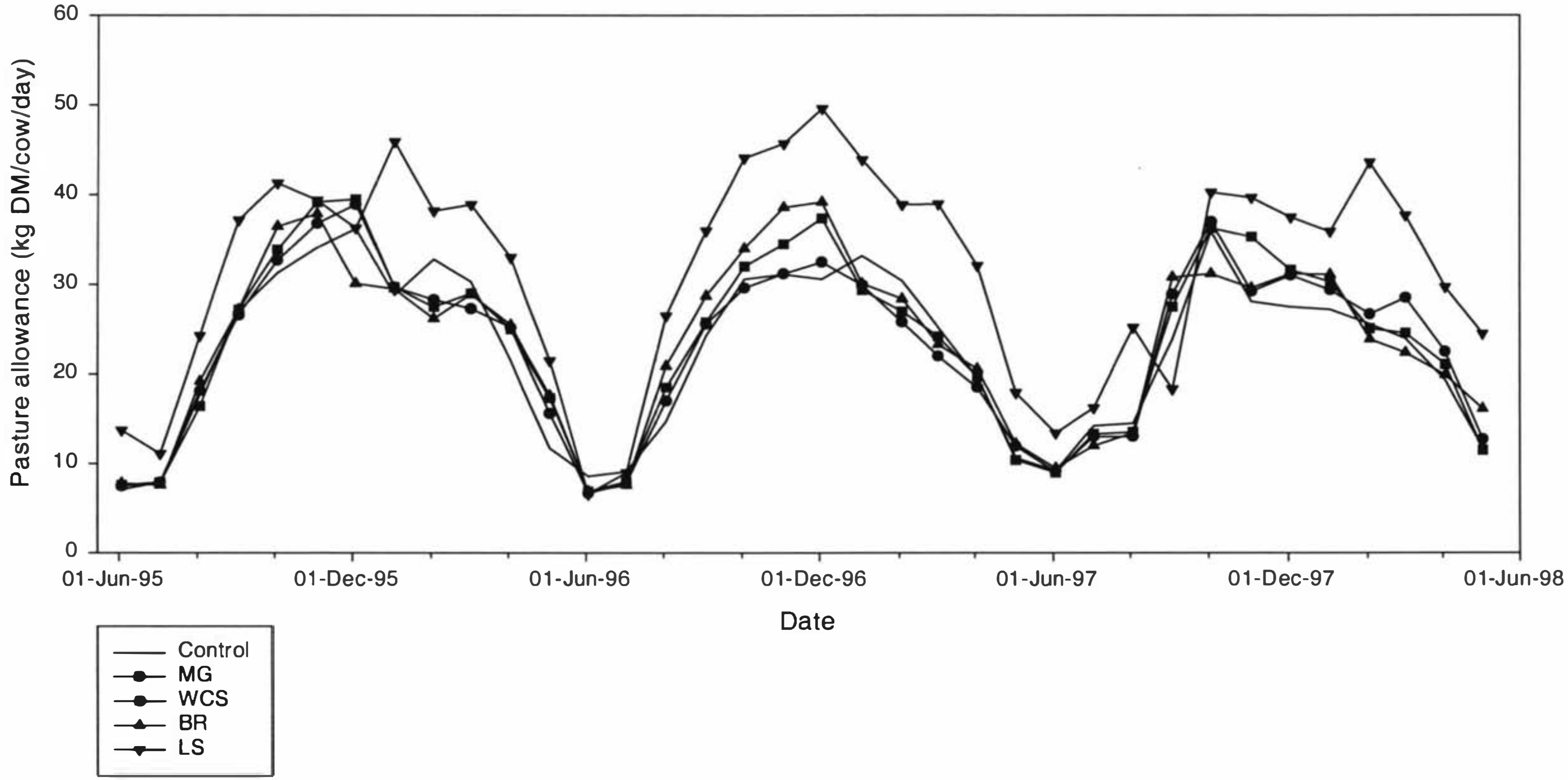


Figure 6.1: Seasonal variation in the pasture allowance offered to herds stocked at 4.41 cows/ha, with no purchased supplement (control), or with supplements of maize grain (MG), maize silage (WCS) or a nutritionally balancing ration (BR), or to herds stocked at 3.35 cows/ha without purchased supplement (LS).

Table 6.4: Mean pasture and supplementary feed dry matter intake (kg DM/cow/day) of each herd during year 1.

Feed	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**
Control farmlet												
Pasture	5.6	6.6	11.4	14.6	14.9	16.9	14.3	13.2	12.4	14.5	12.5	9.1
Pasture silage	0.4											
Total	**6.0**	**6.6**	**11.4**	**14.6**	**14.9**	**16.9**	**14.3**	**13.2**	**12.4**	**14.5**	**12.5**	**9.1**
Maize grain farmlet												
Pasture	5.7	9.1	9.9	11.9	16.1	17.0	15.0	13.4	11.0	12.7	12.8	8.9
Pasture silage	2.8	1.8										1.1
Maize grain		1.4	4.4	5.9	2.1			1.1	4.8	2.5	5.5	2.0
Total	**8.5**	**12.3**	**14.3**	**17.8**	**18.2**	**17.0**	**15.0**	**14.5**	**15.8**	**15.2**	**18.3**	**12.0**
Maize silage farmlet												
Pasture	5.9	8.6	9.2	12.2	15.0	17.6	14.0	13.2	10.3	12.5	12.2	8.9
Pasture silage	2.7	0.8										1.8
Maize silage		1.6	6.2	7.8	2.3			1.2	5.0	2.8	5.4	2.0
Total	**8.6**	**11.0**	**15.4**	**20.0**	**17.3**	**17.6**	**14.0**	**14.4**	**15.3**	**15.3**	**17.6**	**12.7**
Balanced ration farmlet												
Pasture	5.9	9.0	10.8	12.2	15.2	17.0	13.0	13.5	9.4	12.9	11.3	10.3
Pasture silage	2.6	0.6										1.8
Balanced ration		1.5	6.3	7.5	2.4			1.6	5.2	2.9	5.6	3.5
Total	**7.9**	**11.1**	**17.1**	**19.7**	**17.6**	**17.0**	**13.0**	**15.1**	**14.6**	**15.8**	**16.9**	**15.6**
Lower stocked pasture farmlet												
Pasture	10.6	8.3	14.5	17.5	17.5	17.6	15.0	17.2	13.0	16.9	15.0	10.5
Pasture silage									1.1		1.4	2.5
Total	**10.6**	**8.3**	**14.3**	**17.5**	**17.5**	**17.6**	**15.0**	**17.2**	**14.1**	**16.9**	**16.4**	**13.0**

Table 6.5: Mean pasture and supplementary feed dry matter intake (kg DM/cow/day) of each herd during year 2.

Feed	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Control farmlet												
Pasture	6.6	7.1	9.2	12.5	16.1	15.4	13.8	15.5	11.5	10.0	9.0	6.6
Pasture silage			3.1	3.6								
Total	**6.6**	**7.1**	**12.2**	**16.1**	**16.1**	**15.4**	**13.8**	**15.5**	**11.5**	**10.0**	**9.0**	**6.6**
Maize grain farmlet												
Pasture	5.0	6.0	11.4	12.4	14.9	14.6	14.7	12.1	7.2	8.2	7.8	6.5
Pasture silage	4.3	1.0									2.0	2.2
Maize grain		3.7	6.3	7.6	4.3	0.4	4.0	6.2	8.0	7.2	6.7	2.9
Total	**9.3**	**7.7**	**17.7**	**20.0**	**19.2**	**15.0**	**18.7**	**18.3**	**15.2**	**15.4**	**16.5**	**9.6**
Maize silage farmlet												
Pasture	5.0	6.0	12.1	11.9	14.6	15.4	16.4	11.6	7.1	8.1	7.7	5.3
Pasture silage	4.1	0.6										3.8
Maize silage		3.3	5.3	7.0	2.4			3.5	8.0	6.7	6.7	0.4
Total	**9.1**	**9.9**	**17.4**	**18.9**	**17.0**	**15.4**	**16.4**	**15.1**	**15.1**	**14.8**	**14.4**	**9.5**
Balanced ration farmlet												
Pasture	5.2	5.7	12.6	11.5	15.2	17.1	15.9	11.4	8.0	7.8	8.1	6.3
Pasture silage	4.4	0.7										1.0
Balanced ration		3.8	6.4	8.7	3.4			3.4	8.2	7.5	6.9	3.7
Total	**9.6**	**10.2**	**18.6**	**20.2**	**18.6**	**17.1**	**15.9**	**14.8**	**16.2**	**15.3**	**15.0**	**11.0**
Lower stocked pasture farmlet												
Pasture	4.5	7.2	15.0	16.4	19.9	16.8	16.3	16.6	12.4	13.0	11.8	8.7
Pasture silage	5.2	1.6									1.5	1.4
Total	**9.7**	**8.8**	**15.0**	**16.4**	**19.9**	**16.8**	**16.3**	**16.6**	**12.4**	**13.0**	**12.3**	**10.1**

Table 6.6: Mean pasture and supplementary feed dry matter intake (kg DM/cow/day) of each herd during year 3.

Feed	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Control farmlet												
Pasture	5.6	8.2	9.8	13.0	16.8	14.3	14.0	11.6	8.1	9.1	10.3	7.3
Pasture silage												
Total	**5.6**	**8.2**	**9.8**	**13.0**	**16.8**	**14.3**	**14.0**	**11.6**	**8.1**	**9.1**	**10.3**	**7.3**
Maize grain farmlet												
Pasture	5.1	6.9	8.0	14.5	17.7	15.8	15.2	11.9	7.4	9.6	10.3	6.8
Pasture silage	1.2											1.0
Maize grain		5.0	6.5	2.1				4.0	8.0	7.9	8.0	3.1
Total	**6.5**	**11.9**	**14.5**	**16.6**	**17.7**	**15.8**	**15.2**	**15.9**	**15.4**	**17.5**	**18.3**	**10.9**
Maize silage farmlet												
Pasture	5.5	7.3	8.4	12.6	16.6	15.1	15.4	11.1	6.3	6.8	8.9	6.3
Pasture silage	1.4											0.5
Maize silage		0.6	6.6	1.8				4.1	8.0	5.5	7.0	1.6
Total	**6.9**	**7.9**	**15.0**	**14.4**	**16.6**	**15.1**	**15.4**	**15.2**	**14.3**	**12.3**	**15.9**	**8.1**
Balanced ration farmlet												
Pasture	5.3	7.1	8.3	14.5	16.2	15.5	15.2	12.4	6.5	6.1	8.5	7.0
Pasture silage	1.2											
Balanced ration		4.0	6.9	2.0				4.1	8.1	8.1	8.1	7.5
Total	**6.5**	**11.1**	**15.2**	**16.5**	**16.2**	**15.5**	**15.2**	**16.5**	**14.1**	**14.2**	**16.6**	**14.5**
Lower stocked Pasture farmlet												
Pasture	8.0	12.1	10.8	17.0	17.7	17.4	15.3	16.2	8.5	9.0	11.3	9.2
Pasture silage									1.8	3.7		
Total	**8.0**	**12.1**	**10.8**	**17.0**	**17.7**	**17.4**	**15.3**	**16.2**	**10.3**	**12.7**	**11.3**	**9.2**

Table 6.7: Annual yield of milk, mean concentrations of milkfat and protein, and yields of milkfat, protein and milksolids.

Farmlet	Control	Maize Grain	Maize Silage	Balanced Ration	LS Pasture	SED
1995/96						
Mean calving date	28 July	26 July	24 July	28 July	25 July	4.5
Lactation (days/cow)	243	284	287	288	293	6.6
Milk (kg/cow)	3741	4709	4582	4812	4840	215
Milkfat (g/kg)	45.7	47.5	48.6	45.8	45.3	1.4
Protein (g/kg)	34.8	36.9	35.8	35.2	34.8	0.6
Milkfat yield (kg/cow)	170.9	221.7	221.6	218.7	218.6	9.5
Protein yield (kg/cow)	130.0	172.7	163.6	169.0	168.0	7.1
Milksolids yield (kg/cow)	300.9	394.4	385.3	387.7	386.6	16.1
1996/97						
Mean calving date	31 July	24 July	25 July	29 July	27 July	4.9
Lactation (days/cow)	199	288	273	285	261	7.2
Milk (kg/cow)	3111	4918	4314	5201	4515	222
Milkfat (g/kg)	45.2	48.2	47.8	46.0	44.8	1.5
Protein (g/kg)	34.3	36.9	34.7	35.4	34.8	0.6
Milkfat yield (kg/cow)	140.0	235.3	206.0	236.0	200.7	10.0
Protein yield (kg/cow)	106.8	180.8	149.8	183.3	156.6	7.6
Milksolids yield (kg/cow)	246.8	416.1	355.8	419.3	357.2	17.2
1997/98						
Mean calving date	31 July	20 July	19 July	18 July	23 July	4.6
Lactation (days/cow)	210	276	272	299	244	4.6
Milk (kg/cow)	3203	4611	4291	5263	4191	260
Milkfat (g/kg)	46.6	48.3	47.0	44.9	46.7	1.5
Protein (g/kg)	34.8	36.3	34.4	34.9	35.1	0.6
Milkfat yield (kg/cow)	149.0	221.7	200.9	233.3	193.8	11.5
Protein yield (kg/cow)	111.4	167.1	147.1	182.3	146.3	8.7
Milksolids yield (kg/cow)	260.4	388.8	348.0	415.6	340.1	19.8
Average of three Seasons						
Mean calving date	30 July	25 July	23 July	25 July	25 July	2.4
Lactation (days/cow)	217	283	277	291	266	10.7
Milk (kg/cow)	3352	4746	4396	5092	4515	206
Milkfat (g/kg)	45.7	47.7	47.7	45.0	45.3	0.8
Protein (g/kg)	34.6	36.6	34.9	35.0	34.8	0.3
Milkfat yield (kg/cow)	153.3	226.2	209.5	229.3	204.3	8.8
Protein yield (kg/cow)	116.1	173.5	153.5	178.2	156.9	7.1
Milksolids yield (kg/cow)	269.4	399.7	363.0	407.5	361.3	15.8

different types of supplement, or between the supplementary feeding treatments and the LS treatment. In years 2 and 3, the WCS and LS herds had shorter lactations and produced less ($P<0.05$) milk, milkfat, milk protein and MS than the MG and BR herds. The milk yield of the BR herd was greater than that of the MG herd in year 3. The BR herd had higher fat corrected milk yield (FCM) than the cows offered MG, WCS and LS treatments for short periods (Figure 6.2). The MG herd produced milk of higher ($P<0.05$) protein concentration than the other herds in years 2 and 3.

6.4.2.2 Liveweight and body condition score

In each season, all herds lost weight from calving until September, and then generally regained liveweight until the following calving (Figure 6.3). However, by August of year 1, herds receiving supplementary feeds were approximately 25 kg heavier than the control herd, a difference that was maintained for the remainder of the experiment. The greatest difference in liveweight occurred in September when the supplemented herds were 30 to 50 kg heavier than the control herd. The liveweight of the LS herd was similar to that of the supplemented herds except in spring of year 2. By late September of year 2 the liveweight of the LS herd was similar to that of the Control herd, because of a high rate of liveweight loss after calving (Figure 6.3).

The average body condition score of cows in herds receiving supplement, or grazing the LS farmlet, was maintained between 4.2 and 5.0, whereas the body condition score of the control herd fluctuated between 3.2 and 4.6, and was greater than 4.2 for only 15 months out of the whole three year trial. The control cows generally lost body condition during lactation and did not regain it until after the herd had been dried off.

6.4.2.3 Reproductive performance

Measures of reproductive performance are shown in Table 6.8. In years 1 and 2, increasing feeding levels per cow with supplementary feeds, or with a reduced stocking rate, reduced the mean post partum anoestrous interval, and the number of cows treated for anoestrous. However, there were no differences between treatments in the conception rates to artificial insemination, or in the empty rate at the end of the 12 week mating period.

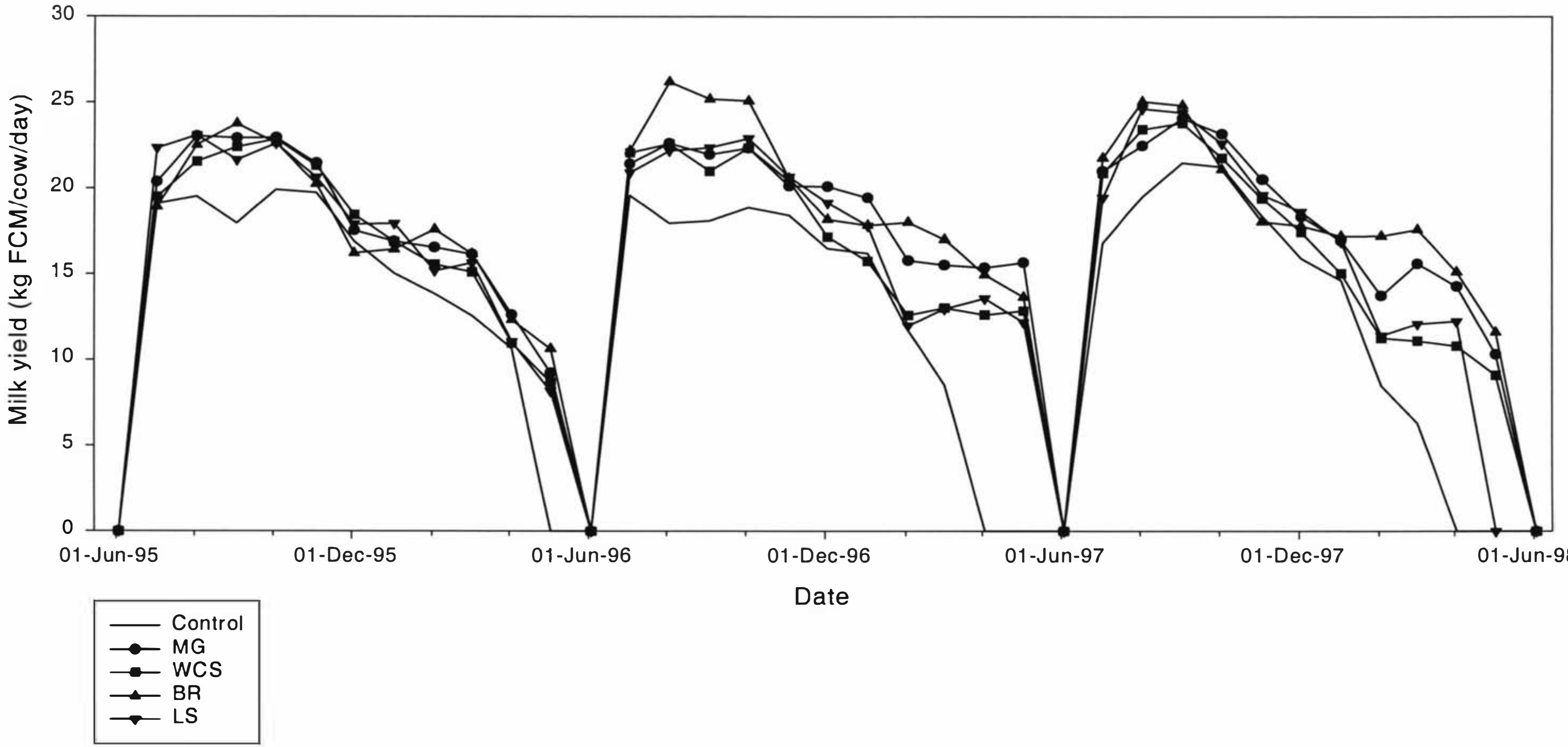


Figure 6.2: Mean daily 4% FCM yield of cows stocked at 4.41 cows/ha with no purchased supplement (control), or with supplements of maize grain (MG), with maize silage (WCS), or with a nutritionally balancing ration (BR), or stocked at 3.35 cows/ha without purchased supplement (LS), over the three complete lactations.

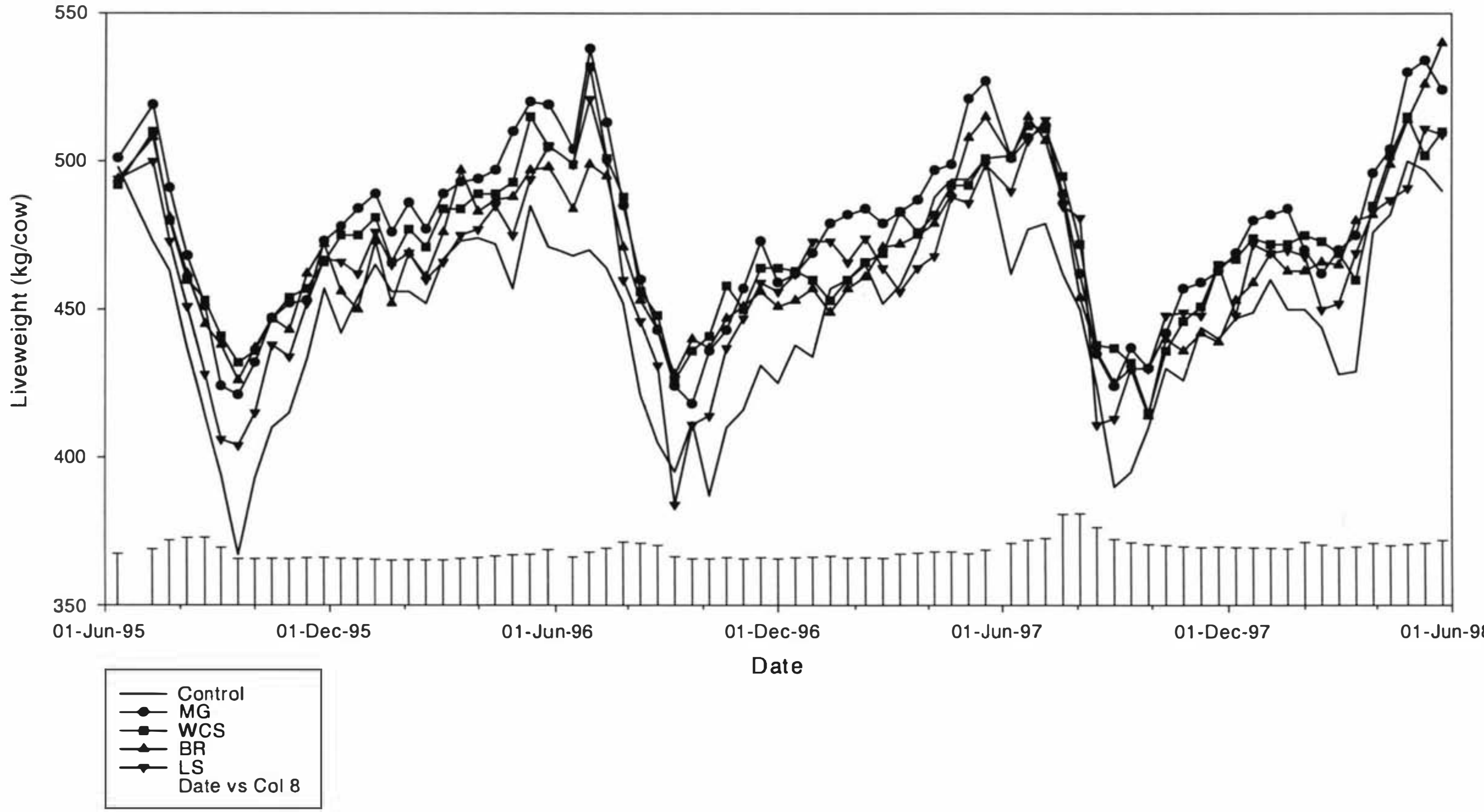


Figure 6.3: Mean liveweight of cows stocked at 4.41 cows/ha with no purchased supplement (control), or with supplements of maize grain (MG), with maize silage (WCS), or with a nutritionally balancing ration (BR), or stocked at 3.35 cows/ha without purchased supplement (LS), over the three complete lactations. Error bars represent SED.

Table 6.8: Reproductive performance of herds stocked at 4.41 cows/ha with no supplementary feed (control), or with supplements of maize grain (MG), with maize silage (WCS) or with a nutritionally balancing ration (BR), or stocked at 3.35 cows/ha without purchased supplement (LS) over three seasons.

	Control	MG	WCS	BR	LS
1995/96 season					
Mean post partum anoestrous interval (days)	57	36	42	47	39
Anoestrous at planned start of mating (% of herd)	48	4	12	24	11
Conception rate to artificial insemination♣ (% of herd)	56	52	44	40	42
Empty rate at conclusion of mating (% of herd)	0	4	16	12	6
1996/97 season					
Mean post partum anoestrous interval (days)	50	43	38	45	40
Anoestrous at planned start of mating (% of herd)	36	8	12	20	16
Conception rate to artificial insemination♣ (% of herd)	60	52	40	56	37
Empty rate at conclusion of mating (% of herd)	8	8	4	4	5
1997/98 season					
Mean post partum anoestrous interval (days)	47	47	55	45	46
Anoestrous at planned start of mating (% of herd)	20	20	16	8	5
Conception rate to artificial insemination♣ (% of herd)	60	52	68	52	74
Empty rate at conclusion of mating (% of herd)	12	8	4	8	16

♣Calculated as the number of pregnancies resulting from the first mating of each cow.

6.5 Discussion

6.5.1 Farmlet performance

6.5.1.1 Pasture substitution

There were few differences between the average annual pasture DMI of cows in the higher stocked herds. However, the average pasture DMI of the control herd was 0.8 (±0.68) kg DM/c/day greater than that of the supplemented herds when adjusted to a common pasture allowance (Table 6.9). A decrease of 0.8 kg DM in pasture DMI associated with supplementary feeding represents an average substitution rate of 0.2, given an average supplement DMI of 3.9 kg DM/cow/day throughout the experiment.

High genetic merit dairy cows require pasture allowances in excess of 50 kg DM/cow/day to maximise pasture DMI (Wales *et al.,* 1998; Wales *et al.,* 1999). The higher stocking rate (4.4 cows/ha) and early calving date chosen for this experiment resulted in pasture allowances which were less than 35 kg DM/cow/day for 9 months of each year. The pasture allowances at the high stocking rate were generally only 20 to 35 kg DM/cow/day during the periods of supplementary feeding (Figure 6.1). Substitution, of supplement for pasture, increases as the allowance of both pasture and supplement increases relative to feed requirements of the cow. As total feed supply increases, the DMI of the cow become progressively less responsive to incremental increases in feed availability (Meijs and Hoekstra, 1984; Stakelum, 1986a, 1986b, and 1986c; Grainger and Mathews, 1989; Robaina *et al.,* 1998). In this trial, the low pasture allowances that occurred as a result of the high stocking rate were the primary reasons for low levels of pasture substitution being observed.

The DMI of cows in the unsupplemented herds was extremely responsive to the availability of extra pasture, as demonstrated by the large increase in pasture DMI (+ 1t DM/cow/year) that resulted from higher pasture allowances offered to the LS herd. Nevertheless, the LS herds ate a smaller proportion of the pasture on offer at each grazing, because more pasture was available (Table 6.9). This is consistent

Table 6.9: Effect of pasture dry-matter allowance (DMA; kg DM/c/day) on pasture dry matter intake (DMI) for each of the treatment herds over the three years of the trial.

Treatment	Regression equations	$100R^2$	r.s.d
Control	DMI = 3.71(±0.68) + 0.34(±0.028)DMA	81	1.5
Maize Grain	DMI = 2.98(±0.85) + 0.34(±0.034)DMA	75	1.9
Maize Silage	DMI = 2.89(±0.84) + 0.32(±0.33)DMA	74	1.9
Balanced Ration	DMI = 2.76(±0.90) + 0.34(±0.035)DMA	73	2.0
LS Pasture	DMI = 5.21 (±1.02) + 0.26(±0.030)DMA	69	2.2

with the curvilinear relationship that is known to exist between pasture allowance and pasture intake (Holmes, 1987).

The lower level of pasture utilisation at each grazing on the LS farmlet resulted in that herd consuming 800 kg DM/ha/year less grazed pasture than the higher stocked herds. However, there was no difference between any of the farmlets in the total amount of pasture consumed per hectare because this herd consumed 680 kg DM/ha/year as pasture silage, which had been conserved from surplus spring pasture on that farmlet.

Pasture allowance, and the extent to which supplementary feeds substitute for pasture, has a major influence on the magnitude of the net change in nutrient intake of the cow caused by the feeding of supplements (Leaver, 1985). Animal production responses are determined by the net change in total nutrient intake (Oldham and Emmans, 1989). Therefore, the milk yield responses measured in this experiment should be larger than responses measured in experiments where high rates of pasture substitution occurred, or where changes in stocking rate have resulted in little change in pasture intake per cow.

6.5.1.2 Milk yields per cow

All the supplementary feeding treatments and the LS treatment resulted in large increases in the annual yield of milk and milk constituents per cow. Increased milk yield was attributable to both increased mean lactation length and an increase in the mean daily milk yield (Figure 6.2). However, the magnitude of the milk yield responses must be considered relative to the severe feed restrictions imposed on the control herd, which resulted in short lactations and low daily yields of milk, milkfat and protein.

The difference between daily milk yields of the control and treatment herds was largest in early spring, when the restricted pasture allowance offered to the control herd caused severe restrictions in pasture DMI. Cows in the control herd did not attain peak yields until pasture growth allowed generous feeding in mid October, when the herd was approximately 75 days in milk (Figure 6.2). During mid lactation, there was little difference between the herds, because rapid pasture growth enabled all herds to be fed generously on pasture. Differences re-emerged in mid to late lactation as pasture production decreased, causing reduced DMI by the control herd and increased supplementary feeding of the treatment herds. These differences in milk yield developed despite the reductions in stocking rate that occurred in summer on the control farmlet as cows were culled from that herd in direct response to the decreasing supply of pasture.

Peak daily yields of 4% FCM by the control, MG, WCS, BR, and LS herds per kg of metabolic liveweight (liveweight$^{0.75}$) were 0.22, 0.24, 0.23, 0.26, and 0.25 kg FCM/kg of metabolic liveweight/day, respectively. This compares with 0.25 and 0.34 kg FCM/kg of metabolic liveweight/day when high genetic merit North American Holstein Friesian cows at peak lactation were grazed at pasture, or offered a total mixed ration (TMR), respectively (Kolver and Muller, 1998). Likewise, over the three lactations, the mean yield of the MG, WCS, BR, and LS herds was 0.18, 0.17, 0.19, and 0.19 kg FCM/kg of metabolic liveweight/day, respectively. These are similar to 0.19 kg FCM/kg of metabolic liveweight/day reported for Holstein Friesian cows grazed at pasture and offered concentrate based supplements (Hoffman *et al.*, 1993). Nevertheless, the milk yields achieved by the present grazing cows are considerably lower than some reported for cows consuming diets of conserved forage and concentrates fed indoors (Kolver and Muller, 1998). These lower yields occurred even when cows were generously fed, with BR providing up to 30% of the daily DMI.

6.5.1.3 Lactation length

Using either supplementary feeds or a reduced stocking rate to increase feeding levels throughout the season allowed lactation length to be increased by 3.5 (±0.5) days for each additional 1000 MJME intake (Figure 6.4). In turn, increased lactation length had a marked effect on annual MS yield (Figure 6.5). One of the major disadvantages of relying on pasture as the only source of feed in high stocked pasture only farm systems is the short lactations, and subsequently low milk yields per cow that often result.

When farm systems rely on pasture as the sole source of feed, the amount of milk produced is largely determined by the amount of pasture that is grown, and the

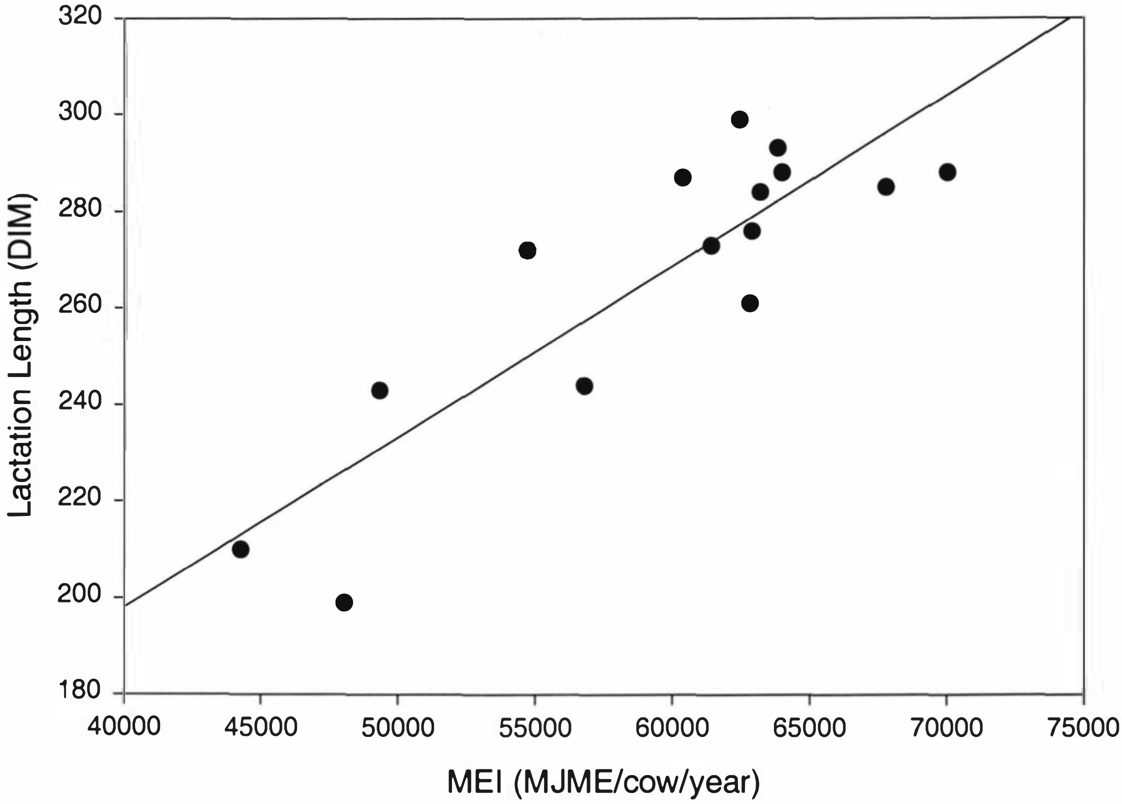


Figure 6.4: The relationship between annual metabolisable energy intake (MEI) and lactation length (DIM) for each herd and each year of the trial.
DIM = 0.0035 (±0.00057)MEI + 56.5 (±33.92)
Adjusted $100R^2 = 73.1\%$; r.s.d. = 15.7.

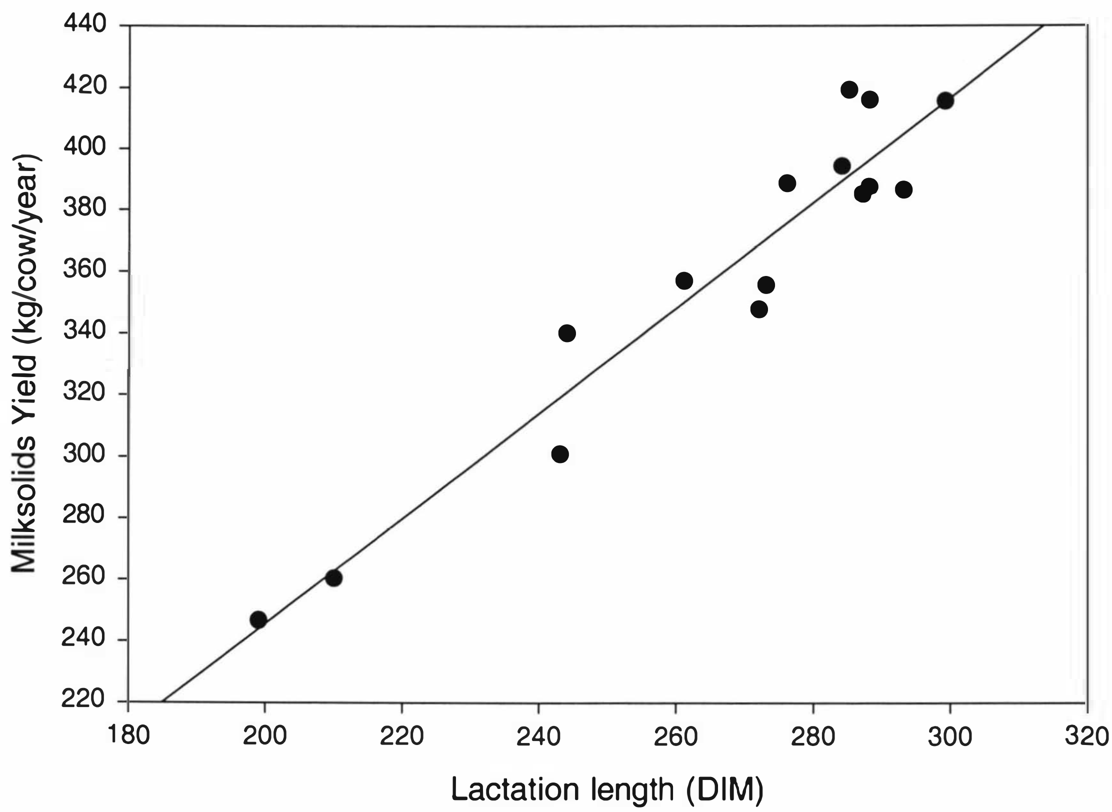


Figure 6.5: The relationship between lactation length (DIM) and annual milksolids yield (MS) for each herd and each year of the trial.
MS (kg/cow/year)= 1.71 (±0.141)DIM – 96.6 (±37.85)
Adjusted $100R^2 = 91.3\%$; r.s.d. = 15.9.

proportion of that pasture which is eaten by the dairy herd (Penno, 1998). It has traditionally been recommended that farmers carry enough cows to ensure that a high proportion of the pasture grown each year can be directly utilised by the grazing dairy herd (Bryant, 1990). However, these high stocking rates result in the herd being generously fed for only a few months of each year, because a disproportionate amount of the pasture grown each year is grown in spring. In this trial, as pasture growth slowed in the summer and autumn, the control herd suffered progressively increasing feed restrictions (Tables 6.4, 6.5, and 6.6). To cope with declining feed availability, the feed demand of the control herd was reduced by prematurely drying off cows. Usually, cows to be culled from the herd are dried off first and sold, then young cows will be dried off, and eventually the entire herd (Bryant and Macdonald, 1987).

One of the key objectives of the decision rules used in this experiment was to ensure that the cows which were to remain in the herd for the following season regained lost body condition before the next calving. To achieve this, cows were dried off early enough, and with sufficient pasture on the farm, to achieve a body condition score of 4.5 to 5.0 by early winter (Macdonald and Penno, 1998). The decision rules resulted in the control herd being milked for 199 to 243 days, much shorter lactations than the 272 to 299 days for the supplemented herds or the 266 to 293 days for the LS herd. The availability and use of supplementary feed, either as bought-in feeds or pasture silage, allowed long lactations at a stocking rate that was sufficiently high to utilise a high proportion of the pasture grown in spring and over the whole year. Low milk yield, rather than poor body condition, resulted in the premature drying off of some cows in the MG herd in year 3 and the WCS herd in years 2 and 3.

6.5.1.4 Milk yield per hectare

MS yield was increased by about 45% when purchased supplementary feeds were used to increase total feed available per hectare by 37%, when compared to either the control or the LS herd (Table 6.10). Of particular interest is the small difference in per hectare productivity between the control and LS herds, both of which relied on pasture as the only source of feed.

Table 6.10: Mean annual pasture and supplement supply, and production of milk, milkfat, milk protein and milksolids from the five farmlet systems for three complete seasons.

	Control	Maize Grain	Maize Silage	Balancing Ration	LS Pasture
Pasture grown (t/DM/ha/year)	18.3	18.9	19.2	19.6	18.2
Purchased supplements offered (t DM/ha/year)	0.3	6.6	5.6	6.7	0.0
Total feed supply (t DM/ha/year)	18.6	25.6	24.8	26.2	18.9
Milk yield (kg/ha/year)	14785	20933	19390	22459	15135
Milkfat yield (kg/ha/year)	676	998	924	1011	684
Milk protein yield (kg/ha/year)	512	765	677	786	526
Milksolids yield (kg/ha/year)	1188	1763	1601	1797	1211

Until recently, research usually demonstrated that increases in stocking rate were associated with increases in production per hectare. The extra milk production was attributed to the increase in pasture utilisation that usually resulted (Holmes and Macmillan, 1982). In the current trial, the LS herd consumed less pasture DM/ha by grazing than the control herd, but they consumed more pasture than the control herd when conserved silage is considered, resulting in no difference in either the total amount of pasture consumed per hectare or milk yield per hectare. Recent research with Jersey and Friesian cows, each at two stocking rates, demonstrated similar results when increasing stocking rate by 1 cow/ha resulted in milk production per hectare changing by less than 5% (Penno, 1998). Simulation modeling has suggested that using a low enough stocking rate to allow generous feeding and the conservation of large amounts of surplus spring pasture to provide pasture silage for the summer and autumn, is the optimum dairying system for New Zealand given current costs and prices (McCall and Clark, 1999). This system uses conserved pasture silage for supplementary feeding in the summer and autumn to achieve long lactations and high yields per cow, and can potentially reduce costs per hectare and increase gross feed conversion efficiency of the cows.

6.5.1.5 Liveweight and body condition

The pattern of liveweight change over the year demonstrates that the management strategy was largely successful in ensuring that body condition lost during lactation, was regained during the dry period, before the subsequent calving (Figure 6.3). Nevertheless, the control herd remained approximately 1 body condition score and 25 kg lighter at the conclusion of the trial than they had been at the beginning, three years earlier. This body condition, lost primarily in year 1, made an unsustainable contribution to the milk produced on the control system in that year. The extra liveweight that was lost probably contributed to the smaller responses to the supplements that were measured that year 1 (see below).

6.5.1.6 Reproductive performance

This trial demonstrated that reducing feeding levels by high stocking rates without offering supplementary feed reduces reproductive performance. Supplementary feeding cows at the HS, or increasing pasture allowance by using the LS, consistently reduced the post partum anoestrous interval and the number of anoestrous cows that required treatment immediately before the planned start of mating. Thin calving body condition, and low DMI after calving increases post-partum anoestrous interval (Grainger and McGowan, 1982; McDougall *et al.,* 1995). Although the low DMI and body condition score of cows in the control herd did not affect overall reproductive performance, a higher proportion of the control herd were treated for anoestrous. In the absence of an effective method for treating anoestrous cows, the reproductive performance of the control herd would have been reduced. Therefore, the use of large quantities of supplementary feed can be an effective method of increasing reproductive efficiency by reducing nutritional anoestrous in highly stocked seasonal pasture based systems. This is an additional important positive response of the herd to extra feed.

6.5.2 Responses to extra feed

6.5.2.1 Responses to additional dry matter and metabolisable energy

Despite the differences in liveweight and body condition that occurred between the herds each season, the management of the herds generally resulted in the body reserves that were lost in early lactation being replaced before the subsequent calving. Any pasture spared as a result of substitution would have either increased subsequent pasture allowance and DMI, been lost from the sward through death and decay, or both (Parsons and Chapman, 1998). Therefore, over the three years of the trial, the whole response to each form of supplementary feed was probably expressed as an increased annual yield of milk and milk constituents. Theoretically, the energy supplied by the supplements should have been enough to allow MS yield increases of about 15g /MJME, if all of the energy had been used directly for milk synthesis (Holmes *et al.,* 1987).

Over the three years of the trial the average marginal responses to the MG, WCS, BR, and LS treatments were 90.5, 78.2, 94.5, and 82.0g MS/kg DM, and 7.3, 7.6, 7.8, and 6.6g MS/MJME, respectively, when compared to the control (Table 6.11). Similarly, the absolute response in annual milksolids yield to extra MEI, irrespective of the source of the feed, was 7.0g MS/MJME (Figure 6.6). The residual differences in liveweight at the conclusion of the trial were negligible given that

Table 6.11: Marginal milkfat, milk protein and milksolids response of the farm systems to incremental units of dry matter (DM) and metabolisable energy (ME) supplied by the three forms of supplementary feed, and from extra pasture (LS), relative to the HS control system.

Farmlet	Maize Grain	Maize Silage	Balanced Ration	LS Pasture
Year 1				
Milkfat (g/kg DM)	47.8	45.7	38.4	37.3
Milkfat (g/MJME)	3.92	4.43	3.24	3.29
Milk protein (g/kg DM)	40.2	30.3	31.3	29.7
Milk protein (g/MJME)	3.30	2.94	2.64	2.62
Milksolids (g/kg DM)	88.0	76.0	69.7	67.0
Milksolids (g/MJME)	7.2	7.4	5.9	5.9
Year 2				
Milkfat (g/kg DM)	52.3	48.5	61.9	50.4
Milkfat (g/MJME)	4.22	4.71	5.09	4.11
Milk protein (g/kg DM)	40.6	31.6	49.4	41.3
Milk protein (g/MJME)	3.27	3.07	4.06	3.37
Milksolids (g/kg DM)	92.9	80.1	111.3	91.7
Milksolids (g/MJME)	7.5	7.8	9.2	7.5
Year 3				
Milkfat (g/kg DM)	51.3	46.5	55.6	49.0
Milkfat (g/MJME)	4.14	4.51	4.58	3.58
Milk protein (g/kg DM)	39.3	32.0	46.8	38.2
Milk protein (g/MJME)	3.17	3.10	3.85	2.79
Milksolids (g/kg DM)	90.6	78.5	102.4	87.2
Milksolids (g/MJME)	7.3	7.6	8.4	6.4
Average of three years				
Milkfat (g/kg DM)	50.5	46.9	52.0	45.6
Milkfat (g/MJME)	4.09	4.55	4.30	3.66
Milk protein (g/kg DM)	40.0	31.3	42.5	36.4
Milk protein (g/MJME)	3.25	3.04	3.52	2.93
Milksolids (g/kg DM)	90.5	78.2	94.5	82.0
Milksolids (g/MJME)	7.3	7.6	7.8	6.6

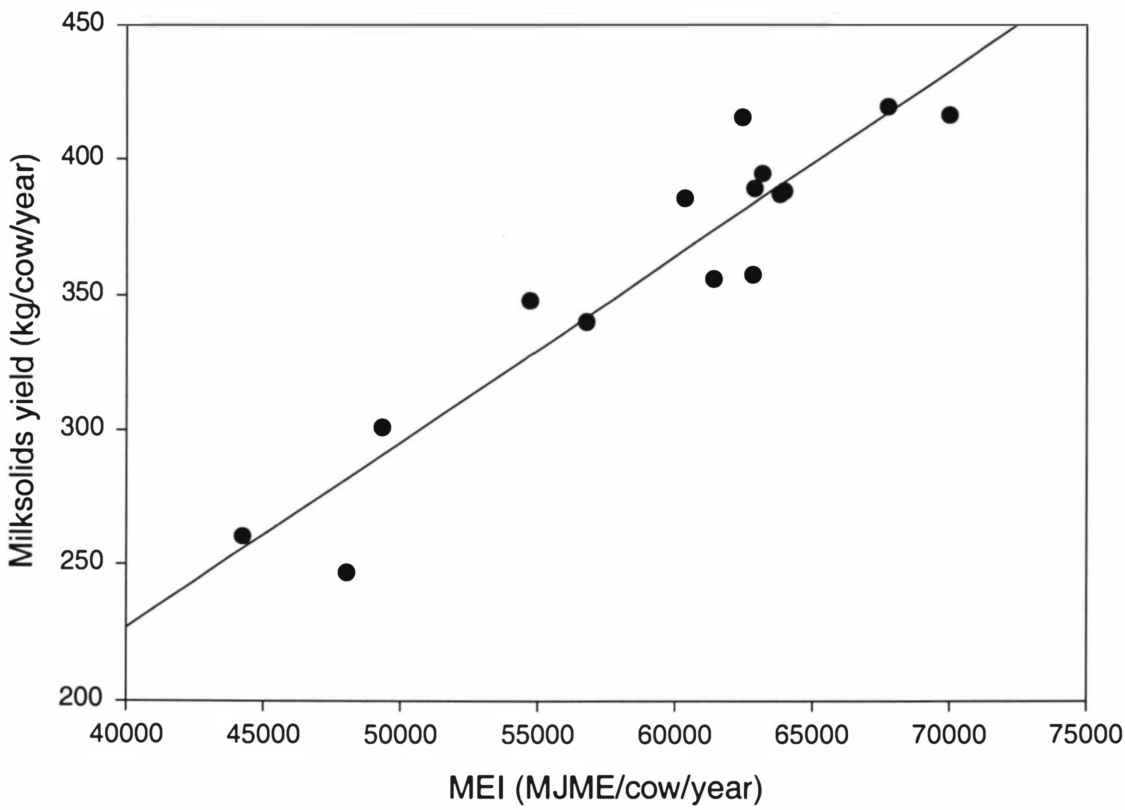


Figure 6.6: The relationship between annual metabolisable energy intake (MEI) and annual milksolids yield (MS) for each herd and each year of the trial.
MS (kg/cow/year) = -58.4 (±46.4) + 0.007 (±0.0008) MEI
Adjusted $100R^2 = 86.5\%$; r.s.d. = 19.6.

approximately 3400 to 4200 kg DM/cow was offered as supplementary feed over the three years of the experiment. These responses were two fold greater than immediate responses reported for similar feeds measured in short-term experiments (Chapter 5), in agreement with previous suggestions that the total response to supplementary feeds is likely to be twice the immediate effect measured in short-term experiments (Kellaway and Porta, 1993). They were similar to those estimated by Broster and Broster (1984) who suggested that the short-term response to increasing the plane of nutrtion of dairy cows was approximately 7g of MS plus 10g liveweight per 1 MJ change in metabolisable energy intake. Nevertheless, they were only half the theoretically possible response (Homes *et al.*, 1987).

When the total annual DMI and MS yield are considered, the gross efficiency of the control, MG, WCS, BR and LS systems was 69, 74, 72, 76, and 72g MS/kg DM. These are similar to the 79g MS/kg DM calculated from cows fed indoors on TMR (Tessman *et al.,* 1991), but were lower than the 96 and 105 g MS/kg DM calculated for cows fed diets of pasture silage, concentrate and grazed pasture of high and low forage content, respectively (Gordon *et al.,* 2000). However, it must be noted that the gross efficiency calculated from the data of Tessman *et al.,* (1991) and Gordon *et al.,* (2000) only included the DM eaten by the cows during lactation.

The lower than expected responses in the present trial were either caused by the supplementary feed yielding less metabolisable energy than theory would suggest, or that the metabolisable energy provided by the supplementary feed was used less efficiently than nutrient requirement standards predict. The actual yield of metabolisable energy from the supplements cannot be assessed. Nevertheless, all sources of extra feed resulted in similar incremental increases in MS yield (Figure 6.6). This suggests that the ME yields of the pasture and supplements were accurately predicted by their estimated ME concentration.

There are several possible reasons for the low milk yield responses (Table 6.12). Firstly, it is unlikely that all the additional ME was used directly for milk production. The efficiency of milk production from ME that is stored as body reserves, then mobilised, is about 20% less than the efficiency of producing milk directly from feed ME eaten (Holmes *et al.,* 1987). If it is assumed that half of the extra ME eaten was used directly for milk production, and the other half was stored as body reserves before being mobilised for milk production, the increase in milk yield resulting from offering supplementary feed accounts for 37000 MJME/ha/year. This represents a loss in efficiency of 3000 MJME/ha/year relative to all the ME being directly used for production.

Secondly, the increased feeding levels resulted in increased maintenance requirements. One reason for the extra days in milk was that the culling of 20% of the herd each year was delayed from early summer until late autumn on the supplemented farmlets. While this allowed these animals to continue to produce milk, it also resulted in additional energy being required for maintenance and the early part of pregnancy. On average, the additional ME required for maintenance and pregnancy was about 9500 MJME/ha/year. Further, over the three years of the experiment, the cows on the HS farmlets with the supplementary feeding treatments were on average 24kg heavier than the cows on the control farmlet. The estimated ME required to maintain this extra liveweight was 4000 MJME/ha/year.

Thirdly, it is likely that some of the extra feed was wasted, or caused some pasture to be wasted. In grazing systems, lower pasture DMI is expressed as increased post grazing pasture mass. However, this increase in post grazing herbage mass is not manifest as a uniform increase in pasture height, but rather an increase in the herbage mass within un-grazed clumps of pasture surrounding dung and urine patches. These clumps of pasture are probably a significant source of loss of pasture through senescence and decay of older pasture material (Parsons and Chapman, 1998). The total ME that can be accounted for by the additional maintenance and production that occurred as a result of the supplementary feeding of the HS herds was 50500 MJME/ha/year (Table 6.12). By difference this means that 19500 MJME/ha/year was wasted as either uneaten supplement, or substituted pasture that subsequently senesced and decayed.

Based on this analysis, it would be difficult to obtain larger responses within grazing systems. As feeding levels are increased, an increasing proportion of the extra ME will be partitioned to body reserves (Broster and Thomas, 1981).

Table 6.12: An estimate of the fate of additional metabolisable energy (ME) provided to the high stocked herds as supplementary feed.

Simple energy balance*	(MJME/ha/year)
Extra ME provided as supplement	**70000**
ME required for increased milk production	
Directly from feed eaten	17000
From body reserves accumulated from supplements	20000
ME required for increased maintenance	
Delayed culling	9500
Maintenance for additional 24 kg liveweight/cow	4000
Total	**50500**
Estimate of losses from wasted supplement and pasture	19500

*Calculations based on equations provided by Holmes *et al.* (1987).

Therefore, lower than optimal efficiency of milk production, and additional liveweight are inevitable. The wasted feed represents less than 10% of the total feed available to these herds, and is less than 30% of the extra feed provided as supplement. It is likely that when supplements are offered to lower stocked herds, considerably more waste might be expected.

6.5.2.2 Differences in milk yield response between types of feed

The cows offered the WCS supplement produced lower yields of milkfat and protein than those offered the MG and BR, mainly because the cows ate less DM from WCS, which contained less ME/kg DM, than cows offered the MG and BR supplements. The WCS supplement consistently resulted in greater milkfat and a lower milk protein response than the MG supplement.

Maize silage has a medium energy ME concentration and a low crude protein content (NRC, 1989). Although maize silage is usually of lower nutritive value than high quality grazed pasture, ease of ingestion usually ensures it is consumed in preference. At high pasture allowances, this may result in direct substitution of maize silage for grazed pasture (Hutton and Douglas, 1975), perhaps even reducing total energy intake and milk yield (Bryant and Donnelley, 1974). However, offering maize silage supplements usually increases milk yields when cows are grazed on restricted amounts of pasture (Bryant and Donnelly, 1974; Campbell *et al.,* 1978; Stockdale, 1995; Stockdale and Dellow, 1995; Stockdale, 1996; Stockdale, 1997a; Stockdale, 1997b). At low pasture allowances, as was the case in this experiment, offering forage supplements often has little effect on pasture intake and can restore total DMI to levels achieved when generous amounts of pasture were offered (Hutton and Douglas, 1975; Bryant, 1978; Phillips and Leaver, 1985). Again, the low levels of pasture substitution that occurred caused a large increase in ME intake, and relatively large milk yield responses.

Yields of milkfat and protein produced by cows offered the BR were similar to those of cows offered the MG in all years. In year 1, the milkfat and protein responses of cows offered the BR were lower than those from MG and WCS, however, in years 2 and 3, BR resulted in larger responses. It is likely that the large increase in response from the BR supplement in years 2 and 3 was due to improvements in the skills required to balance the nutrients contained in the supplement with the nutrients provided by pasture. Pasture chemical composition varied little between years, but the BR contained more concentrate and less maize silage in years 2 and 3. The form of UDP also changed from blood meal and meat and bone meal, to fishmeal. Nevertheless, subtle changes to the composition of the ration are unlikely to have marked effects on milk production given that the ration was formulated to exceed current estimates of nutrient requirements (Hoffman *et al.*, 1993).

6.5.2.3 Differences in milk yield response between years

The MS responses to extra ME provided by the supplement were greater in years 2 and 3 than in year 1 by 6%, 18%, 53%, and 17% for MG, WCS, BR, and LS treatments, respectively (Table 6.11). Broster *et al.* (1993) reviewed experiments examining level of feeding over multiple lactations and concluded that the level of nutrition in one lactation often affects the milk yield in the subsequent lactation. Further, the effects of underfeeding during lactation, particularly the end of a lactation, consistently caused reduced milk yield and increased liveweight gain in the subsequent lactation (Broster *et al.*, 1993). In the second and third years of this experiment, the MS yield of the control herd was 16% lower than in year 1. Shorter lactation lengths and lower annual DMI per cow largely explained this, although annual pasture production per hectare changed little between years. The longer lactation during year 1 was partially due to the fact that one score of body condition was mobilised and not replaced. Previous research has estimated that this would have been expected to contribute approximately 15 kg MS/cow (Grainger and McGowan, 1982). After adjustments for the MS which was probably contributed by the loss in body condition in the control herd, the MS responses to the MG, WCS, BR and LS treatments would have been 8.3, 8.6, 6.9, and 7.2g /MJME in year 1, respectively, which were similar to the actual responses achieved in years 2 and 3.

The largest single difference between years was that in years 2 and 3, larger quantities of supplement were offered during the late summer and early autumn in response to poor pasture growth resulting from the summer moisture deficit in these two years, compared with year 1. The late summer is also the period of lowest pasture CP content (Table 6.1), particularly during dry summers. Increased DMI of

WCS and MG, relative to pasture DMI, and lower pasture CP content, resulted in the CP content of the total diet ranging from 14.3 to 11.7g/100g DM during February of years 2 and 3. The marginal responses to maize silage offered to pasture fed cows declines markedly once the CP concentration of the total diet is below 14g/100g DM (Stockdale, 1995). Hutton and Douglas (1975) suggested that maize silage should not exceed 30% of the daily DMI of grazing dairy cows because of low concentrations of CP, Ca and P. Further, providing nitrogen and protein supplements to grazing cows when maize silage exceeds 30% of total DMI has been shown to increase milk yields, even when the CP content of the total diet should theoretically have been adequate (Hutton and Douglas,1975; Macdonald *et al.*, 1998). During the present trial WCS exceeded 30% of total DMI for 13 months, and was as high as 56% in some months. It can be concluded that the CP content of the diet eaten by the MG and WCS herds was sometimes low enough to reduce the milk yield response to those diets.

The marginal MS response by cows eating limited amounts of pasture usually decreases as the level of supplementation increases, particularly when the supplement is in the form of a concentrates which provide little dietary fibre (Stockdale *et al.*, 1987). Stockdale *et al.* (1987) found that at concentrate intakes higher than 6 kg DM/cow/day, the NDF concentration of the diet fell below 25%, milkfat concentration decreased and the milkfat yield also decreased. During the present experiment, supplementary feeding with MG caused the NDF concentration of the total diet to decrease to values below 30% for 4 months in year 2, and 5 months in year 3. Nevertheless, this did not appear to reduce the milkfat concentration of the herds during the periods of low NDF concentration, or over the lactation (Table 6.7).

6.6 Conclusions

Pasture availability limited the annual milksolids yield of seasonally calved grazing dairy cows at high stocking rates. Low pasture DMI resulted in reduced milksolids yield immediately after calving in late winter and early spring, and during the late summer/autumn period. Body condition lost immediately after calving and during subsequent periods of feed deficit, and the pasture deficit itself, necessitated early drying off of individual cows to ensure their body reserves could be replenished before the following calving. Low body condition at calving and low DMI after calving resulted in an extended post partum anoestrous interval and high rates of anoestrous at the planned start of mating, which could have reduced reproductive efficiency had non-cycling cows not been treated.

Responses of 6.5 to 8.0 g MS/MJME were achieved when supplementary feeds or a reduced stocking rate were used to ensure that grazing cows could be better fed throughout the year. While these responses were about twice as large as responses measured previously during short-term trials (Chapters 4 and 5), they were only half the theoretically possible response. These poor responses can be explained by losses in efficiency associated with an increasing proportion of ME being laid down as body reserves, additional maintenance required for heavier cows and longer lactations, and losses by wasted feed, and were consistent with other long-term experiments that have measured the response of cows to increased feeding level. On this basis, it was concluded that it is probably very difficult to achieve larger long-term responses within grazing systems. Supplements that balanced the total diet for protein, fibre and minerals produced slightly larger responses per unit of supplementary energy than the responses to supplements of maize grain and maize silage alone, or the responses to extra pasture. However, differences in responses to extra feed between the different types of extra feed were small and it is concluded that the main limiting factor in these systems were nutrients that provided metabolisable energy.

6.7 References

Broster, W. H. and Broster, V. J. 1984. Long term effects of plane of nutrition on the performance of the dairy cow. *Journal of Dairy Research* **51:** 149-196.

Broster, W. H., Broster, V. J. and Clements, A. J. 1993. Feed utilisation of the dairy cow over multiple lactations: A review. *Livestock Production Science* **34:** 1-21.

Broster, W. H. and Thomas, C. 1981. The influence of level and pattern of concentrate input on milk output. In: *Recent Advances in Animal Nutrition.* Ed. W. Haresign. Butterworths, London. Pages 49-69.

Bryant, A. M. 1978. Summer supplementary feeding. *Proceedings of the Ruakura Farmers' Conference* **30:** 163.

Bryant, A. M. 1990. Optimum stocking and feed management practices. *Proceedings of the Ruakura Farmers' Conference* **42:** 55-59.

Bryant, A. M. and Donnelly, P. E. 1974. Yield and composition of milk from cows fed pasture herbage and supplemented with Maize and pasture silages. *New Zealand Journal of Agricultural Research* **17:** 299 – 304.

Bryant, A. M. and Macdonald, K. A. 1987. Management of the dairy herd during a dry summer. *Proceedings of the Ruakura Farmers' Conference.* **39:** 53-56.

Campbell, A. G., Clayton, D. G. and Macdonald, K. A. 1978. Dairy cattle management: Maize pasture rotations. *Proceedings of the Ruakura Farmers' Conference* **30:** 166.

Chesterton, R. N. and Marchant, R. M. 1985. Early induction of dairy cows. *Proceedings of the 2nd seminar of the Dairy Cattle Veterinarians' Society of the New Zealand Veterinary Association* **2:** 52.

Clark, D. A. 1993. Silage for milk production. *Proceedings of the Ruakura Farmers' Conference* **45:** 41-46.

Edwards, N. J., and Parker, W. J. 1994. Increasing per cow milksolids production in a pasture-based dairy system by manipulating the diet: A review. *Proceedings of the New Zealand Society of Animal Production* **54:** 267-273.

Fox, D. G., Sniffen, C. J., O'Connor, J. D., Russell, J. B. and Van Soest, P. J. 1992. A Net Carbohydrate and Protein System for evaluating cattle diets. *Journal of Animal Science* **70:** 3578-3596.

Gordon, F. J., Ferris, C. P., Patterson, D. C. and Mayne, C. S. 2000. A comparison of two grassland-based systems for autumn calving dairy cows of high genetic merit. *Grass and Forage Science* **55:** 83-96.

Grainger, C., and McGowan, A. A. 1982. The significance of pre-calving nutrition of the dairy cow. *Dairy production from pasture.* Eds. K. L. Macmillan and V. K. Taufa. Clark and Matherson Ltd. Hamilton N.Z. Pages 134-171.

Grainger, C., and Mathews, G. L. 1989. Positive relationship between substitution rate and pasture allowance for cows receiving concentrates. *Australian Journal of Experimental Agriculture* **29:** 355-360.

Hoffman, K., Muller, L. D. Fales, S. L. and Holden, L. D. 1993. Quality evaluation and concentrate supplementation of rotational pasture grazed by lactating dairy cows. *Journal of Dairy Science* **76:** 2651-2663.

Holmes, C. W. 1987. Pastures for dairy cows. In Livestock Feeding on Pasture. Ed. A. M. Nicol. *New Zealand Society of Animal Production, Occasional Publication* **10:** 133-143.

Holmes, C. W., and Macmillan, K. L., 1982. Nutritional management of the dairy herd grazing on pasture. In Dairy Production From Pasture. *Dairy production from pasture.* Eds. K. L. Macmillan and V. K. Taufa. Clark and Matherson Ltd. Hamilton N.Z. Pages 244-274.

Holmes, C. W., Wilson, G. F., Mackenzie, D. D. S., Flux, D.S., Brookes, I. M. and Davey, A. W. F. 1987. *Milk Production from Pasture.* Eds. C.W. Holmes and G.F. Wilson. Butterworths of New Zealand Ltd. Wellington.

Hutton, J. B. and Douglas, J. A. 1975. Growing and using maize silage on the dairy farm. *Proceedings of the Ruakura Farmers' Conference* **27:** 76-82.

Johnstone, P. D. 1979. A statistical appraisal of a sacred cow. *Proceedings of the New Zealand Society of Animal Production* **39:** 281-283.

Kellaway, R. C., and Porta, S. 1993. *Feeding concentrates: supplements for dairy cows.* Ed E. Hopkins. Agmedia, Melbourne, Australia.

Kolver, E. S., and Muller, L. D. 1998. Performance and nutrient intake of high producing Holstein cows consuming pasture or a total mixed ration. *Journal of Dairy Science* **81:** 1403-1411.

Lean, I. J., Parker, W. J., and Kellaway, R. C. 1996. Improving the efficiency of pasture-based dairy production. *Proceedings of the New Zealand Society of Animal Production* **56:** 270-275.

Leaver. J. D. 1985. Effect of supplements on herbage intake and performance. Grazing. Ed. J. Frame. *Occasional Symposium of the British Grasslands Association* **19:** 79-90.

Leaver, J. D., Campling, R. C. and Holmes, W. 1968. The use of supplementary feeds for grazing dairy cows. *Dairy Science Abstracts* **30,7:** 355-361.

LIC, 1999. *Economic Survey of Factory Supply Dairy Farmers 1998/1999.* Livestock Improvement Corporation Limited, Hamilton, New Zealand.

Macmillan, K. L. 1995. Reducing the use of induced calving. *Proceedings of the Ruakura Farmers' Conference* **47:** 36-41.

Macdonald, K. A., and J. W. Penno. 1998. Management decision rules to optimise milksolids production on dairy farms. *Proceedings of the New Zealand Society of Animal Production* **58:** 132-135.

Macdonald, K. A., Penno, J. W. Kolver, E. S. Carter, W. A. and Lancaster, J. A. 1998. Balancing pasture and Maize silage diets for dairy cows using urea, soybean meal or fishmeal. *Proceedings of the New Zealand Society of Animal Production* **58:** 102-105.

McCall, D.G. and Clark, D. A. 1999. Contrasting characteristics of optimised dairy grazing systems in Northeast USA and New Zealand. 2. System analysis. *Journal of Dairy Science* **82:** 1808-1816.

McDougall, S., Burke, C.R., Williamson, N.B. and Macmillan, K. L. 1995. The effect of stocking rate and breed on the period of postpartum anoestrous in grazing dairy cattle. *Proceedings of the New Zealand Society of Animal Production* **55:** 236-238.

Meijs, J. A. C., and Hoekstra, J. A.1984. Concentrate supplementation of grazing dairy cows. I. Effect of concentrate intake on and herbage allowance on herbage intake. *Grass and Forage Science* **39:** 59-66.

Moller, S. 1997. *An evaluation of major nutrients in dairy pasture in New Zealand and their effects on milk production and herd reproductive performance.* Ph.D. Thesis, Massey University, Palmerston North, New Zealand.

Muller, L. D. 1993. Nutritional supplementation and ration balancing for high producing dairy cows. In: *Improving the Quality and Intake of Pasture Based Diets for Lactating Dairy Cows.* Eds. N. J. Edwards and W. J. Parker. Massey University Department of Agricultural and Horticultural Systems Management Occasional Publication No. 1. pp. 33-58.

National Research Council. 1989. Nutrient requirements of Dairy Cattle. 6th rev. ed. *National Academy of Science.* Washington, DC.

Oldham, J. D. and Emmans, G. C. 1989. Prediction of responses to required nutrients in dairy cows. *Journal of Dairy Science* **72:** 3212-3229.

Parsons, A. J., and Chapman, D. F. 1998. Principles of grass growth and pasture utilisation. In *Grass for dairy cattle.* Eds. J. H. Cherney, and D. J. R. Cherney CABI Publishing, Wallingford, Oxon, UK.

Penno, J. W. 1998. Principles of profitable dairying. *Proceedings of the Ruakura Farmers' Conference* **50:** 1-14.

Phillips, C. J. C. and Leaver, J. D. 1985. Supplementary feeding of forage to grazing dairy cows. *Grass and Forage Science* **40:** 49-51.

Pinares, C. and Holmes, C. W. 1996. Effects of feeding silage and extending lactation on the pastoral dairy system. *Proceedings of the New Zealand Society of Animal Production* **56:** 239-241.

Robaina, A. C, Grainger, C. Moate, P. Taylor, J. and Stewart, J. 1998. Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* **38:** 541-549.

SAS. 1995. SAS/STAT Users' Guide, Version 6. SAS Institute Inc. Cary. NC.

Scott, J. D. J. and Smeaton, D. C. 1980. Sheep and cattle nutrition. Eds. J. D. J. Scott., N. Lamont., D. C. Smeaton., and S. J. Hudson, Agricultural Research Division, Ministry of Agriculture, Ruakura, Hamilton, New Zealand.

Stakelum, G. 1986a. Herbage intake of grazing dairy cows. 1. Effect of autumn supplementation with concentrates and herbage allowance on herbage intake. *Irish Journal of Agricultural Research* **25:** 31-40.

Stakelum, G. 1986b. Herbage intake of grazing dairy cows. 2. Effect of herbage allowance, herbage mass and concentrate feeding on the intake of cows grazing primary spring grass. *Irish Journal of Agricultural Research* **25:** 41-51.

Stakelum, G. 1986c. Herbage intake of grazing dairy cows. 3. Effect of herbage mass, herbage allowance and concentrate feeding on the herbage intake of dairy cows grazing on mid-summer pasture. *Irish Journal of Agricultural Research* **25:** 179-189.

Stockdale, C. R. 1995. Maize-silage as a supplement for pasture fed dairy cows in early and late lactation. *Australian Journal of Experimental Agriculture* **35:** 19-26.

Stockdale, C. R. 1996. Substitution and production responses when lactating dairy cows graze a white clover pasture supplemented with Maize silage. *Australian Journal of Experimental Agriculture* **36:** 771-776.

Stockdale, C. R. 1997a. Influence of energy and protein supplements on the productivity of dairy cows grazing white clover swards in spring. *Australian Journal of Experimental Agriculture* **37:** 151.

Stockdale, C. R. 1997b. Supplements improve the production of dairy cows grazing either white clover or paspalum-dominant pastures in late lactation. *Australian Journal of Experimental Agriculture* **37:** 295.

Stockdale, C. R., Callaghan, A. and Trigg, T. E. 1987. Feeding high energy supplements to pasture-fed dairy cows. Effects of stage of lactation and level of supplement. *Australian Journal of Agricultural Research* **38:** 927-940.

Stockdale, C. R., and Dellow, D. W. 1995. The productivity of lactating cows grazing white clover and supplemented with maize silage. *Australian Journal of Agricultural Research* **46:** 1205-1217.

Tessman, N. J., Radloff, H. D., Kleinmans, J., Dhiman, T. R. and Satter, L.D. 1991. Milk production response to dietary forage:grain ratio. *Journal of Dairy Science* **74**: 2696-2707.

Wales, W. J., Doyle, P. T. and Dellow, D. W. 1998. Dry matter intake and nutrient selection by lactating dairy cows grazing irrigated pastures at different pasture allowances in summer and autumn. *Australian Journal of Experimental Agriculture* **38:** 451-460.

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

Ulyatt, M. J., Lee, J. and Corson, D. 1995. Assessing feed quality. *Proceedings of the Ruakura Farmers' Conference* **47:** 59-62.

van de Haar, M. H. Bucholtz, R., Beverly, R., Emery, M., Allen, C., Sniffen, C. and Black, C. 1992. Users manual for Spartan dairy ration evaluator/balancer. Version 2. Michigan State University Cooperative Extension Service.

Velleman, P. F. 1997. Data Desk, Version 6. Data Description, Ithaca, NY.

CHAPTER SEVEN

GENERAL DISCUSSION AND IMPLICATIONS FOR DAIRY FARMERS MAKING SUPPLEMENTARY FEEDING DECISIONS

CHAPTER 7: GENERAL DISCUSSION AND IMPLICATIONS FOR DAIRY FARMERS MAKING SUPPLEMENTARY FEEDING DECISIONS

7.1 Introduction

The aim of this thesis was to develop a unifying biophysical framework that could be used as a conceptual model to help farmers make better predictions about the response of grazing dairy cows to supplementary feeds. There is a large body of literature about the marginal milk yield response of pasture-fed cows to varying amounts of specific supplementary feeds (Chapter 2). The predominant feature of this evidence is the wide variability in the magnitude of the reported responses, which does not provide a solid basis from which dairy farmers can make sound economic decisions. To be useful, a unifying framework must help to explain some of the variability in previously reported experiments, and thus provide a basis for improved prediction of responses.

The experiments reported in this thesis were designed to develop a conceptual model by examining the key factors that influence the immediate and long-term milk yield response to supplements. Particular emphasis was placed on: 1) the effects of stage of lactation (because the cows' demand for feed varies with the lactation cycle); 2) the effects of season of the year (because the physical and chemical structure of the pasture offered varies through the year); 3) the effects of type of supplementary feed (differing chemical and structural composition); and 4) the response of the whole farm system to inputs of supplementary feed. An important feature of all experiments was that the groups of cows were offered restricted amounts of pasture during each period of supplementary feeding.

7.2 Limitations of the methods

This thesis is based on two large grazing studies. The key objective of these studies was to develop an improved understanding of the mechanisms that determine the magnitude of the milk yield response by grazing cows to extra feed provided as supplement. The milk yield, liveweight and supplementary feed intake of grazing cows can be measured accurately, allowing the accurate calculation of marginal responses. However, while developing an improved understanding of the pasture intake response to supplements was critical to improving our understanding of the reasons for the large variability in milksolids response, measuring the pasture dry matter intake (DMI) by grazing cows is notoriously difficult (Garcia, 2000).

The alkane marker technique was chosen as the preferred method of determining pasture DMI as it provides an estimate for individual cows, and has been validated for pasture-fed cows indoors (Dove and Mayes, 1991). While some recent studies have suggested close agreement between pasture DMI estimates based on the alkane technique and the pasture DMI back-calculated from milk yield and liveweight using energy requirement standards (Garcia, 2000), others have shown wider discrepancy between the two measures (Robaina *et al.*, 1998). The pasture DMI data presented in Chapter 3 is calculated only from the alkane technique, and therefore the DMI and calculated pasture substitution rate of individual treatment groups must be interpreted with some caution.

The second important limitation to this work is that the short-term trials (Chapters 3 to 5) and the long-term farmlet trial (Chapter 6) were run simultaneously. Had the short-term work been completed first, a comparison of the long-term supplementary feeding responses by cows at a range of stocking rates, may have been more useful in the development and refinement of the biophysical model that was derived from the short-term trials.

During this research, it was hypothesised that the most important factor that determined the cows' response to supplements is the relative feed deficit (RFD) of the cow. This was defined as the daily metabolisable energy intake (MEI) that the cow requires to meet the energetic costs of maintenance and pregnancy and attaining her target milk yield and rate of change in body reserves, minus her actual daily MEI ($MEI_{target} - MEI_{actual}$). Unfortunately, RFD cannot be directly measured because the cows "targets" for milk yield and rate of change in body reserves are hypothetical. Therefore, the change in milksolids yield by the control cows that occurred as feed restrictions were imposed at the onset of each experimental period, was adopted as an indirect, but pragmatic estimate of RFD.

A third limitation arose because RFD and season of the year were confounded to some extent. The short-term trials compared cows at different stages of lactation, and therefore with different feed demands, at each time of the year. Pasture allowance and quality, which were closely associated with time of the year and therefore experimental period, were found to be more important determinants of RFD than stage of lactation. Certainly, the comparisons between season are less statistically vigorous than those between stages of lactation within season. In future, the concept of relative feed deficit (Chapter 5) should be tested by measuring the supplementary feeding response by dairy cows of similar feed demand grazing a range of pasture allowances. Further, there is no doubt that an improved method for estimating RFD could be developed, and this should be a priority for future supplementary feeding research.

7.3 Prediction of pasture substitution

The average substitution rate (SR) derived from the literature review was 0.31 kg pasture DM/kg DM provided as supplement. In the present trials, SR ranged from 0.1 to 0.5 during the short-term trials (Chapter 3), and during the long-term study the SR was estimated as 0.2 kg DM/kg DM (Chapter 6). These SR's were within the range reported in the literature (Chapter 2). However, differences in SR were not closely associated with either stage of lactation, season of the year or type of supplement. Therefore, it was concluded that some other factor, or more likely several interrelated factors, must be of greater importance than either stage of lactation, season of the year or type of supplementary feed.

Unsupplemented pasture DMI (PDMI), the pasture DMI of the unsupplemented cows expressed per 100 kg liveweight, has previously been shown to be positively associated with SR (Grainger and Mathews, 1989). In the present experiments, SR increased from 0.0 to 0.6 kg DM/kg DM as the amount and quality of pasture on offer allowed the unsupplemented cows to increase pasture DMI from 1.5% to 3.5% of liveweight. Interestingly, the relationships between PDMI and SR observed during the experiments reported in Chapter 3 were very similar to those reported by Grainger and Mathews (1989). This suggests that SR was determined by the relative level of feeding provided by the pasture on offer to the group of cows receiving no supplements.

In a practical sense, farmers could use PDMI to estimate the expected SR based on either the pasture DMI achieved immediately before the supplement was offered, or based on known relationships between pasture allowance and pasture DMI (e.g. Wales *et al.*, 1998). However, it is not the SR that determines milk production, but rather the total intake of pasture and supplement that results from a given allowance of pasture and supplementary feed. The data reported in Chapter 3 also suggested that increasing total metabolisable energy (ME) allowance, from either pasture or supplement, resulted in a linear increase in ME intake. While changes in sward structure resulted in these relationships differing between seasons, within each season a 1.0 MJME increase in total feed allowance resulted in a 0.65 increase in total ME intake. It is likely that the responses were linear only because of the low pasture allowances (>35kg DM/cow/day) used in these experiments. Indeed, the relationship between PDMI and SR implies that ME intake response to incremental increases in ME allowance must diminish at higher allowances.

7.4 Prediction of milksolids responses

The review of short-term supplementary feeding trials in Chapter 2 concluded that the average response to supplements by pasture-fed cows was 4.1g MS and 11.5g liveweight/MJME. In trial 1, the immediate responses ranged from 2.0 to 5.6g MS/MJME and from 0.3 to 11.1g liveweight/MJME, and total responses ranged from 3.6 to 7.5g MS/MJME. In trial 2, the immediate responses ranged from 0.3 to 3.3g MS/MJME and from 1.9 to 6.4g liveweight/MJME, and total responses ranged from –0.1 to 4.7g MS/MJME (Chapter 5). The total response to supplementary feeding measured at high stocking rates in the long-term experiment ranged from 7.3 to 7.8g MS/MJME (Chapter 6).

The marginal immediate responses in milksolids (MS) and liveweight calculated from the present experiments were within the range of those calculated from other experiments (Chapter 2). Nevertheless, they were considerably smaller than the 15g milksolids/MJME theoretically possible if all the additional ME provided by supplements were used directly for milk synthesis (Holmes *et al.,* 1987). The ME required for the immediate milksolids and liveweight responses calculated from trial 1 and trial 2 accounted for only about 0.5 and 0.3 MJME/MJME provided as supplementary feed, respectively. Part of the discrepancy between these results and theory can be explained by pasture substitution. Average substitution rates of 0.21 and 0.34 were measured during the experimental periods of trials 1 and 2, respectively (Chapter 3). Thus, the combined immediate responses (milksolids, liveweight and pasture substitution) accounted for about 0.7 MJME/MJME provided as supplement in trials 1 and 2.

Stage of lactation had no consistent effect on the magnitude of the immediate milksolids or liveweight gain response to the supplementary treatments during the short-term trials (Chapter 4). Offering supplements in spring generally resulted in smaller increases in milksolids and larger increases in liveweight gain than when supplements were offered during other seasons, although once again the pattern was inconsistent. Further, responses in milksolids yield (g MS/MJME) to different forms of supplementary feed were similar, with the exception of improved responses resulting from protein-rich supplements that were offered during periods when the crude protein concentrations of the pasture were too low to sustain high milksolids yield. It can be concluded that stage of lactation and season of the year are probably of smaller influence on the magnitude of milksolids yield response to supplementary feed than some other factors.

Immediate milksolids responses were generally smaller in trial 2 than during trial 1 (Chapter 5). The key differences between the trials were that the amount of supplementary feed offered in trial 2 was 80 MJME/cow/day, compared to only 50 MJME/cow/day in trial 1, and that higher pasture DMI resulted in generally higher milksolids yields in trial 2 than trial 1. While a diminishing marginal milksolids response and an increasing liveweight response to incremental increases in ME intake might be expected (Broster and Thomas, 1981), the liveweight gain, carryover and total milksolids responses also tended to be smaller during trial 2 than trial 1.

The smaller responses of trial 2 were most notable during the spring, and were associated with higher pasture allowances than those offered during the spring period of trial 1. The highest pasture intakes measured during the series of experiments also occurred during the spring experimental period of trial 2 (Chapter 3). Generally, supplementary feeds resulted in the largest increases in milksolids yield during periods when cows offered the pasture only control treatment exhibited the lowest milksolids yields. This suggested that the magnitude of any supplementary feeding response was relative to the level of underfeeding resulting from the pasture intakes that could be attained from the allowance and quality of pasture offered. However, underfeeding can be considered only by taking into account both the amount and quality of the feed offered and the current feed requirements of the cow.

It was suggested in Chapter 4 that some of the variation in responses between experiments reported in the literature can be explained by variation in the magnitude of the reduction in milksolids yield that was reported for the groups of cows offered the restricted pasture-only control treatments. This does provide a unifying measure of the level of underfeeding that was imposed on the unsupplemented comparison group, or that would have been imposed on the experimental group in the absence of the supplement. Irrespective of stage of lactation or time of the year, a new feeding regime that results in a large reduction in milksolids yield is more severe than a new feeding regime that allows the cow to maintain milksolids yield.

To compare between the present experiments, the reduction in milksolids yield observed for cows offered the pasture only control treatments was calculated to represent the RFD for each stage of lactation within each experimental period (Chapter 5). The RFD explained much of the variation in the immediate and total milksolids response observed during the present trials, with larger responses measured in association with larger RFDs. Immediate milksolids responses were smaller when higher milksolids yields were achieved by the unsupplemented cows, and with higher ME intake from supplement. Stage of lactation, as days in milk, may have also had a small negative effect on the magnitude of the immediate milksolids response to supplementary feeds (P=0.07).

The model described in Chapter 5, will provide a framework to enable farmers to predict the total milksolids responses using RFD, pasture and supplementary feed allowance, and stage of lactation as a basis for determining the probable total responses in milksolids yield. Large total milksolids responses can be expected when (in order of importance):

- The basal level of feeding has been high but is declining, and at the time of supplementary feeding will be insufficient to maintain current milksolids yields
- the herd will be offered a low pasture allowance
- and a small amount of supplement is to be offered.

Obviously, it is not necessary for all the above factors to be achieved simultaneously for reasonable milksolids yield responses to be expected, but it is likely that all conditions must exist before the theoretically possible responses will be achieved. Achieving the theoretically possible milksolids responses to supplements also requires that all the substituted pasture is subsequently eaten and contributes to milksolids yield at some time in the future. This model only predicts a value for the milksolids response to supplements. As discussed earlier, the substitution rate can be predicted from PDMI. However, neither model predicts the effect that substituted pasture has on future milksolids production. Interestingly, the milksolids response model implies that providing supplementary feed early in lactation, and maintaining higher milksolids yield, creates the potential for larger RFD and larger milksolids responses later in lactation.

To consider the interactions of supplements within the whole farm system, Chapter 6 described a grazing experiment that was designed to determine the long-term effects of supplementary feeding. This three-year study allowed supplementary feeding and the associated pasture substitution to influence pasture growth and animal performance over three lactations within farmlet systems.

As was demonstrated in the short-term studies, type of supplementary feed had little effect on the magnitude of the total response, which was largely determined by the amount of ME provided by the supplement. As predicted, the total responses were larger than the average responses achieved during the short-term studies, however, when the conditions at the time of supplementary feeding are considered they were similar to the total responses that might be predicted using the model described in Chapter 5.

The high stocking rates (4.4 cows/ha), caused low pasture allowances (20 to 35 kg DM/cow/day) during periods of supplementary feeding. While it is not possible to calculate the actual RFD, given an average total response of 7.6 g MS/MJME, an average allowance of 27.5 kg DM/cow/day of pasture with an ME concentration of 12 MJ/kg DM, and an average daily supplement allowance of 60 MJME/cow/day (Chapter 6), the model described in Chapter 5 would estimate that RFD averaged 0.46 kg MS/cow/day. Over a 285 day lactation this equates to 131 kg MS/cow, which corresponds closely to the annual increase in milksolids yield of 120 kg MS/cow achieved by offering supplementary feed.

The close agreement between responses predicted from the short-term experiments described in Chapters 3 to 5, and the responses achieved during the long-term experiment described in Chapter 6, suggests that under ideal conditions, the total increase in milksolids yield was only about half of the theoretically possible response. In part this discrepancy can be explained by the loss in efficiency associated with ME being stored as body reserves before being mobilised to provide energy for milk production, and the increase in the ME maintenance requirements of the herd associated with delayed culling and increased liveweight. There may also be increases in maintenance associated with increased feed intake and increased milk yield (Agnew and Yan, 2000). Nevertheless, the energy requirements for the increased milksolids yield and the increase in maintenance only account for about 0.7 MJME/MJME provided as supplement (Chapter 6).

Discrepancies commonly exist between the responses that are theoretically possible and those that are observed, however they are difficult to explain (AFRC, 1998). Feeding standards generally describe the requirements of ruminants in terms of energy and protein. These simplifications are usually sufficient for the purpose of providing a diet that meets energy and protein requirements of a group of animals at known and static levels of performance. Nevertheless, there is a growing acceptance that they are inadequate for the purpose of predicting the change in animal performance that is likely to result from a specific change in the nutrition to that group. Further, pasture substitution results in these predictions being less accurate under grazing conditions than when cows are offered a total mixed ration indoors.

The effect that substituted pasture has on subsequent pasture growth and DMI remains unknown. The energy requirements for the responses attained during the long-term experiment presented in Chapter 6 suggest that substituted pasture may contribute little to subsequent production. It is likely that animal related factors such as the accumulation of body reserves and the maintenance of a higher milksolids yield accounted for the accumulation of milksolids responses over each season, and the larger milksolids responses in the second and third season compared to the first. However, there was little evidence that the substituted pasture subsequently contributed to higher pasture DMI. At the high stocking rate, there was no difference in the annual pasture DMI of the supplemented and unsupplemented herds despite the supplemented herds having longer lactations, delayed culling, higher annual pasture yields and higher daily pasture allowances. This suggests that the pasture that was substituted was lost through senescence and decay preventing it being eaten at subsequent grazings.

The high level of agreement between the short- and long-term studies provides further evidence that substituted pasture had little effect on milksolids production from the farm system. The largest total milksolids responses attained during the short-term studies, which did not account for the milksolids production that may result from pasture substitution, are of similar magnitude to the responses measured during the long-term study which provided the ideal opportunity for the expression of pasture related carryover responses. Thus it is reasonable to conclude that the 0.3 MJME/MJME provided by supplements in the long-term trial, that cannot be accounted for as extra production, liveweight or maintenance, was wasted. If all of the substituted pasture (0.2 kg DM/kg DM) were lost through senescence and decay, that would mean that only 0.1 MJME/MJME of the supplement was lost by waste. Discovering the fate of substituted pasture is an important area for future research. Milksolids responses by grazing systems to supplementary feeds might be improved if the loss of ME from wasted pasture could be reduced.

7.5 Conclusions

- The magnitude of any supplementary feeding response (both DMI and total milksolids production) was largely determined by the level of feeding that the pasture provides, relative to the current feed requirement of the herd (relative feed deficit).

- The reduction in milksolids yield of the unsupplemented cows that occurred as restricted feeding was imposed provided an indirect measure of the relative feed deficit, and explained much of the variation within the present trials and between some published experiments.

- At a common relative feed deficit, stage of lactation had little effect on the supplementary feeding response by grazing dairy cows, other than it's effect on the cow's demand for feed, and therefore on the relative feed deficit.

- While time of the year did affect the supplementary feeding response, it was probably caused by the relative level of feed restriction imposed by the allowance and quality of pasture on the experimental groups at that particular time.

- Larger responses were attained by providing a ration that balanced the nutrients in the pasture than providing energy concentrates alone, only when the pasture contained insufficient crude protein to enable high milksolids yields.

- The responses by grazing cows to supplementary feed are smaller than the theoretically possible responses. It is likely that this discrepancy is due to two factors. Firstly, it is not possible to ensure all the additional ME provided is used directly for milk production without changing the body reserves or increasing the maintenance requirements of the herd. Secondly, a high proportion of the pasture that is left ungrazed, because of the relationship between total ME allowance and pasture intake, is subsequently wasted.

- Within the whole farm system, large milksolids responses will result from supplementation strategies that aim to extend lactation by increasing ME allowance during periods of low pasture ME allowance, thereby minimising pasture substitution and waste, but maximising annual ME intake.

7.6 References

Agnew, R. E. and Yan, T. 2000. Impact of recent research on energy feeding systems for dairy cattle. *Livestock Production Science* **66**: 197-215.

AFRC 1998. *Responses in the Yield of Milk Constituents to the Intake of Nutrients by Dairy Cows.* CAB International, Wallingford.

Broster, W. H. and Thomas, C. 1981. The influence of level and pattern of concentrate input on milk output. In: *Recent Advances in Animal Nutrition.* Ed. W. Haresign. Butterworths, London. Pages 49-69.

Dove, H. and Mayes, R. W. 1991. The use of plant wax alkanes as marker substances in studies of the nutrition of herbivores: a review. *Australian Journal of Agricultural Research* **42:** 913-952.

Garcia, S. C. 2000. Management of pasture-based dairy systems which differ in their calving season: effects on herbage accumulation, herbage DM intake, and total DM intake. *Systems, component, and modelling studies of pasture-based dairy systems in which the cows calve at different times of the year.* Ph.D. Thesis, S. C. Garcia, Massey University, Palmerston North. Pages 113-141.

Grainger, C. and Mathews, G. L. 1989. Positive relationship between substitution rate and pasture allowance for cows receiving concentrates. *Australian Journal of Experimental Agriculture* **29:** 355-360.

Holmes, C. W., Wilson, G. F., Mackenzie, D. D. S., Flux, D. S., Brookes, I. M., and Davey, A. W. F. 1987. *Milk Production from Pasture.* Eds. C. W. Holmes and G.F. Wilson. Butterworths, Wellington.

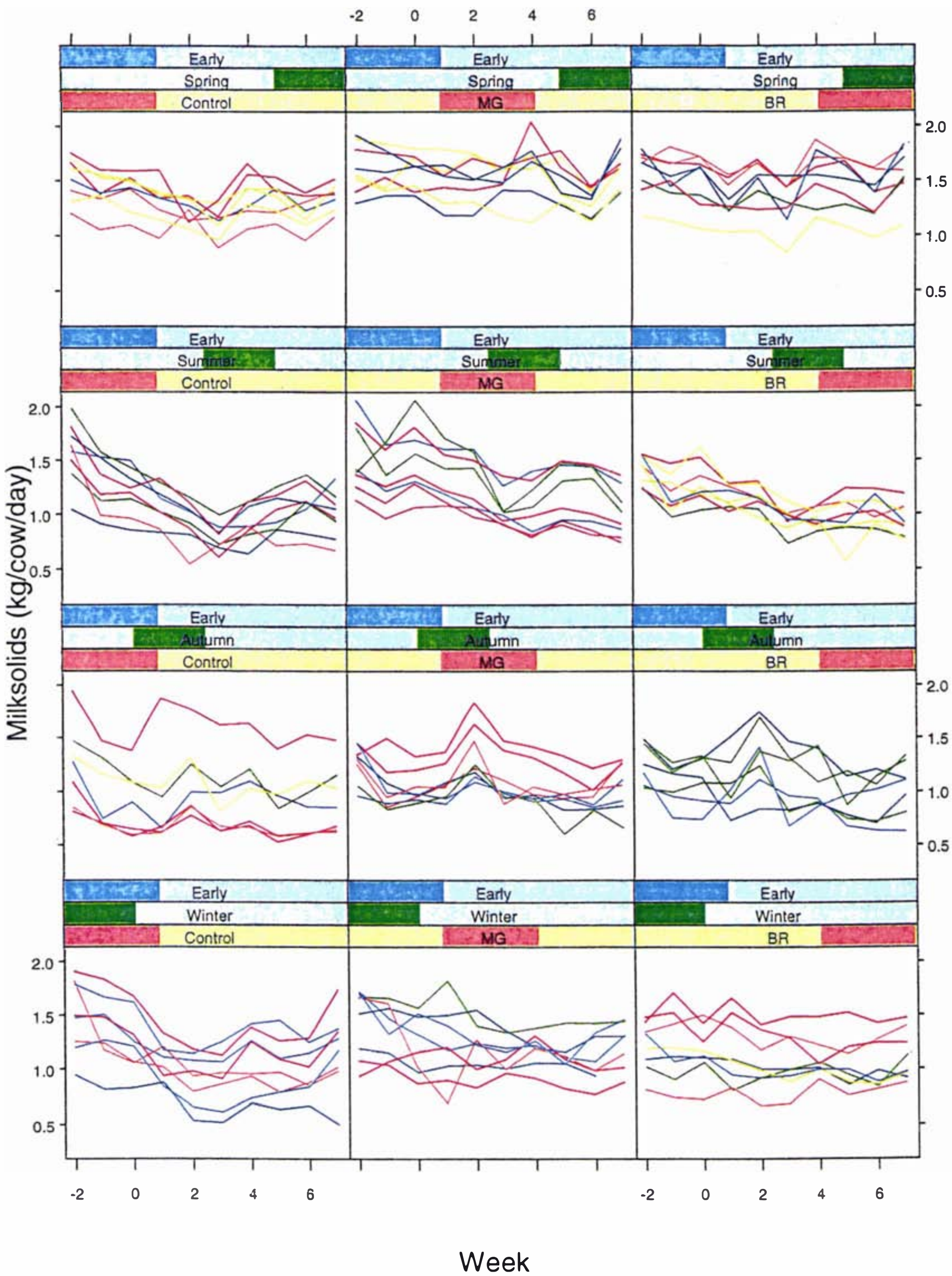
Robaina, A. C, Grainger, C., Moate, P., Taylor, J. and Stewart, J. 1998. Responses to grain feeding by grazing dairy cows. *Australian Journal of Experimental Agriculture* **38:** 541-549.

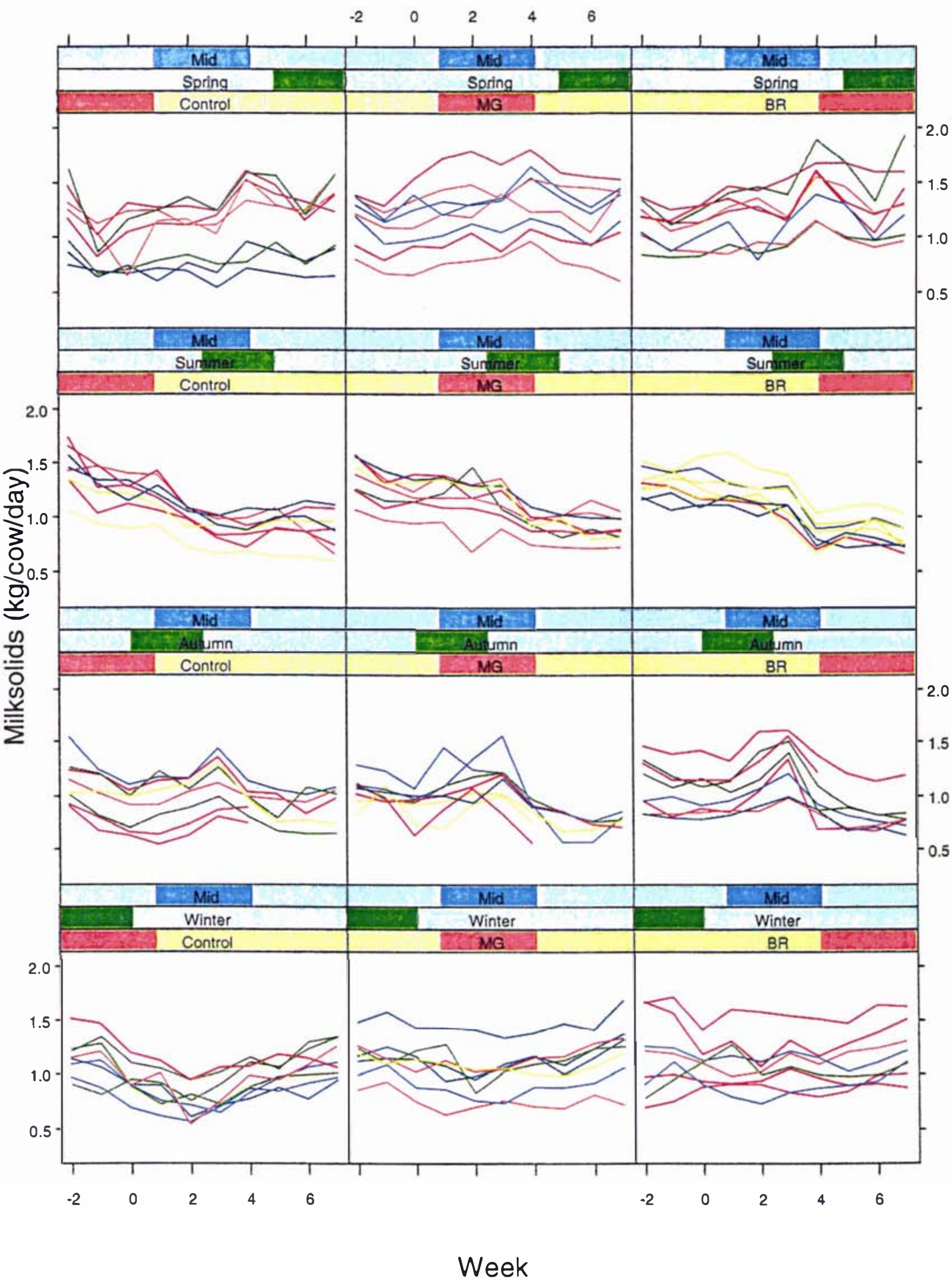
Wales, W. J., Doyle, P. T. and Dellow, D. W. 1998. Dry matter intake and nutrient selection by lactating dairy cows grazing irrigated pastures at different pasture allowances in summer and autumn. *Australian Journal of Experimental Agriculture* **38:** 451-460.

APPENDICES

APPENDIX 1:TRELLIS GRAPHS OF THE MILKSOLIDS YIELD AND LIVEWEIGHT OF EACH COW DURING TRIALS 1 AND 2

Figure A1.1: Daily milksolids yield of each cow in the early, mid and late lactation experimental groups offered the control, maize grain (MG) and balancing ration (BR) feeding treatments, measured during the uniformity (weeks –2 to –1), supplementary feeding (weeks 0 to 4), and carryover (weeks 5 to 7) periods of trial 1.


Early
Spring
Control
MG
BR
Summer
Autumn
Winter
Milksolids (kg/cow/day)
Week
-2
0
2
4
6
0.5
1.0
1.5
2.0


Mid
Spring
Control
MG
BR
Summer
Autumn
Winter
Milksolids (kg/cow/day)
Week
-2
0
2
4
6
0.5
1.0
1.5
2.0

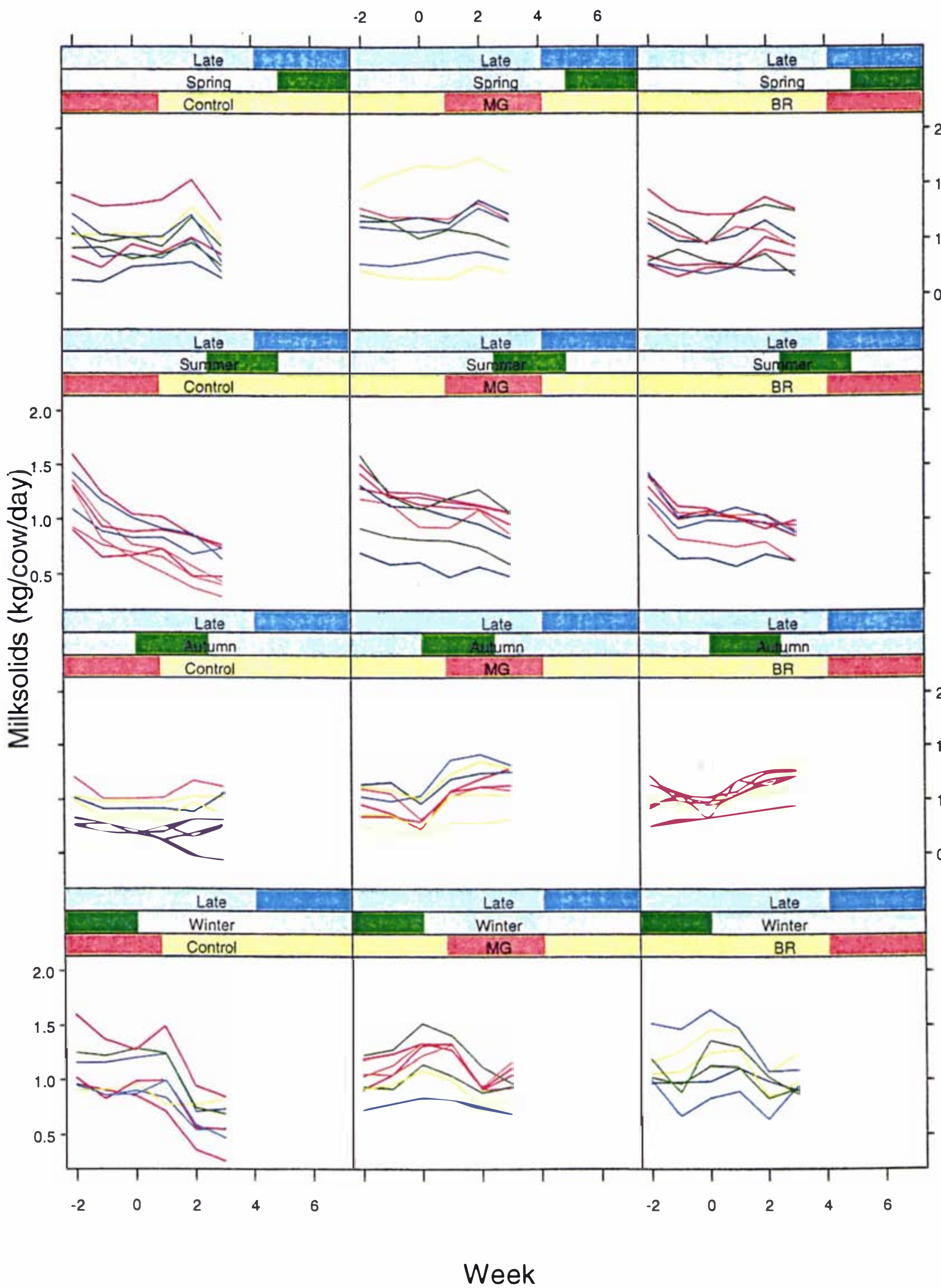
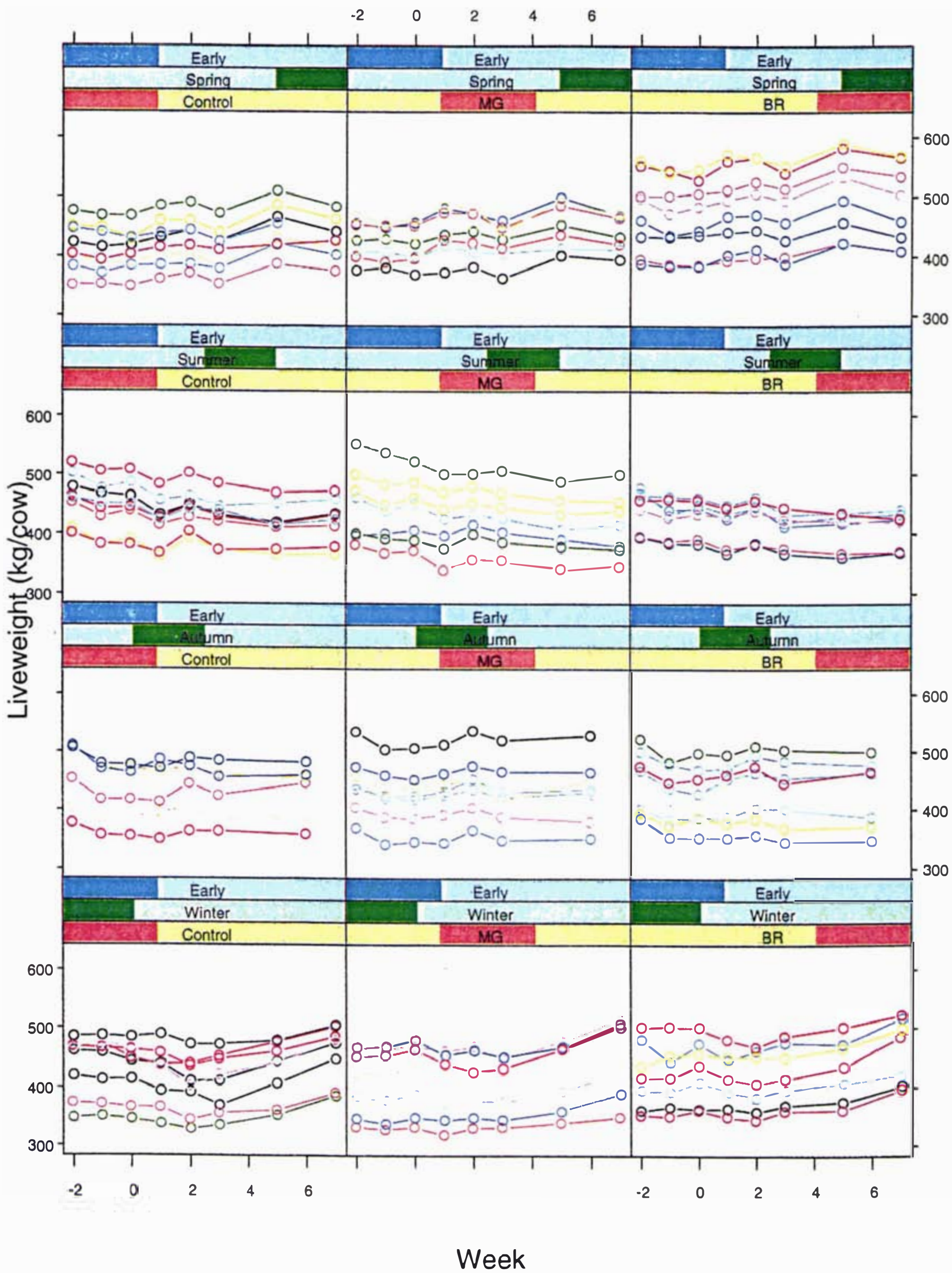
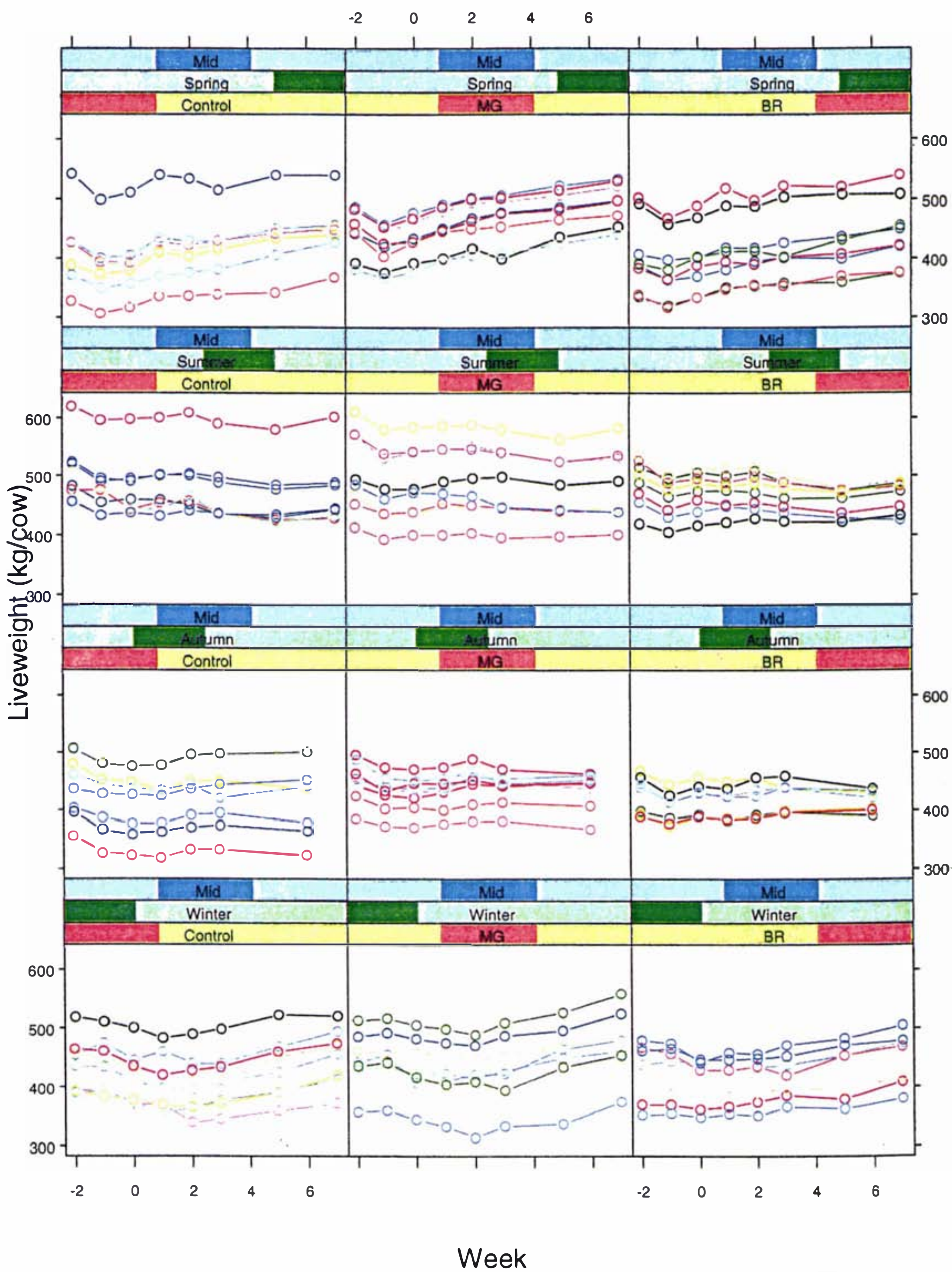

Late
Spring
Control
MG
BR
Summer
Autumn
Winter
Milksolids (kg/cow/day)
Week
-2
0
2
4
6
0.5
1.0
1.5
2.0

Figure A1.2: Liveweight of each cow in the early, mid and late lactation experimental groups offered the control, maize grain (MG) and balancing ration (BR) feeding treatments, measured during the uniformity (weeks –2 to –1), supplementary feeding (weeks 0 to 4), and carryover (weeks 5 to 7) periods of trial 1.



Early
Spring
Control
MG
BR
Summer
Autumn
Winter
Liveweight (kg/cow)
Week
-2
0
2
4
6
300
400
500
600


Mid
Spring
Control
MG
BR
Summer
Autumn
Winter
Liveweight (kg/cow)
Week
-2
0
2
4
6
300
400
500
600

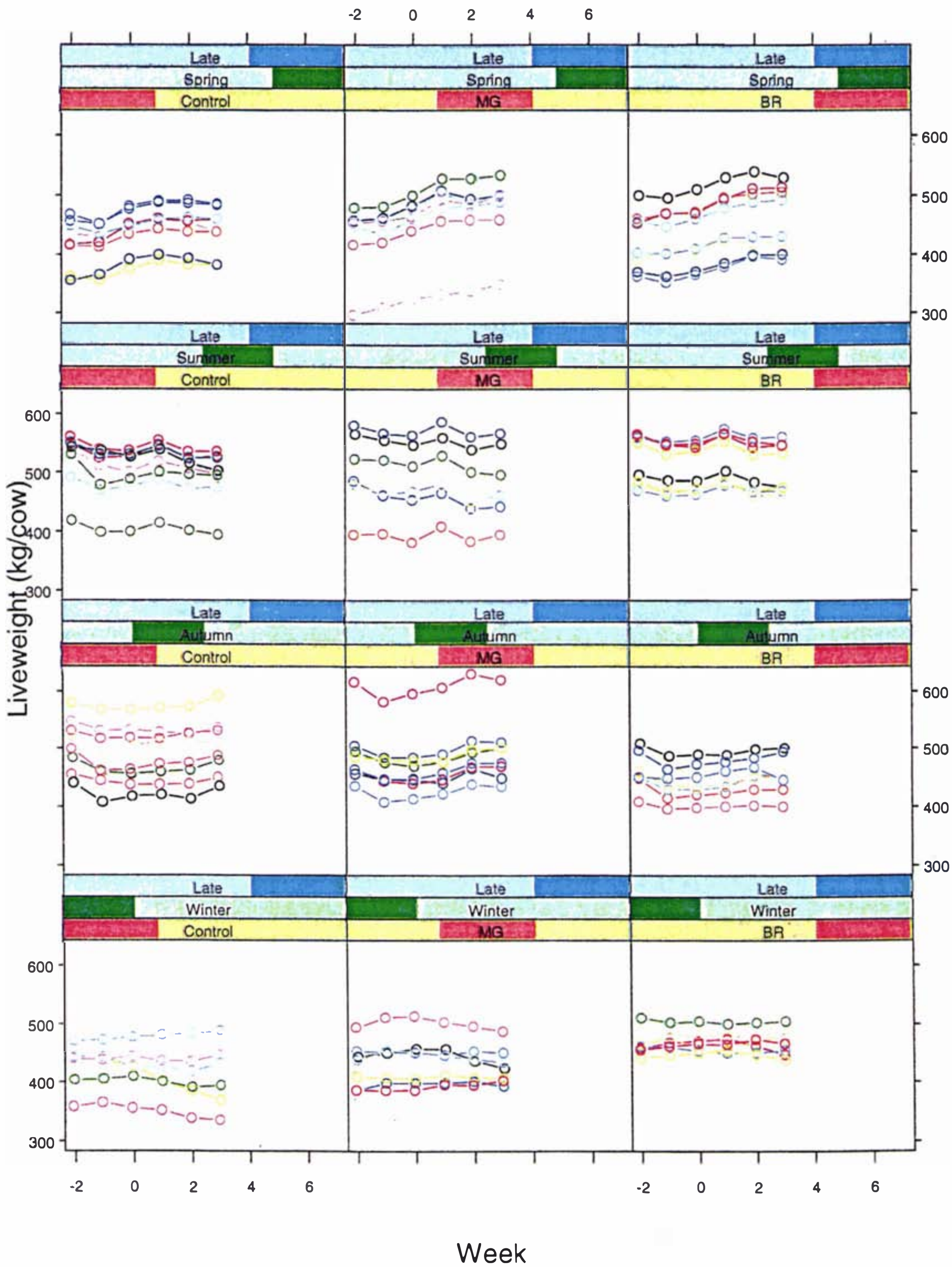
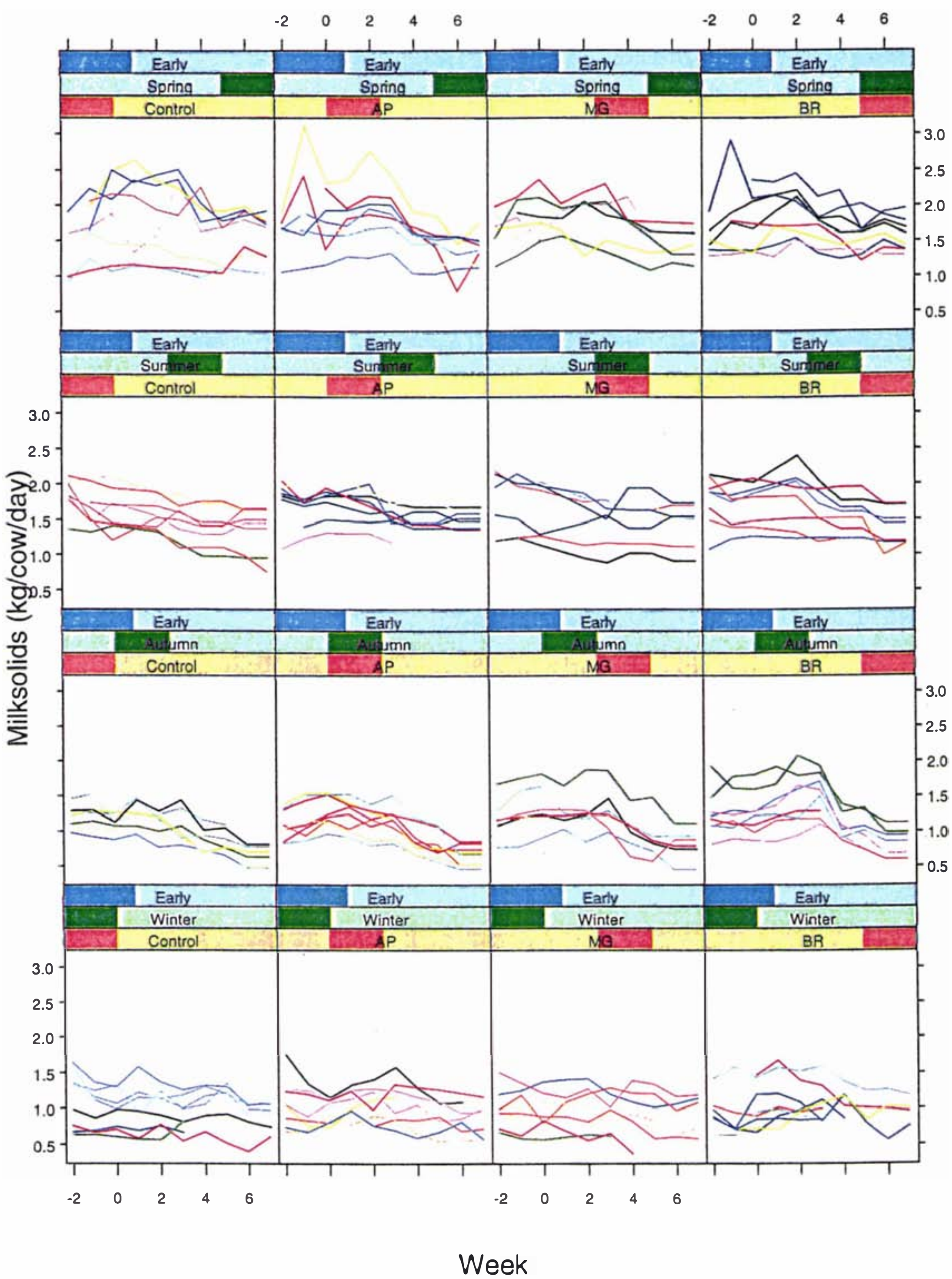
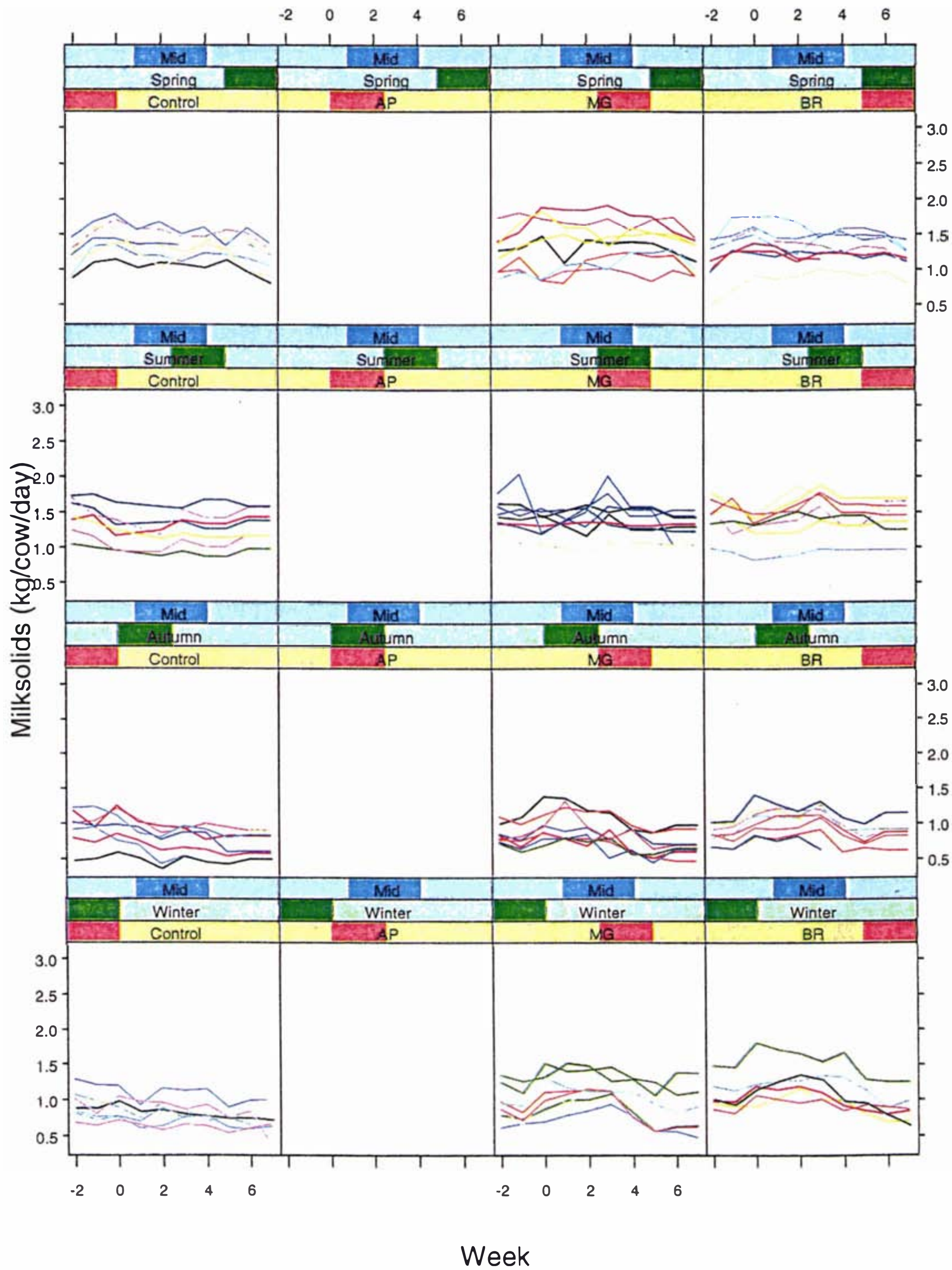

Late
Spring
Control
MG
BR
Summer
Autumn
Winter
Liveweight (kg/cow)
Week
-2
0
2
4
6
300
400
500
600

Figure A1.3: Daily milksolids yield of each cow in the early, mid and late lactation experimental groups offered the control, generous pasture (AP), maize grain (MG) and balancing ration (BR) feeding treatments, measured during the uniformity (weeks –2 to –1), supplementary feeding (weeks 0 to 4), and carryover (weeks 5 to 7) periods of trial 1.


Early
Spring
Control
AP
MG
BR
Summer
Autumn
Winter
Milksolids (kg/cow/day)
Week
-2
0
2
4
6
0.5
1.0
1.5
2.0
2.5
3.0


Mid
Spring
Summer
Autumn
Winter
Control
AP
MG
BR
Milksolids (kg/cow/day)
Week
-2 0 2 4 6
0.5 1.0 1.5 2.0 2.5 3.0

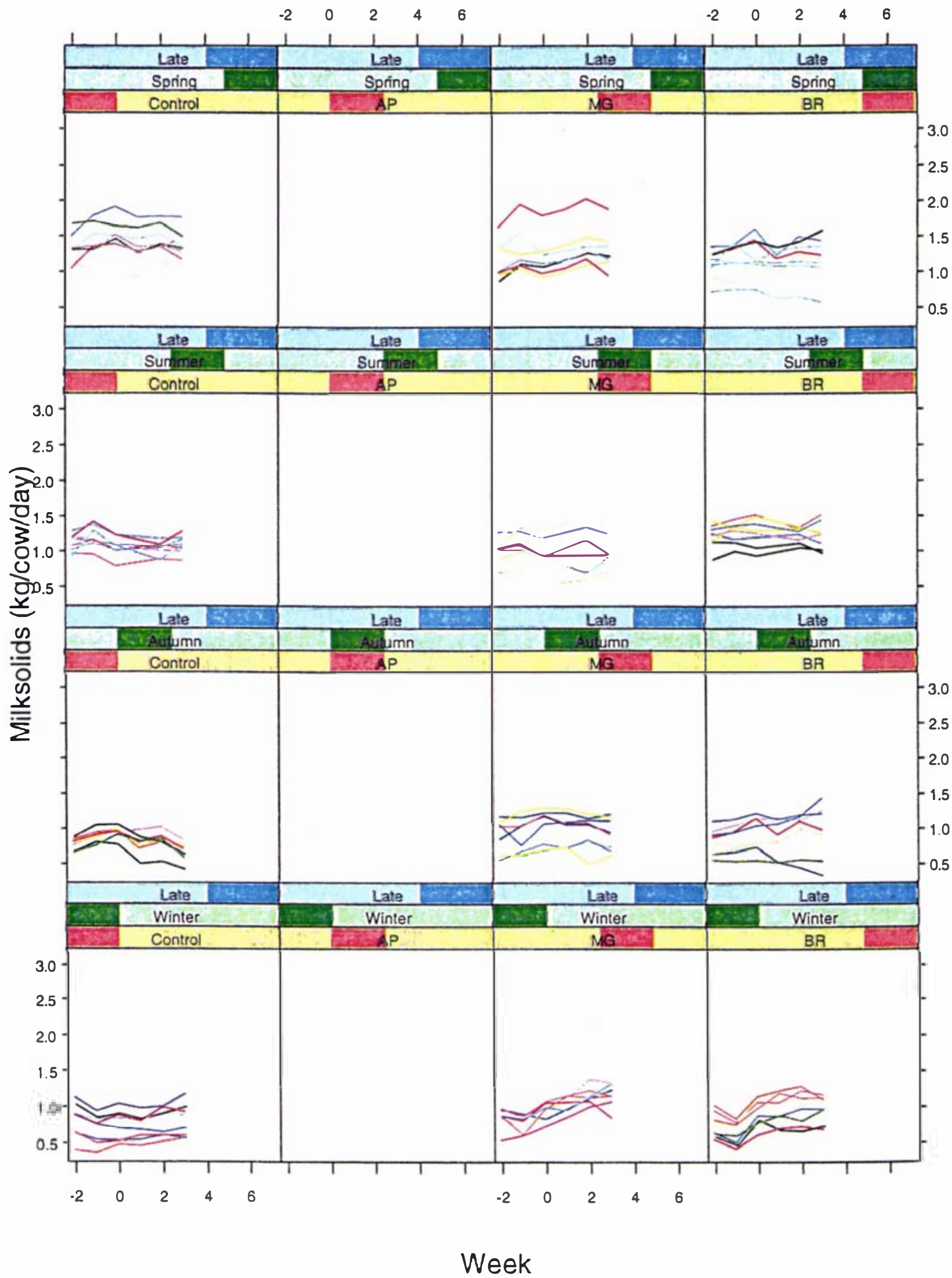
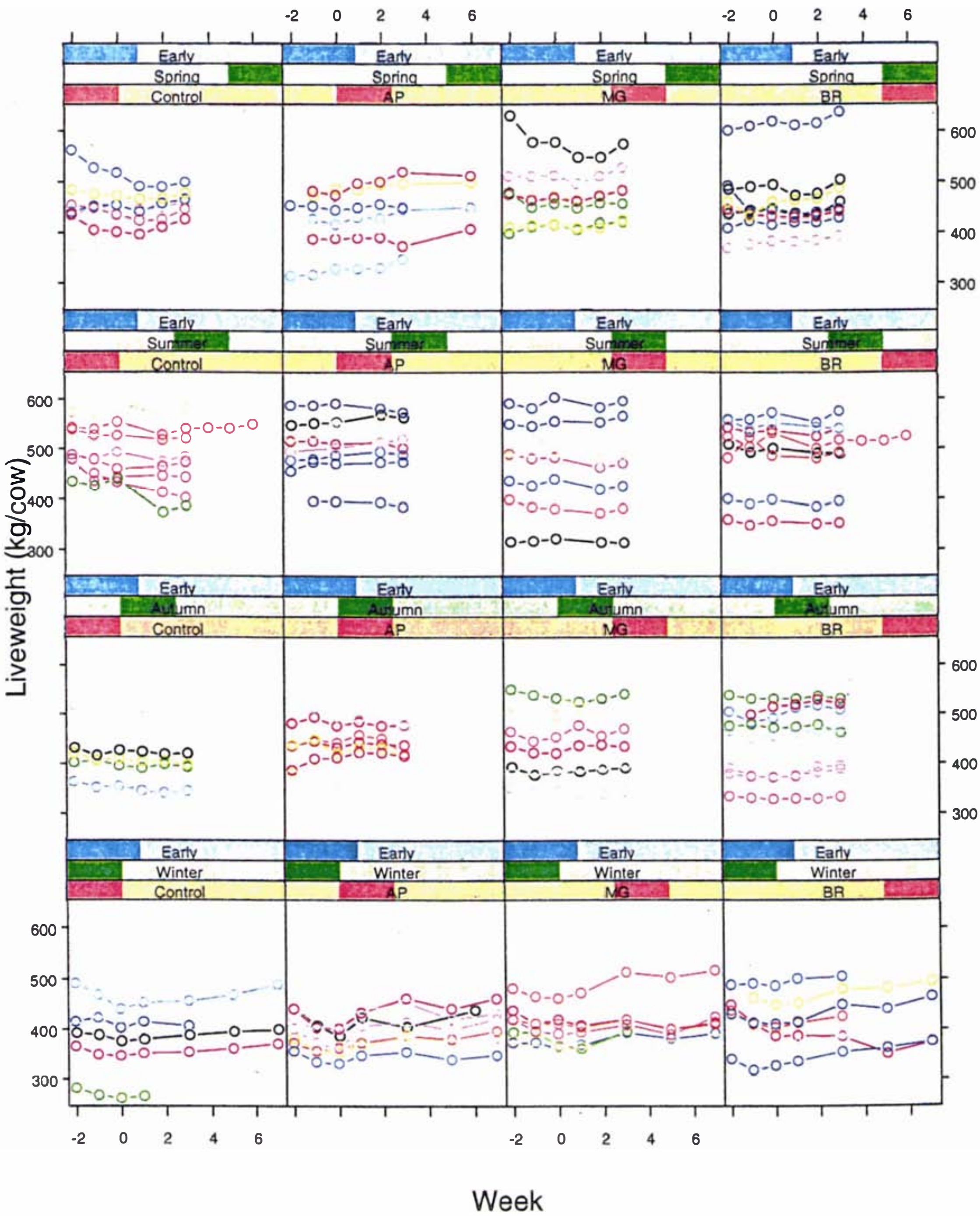
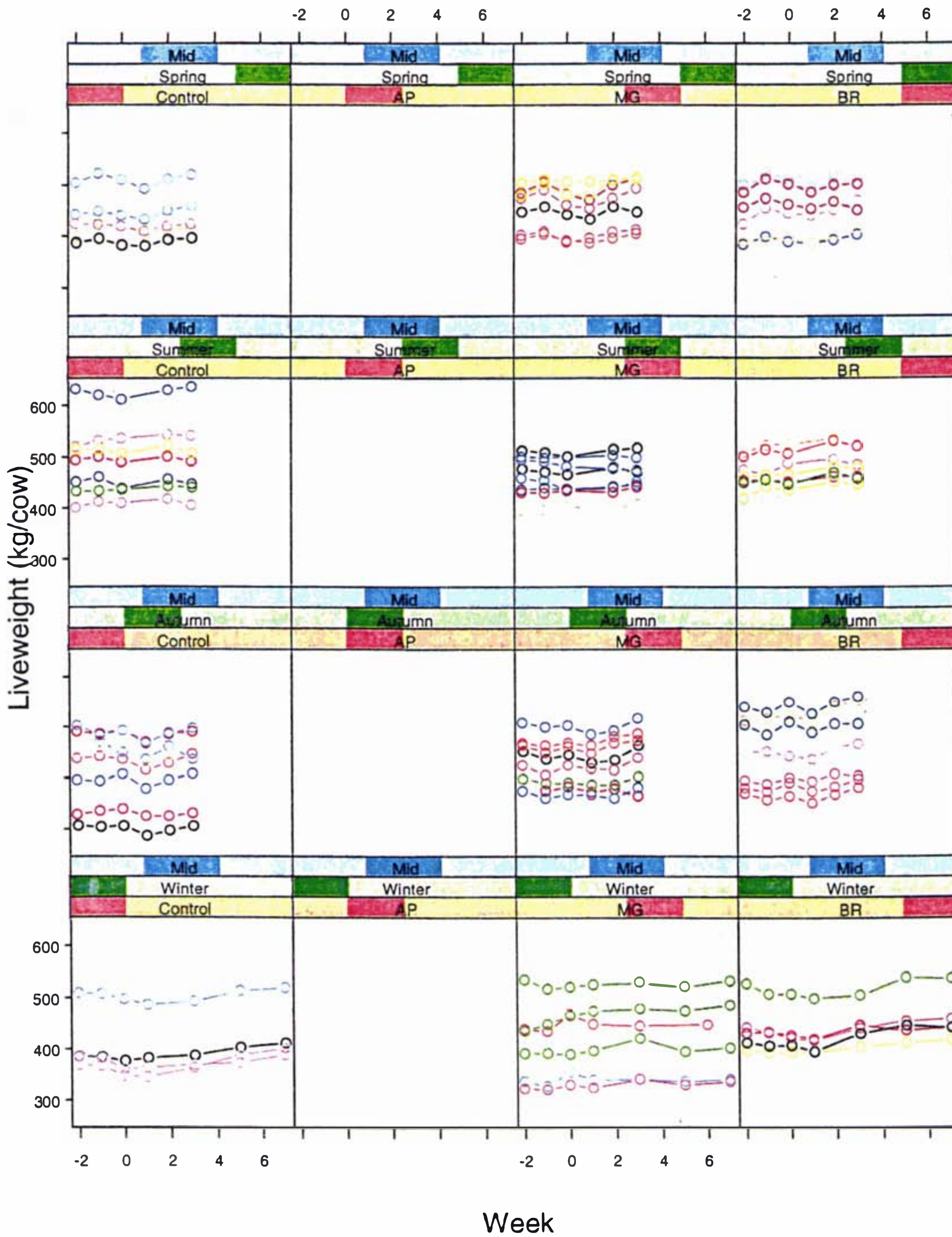
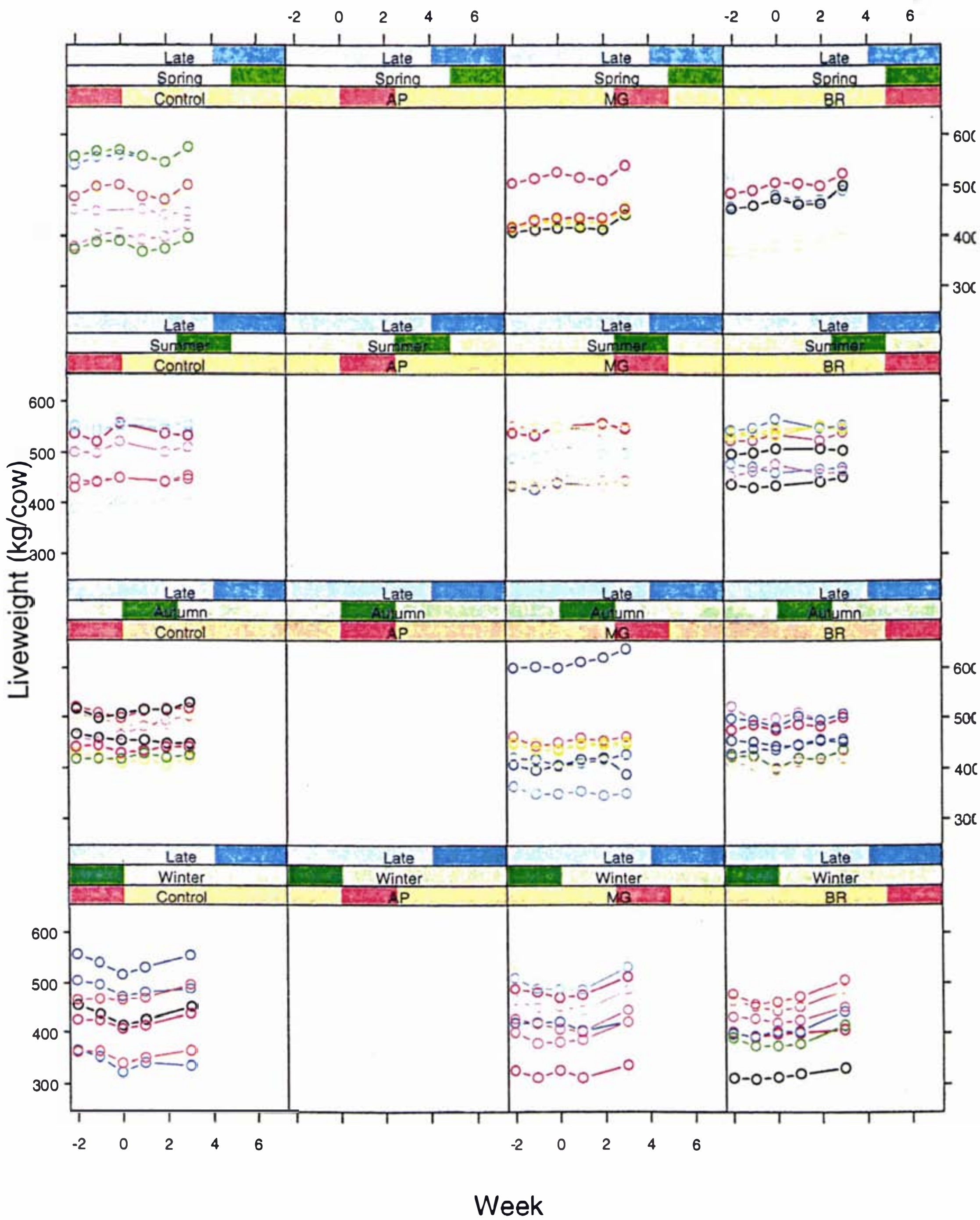

Late
Spring
Summer
Autumn
Winter
Control
AP
MG
BR
Milksolids (kg/cow/day)
Week
-2 0 2 4 6
0.5 1.0 1.5 2.0 2.5 3.0

Figure A1.4: Liveweight of each cow in the early, mid and late lactation experimental groups offered the control, generous pasture allowance (AP), maize grain (MG) and balancing ration (BR) feeding treatments, measured during the uniformity (weeks –2 to –1) and supplementary feeding (weeks 0 to 4) periods of trial 2.


Early
Spring
Control
AP
MG
BR
Summer
Autumn
Winter
Liveweight (kg/cow)
Week


Mid
Spring
Control
AP
MG
BR
Summer
Autumn
Winter
-2
0
2
4
6
300
400
500
600
Liveweight (kg/cow)
Week


Late
Spring
Control
AP
MG
BR
Summer
Autumn
Winter
Liveweight (kg/cow)
Week
-2
0
2
4
6
300
400
500
600

APPENDIX 2: DATA FROM TRIAL 1 PUBLISHED IN THE PROCEEDINGS OF THE NEW ZEALAND SOCIETY OF ANIMAL PRODUCTION