A model to aid decisions regarding feeding of concentrates to dairy cattle

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PREFACE

The impetus for this work came from the dairy farming community of Tasmania. Constant questioning by individuals and argument at discussion groups as to the value of concentrates in a pasture based system, prompted the investigation. Factors affecting responses, especially in the long term are not well recorded. It was therefore considered useful to try and bring as much information together as possible and put it in a format to aid decisions regarding feeding concentrates. The process has been a most rewarding one and I trust readers will find what follows both interesting and valuable.

Peter Neaves

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GLOSSARY OF TERMS

BI	breeeding index, a measure of cow genetic merit used in New Zealand.
CS	Condition Score, a measure of cow fat cover where 2 is very thin and 7 is very fat.
Conc	Concentrate feed.
CP	Crude protein.
dig	Digestibility.
DM	Dry matter.
FCM	Fat corrected milk (4% milk fat).
kg/c/d	Kilograms per cow per day.
l	Litres.
LIC	Livestock Improvement Corporation.
LW	Liveweight.
ME	Metabolisable energy.
MF	Milkfat.
MJ ME	Megajoules.
MS	Milksolids.
NE	Net energy.
NDF	Neutral detergent fibre.
OM	Organic matter.
P	Protein.

TABLE OF CONTENTS

LIST OF TABLES.

LIST OF FIGURES

ABSTRACT

A model to aid decisions regarding the feeding of concentrates to dairy cows was constructed. The literature regarding milk and liveweight responses to concentrates, pasture growth, nutrient effects on reproductive performance and modelling methods, was reviewed to establish important relationships and a process for model development. The milk response to concentrate supplementation is largely influenced by the substitution rate and marginal energy partitioning to milk and liveweight gain. Substitution rate increases with pasture intake, because as cows approach their intake limit there is reduced scope for further increases in intake. At lower pasture digestibilities substitution rate is also lower and when high fibre concentrates are fed there is less substitution because rumen fermentation is not affected to the same extent as when high carbohydrate concentrates are used. Concentrate feeding level *per se*, stage of lactation and season of the year do not appear to affect substitution rate in any consistent way.

Marginal nutrient partitioning describes what happens to the *extra* energy consumed. Total energy intake is negatively related to marginal partitioning to milk. Cows of low condition score partition more energy to liveweight gain than cows of similar genetic merit of higher condition score. High genetic merit cows tend to converge to a lower condition score than cows of low genetic merit, thus genetic merit has an indirect effect on marginal nutrient partitioning. Concentrate intake level was not important until intake levels reached approximately 50% of the diet and/or fibre intake decreased below a critical level. Stage of lactation does not affect marginal nutrient partitioning in any consistent way.

Pasture growth rate was estimated to increases by 2.6 kg DM/ha for each 100 kg DM extra remaining after grazing at least up to a residual pasture mass of 1800 kg DM/ha and possibly beyond this. Therefore, one outcome of substitution is likely to be increased pasture growth. The utilisation of the extra pasture growth and hence its financial value, can be estimated from the feed supply and demand on the farm.

Nutrition in early lactation and specifically energy balance, affects reproductive performance. A complex relationship between cow condition, milk production and intake exists. Cows in low condition score (< 4.3) and losing weight are most likely to benefit from extra feed in the period prior to mating. The benefit may be as high as 12 kg MS/cow through earlier calving in the following lactation if all cows in the herd improve reproductive performance.

A stepwise decision framework was chosen to model the decision problem. A paper model using a set of graphs, tables and calculations to represent the information described above was developed to predict both short-and long-term financial benefit of feeding concentrates to pasture fed dairy cows. Preliminary field testing revealed the model was time consuming and difficult to use for scenario analysis. A spreadsheet version of the model was therefore developed, however it has less value as an educational tool for farmers. It was concluded that it provides a useful framework for analysing decisions regarding concentrate feeding in the field.

CHAPTER ONE

INTRODUCTION

The level of per cow production achieved by dairy cows in New Zealand and Australia is low compared to those achieved in Europe and North America. This is principally because dairy farming in Australia and New Zealand is pasture-based and to acheive high utilisation of pasture, some underfeeding is required (Hodgson 1975). Holmes and Hughes (1993) suggested the major disadvantages of low per cow production are that more cows must be milked to achieve a certain gross income and a larger quantity of feed is eaten per kg of milk produced because more is required for maintenance.

The seasonality of pasture growth is a major constraint to dairy production from grazed pasture and most farmers match feed demand to the supply as much as possible by calving in the spring and drying off in the autumn. The Livestock Improvement Corporation (LIC) dairy statistics (LIC 1994) showed that the mean planned start of calving date was mid-to late July for North Island farmers and early-to mid August for South Island farmers in 1993/94, reflecting regional differences in the pattern of pasture growth. However, reliance on grazed pasture makes farmers vulnerable to the large variations in pasture growth. For example, a dry summer in 1988/89 and cold weather in the spring of 1986/87 severly reduced national milk production (Holmes and Hughes 1993).

During the 1970s and 1980s dairy farmers in New Zealand focused on increasing per hectare production by increasing stocking rate. Herd size increased on average by four cows/year from 1981 to 1993 and stocking rate increased from 2.1 to 2.5 cows/ha (LIC 1994). Over the same period average milk production/cow increased from 144 to 160 kg MF/c (LIC 1994). However, a number of farms in New Zealand have reached the stage where further increases in production of milksolids depend on increasing the amount, and improving the distribution, of feed (Bryant 1994). Thus, some farmers have focused on increasing per cow production by feeding cows better (e.g. Edgecombe and Edgecombe 1994, Garrity 1994). Increasing per cow production has the advantage that milksolids production is increased without putting more pressure on existing resources such as dairy sheds, laneways and labour through higher cow numbers. Feeding a supplement is one way to produce high milk yields per cow through higher average daily production or longer lactations, and at the same time to reduce the risk associated with seasonal pasture production (Holmes and Hughes 1993, Parker and Edwards 1994).

Many types of supplementary feeds are available to dairy farmers including hay, silage, maize silage, apple pomace, fodder crops and concentrates such as cereal grains and pelleted rations. Concentrate feeds are very popular in Australia where they are inexpensive and readily available. A recent survey reported that 77% of dairy farmers in Australia were feeding concentrates to lactating cows. Even in Victoria, where production is predominantly pasture-based and seasonal, the figure was still 69% (Kelloway and Porta 1993). In New Zealand, the proportion of farmers feeding supplements is low and those that do mainly choose to feed maize silage or fodder crops because concentrate feeds are expensive. However, there is evidence to show that concentrate feeding can still be profitable at prices up to $500/ tonne in some circumstances (McCallum *et al.* 1994, Parker and Edwards 1994).

The focus of this analysis is restricted to concentrate feeds for a number of reasons. In Australia, the use of concentrate feeds is increasing, so it is important that information be available about the likely responses. Concentrate feeds are relatively uniform in energy concentration so it is easier to interpret results from experiments with concentrate feeds. There is also a large amount of research pertaining to concentrate feeding of dairy cows on which to draw. Incorporating a broader range of supplements would considerably increase the scope of the study.

It is often unclear if a particular farmer will make money from feeding concentrates and this creates problems in developing recommendations for their use. This is because the response to additional feed inputs can vary greatly under different farming conditions. The aim of this project is to develop a non computerised decision support model to enable consultants and farmers in the field to make a rapid and reasonable prediction of the response to concentrate feeding for a given situation. This framework will allow an assessment of the likely profitability of various levels of concentate input.

1.1. The systems approach

Often, management decisions are made on the basis of assumed outcomes. For example, the response to supplements is often assumed to be 0.5 l/kg concentrate as an immediate response and 0.5 l/kg concentrate as a residual response (e.g. Mackle and Bryant 1994). However, such an assumption takes no account of the amount of pasture available, level of concentrate feeding, cow condition and stage of lactation for example. A systems approach attempts to take all factors into account and would, for example, determine the effect of concentrate feeding on aspects other than just immediate milk production such as reproductive performance, pasture production and hence ultimately farm profitability. The number of factors influencing the dairy cow's response to concentrates indicates that a systems approach is required.

A system is made up of many component parts and importantly, the system is more than the sum of the parts. Spedding (1988) defined a system as, '*a group of interrelated components that interact for a common purpose and react as a whole to internal and external stimuli*'. Dent and Blackie (1979) suggested, '*the complex interrelationships between component parts precludes legitimate study of sectors of the system in isolation.*' This concept of systems thinking is supported by others (e.g. Anderson and White 1991, Squires 1991).

Agricultural systems or systems agriculture is defined as the, '*application of systems approaches to the improvement of problem situations and is concerned with the identification of problem situations by the participants*' (Bawden *et al.* 1990). An important feature about systems is that *the boundary is where the researcher or farmer chooses to draw it.* The existence of the circulatory system in an animal, a grazing system or account recording system for example means that there are systems within systems and so modelling involves intregrating and linking the various sub-systems. The boundary of the system must be clearly defined because it is often impractical to take all factors into account (Squires 1991).

The traditional approach to research has been to break the system down into its component parts (i.e. reductionism) assuming that the system equalled the sum of the parts. Studying the parts provided greater understanding of these components but this often occurred in isolation of the the system. It is not practical to take the farming system into account for all farm research because of cost, labour requirements and physical constraints. Thus, the reductionist approach was a valid one, but a systems approach broadens the analysis in the direction of holism, which is very valuable for management decisions (Squires 1991).

In the past, attempts to model the whole farm were inadequate. The complexity of any particular farming system and a lack of computer power meant that models were too general to be of any use for farm management decision making. In fact, there are an infinite number of possible farming systems if the timing of all inputs is considered. Some authors argue that the complexity of agricultural systems alone provides justification for modelling, believing that the biological system is too variable to produce meaningful results from experiments (Woodward *et al.* 1993).

A model to predict the response to concentrate feeding needs to incorporate as much of the farming system as practical if it is to be useful for farmers and their advisors. However, boundaries must be drawn for simplicity and ease of use. For example, parts of the farming system such as labour use, fertiliser applied and the pasture reseeding program are unlikely to be be necessary to predict the response to concentrate feeding. In effect they would be excluded from the system. The placement of the boundary needs to ensure that a reliable prediction can be made without requiring excessive information. Thus, the model will incoroprate milk and liveweight responses in the short-and long-term, and affects on pasture growth and herd reproductive performance.

1.2. Background information on aspects of feeding concentrates.

1.2.1. Energy requirements of lactating dairy cows.

The energy requirements of dairy cows for lactation and liveweight gain are set out below. Information comes from AFRC (1993).

The system is based on the relationship between metabolisable energy (ME) and Net energy (NE):

$$E = ME \times k$$

where k is the efficiency of utilisation of ME for the relevant metabolic process. The k value is different for different metabolic processes i.e. maintenance, lactation and liveweight gain. It also depends on the ratio of ME to gross energy (GE) in the diet. An average value for k_l (lactation) determined from a large amount of data is 0.63 and an average for k_g (liveweight gain) is 0.95 * k_l or 0.60. The k value shows the proportion of metabolisable energy that is actually used for milk production or liveweight gain. The remainder is lost as heat.

Requirements for milk

The energy value (EV, net energy) of milk can be determined from either of the following equations:

$$EV\ (MJ/kg) = 0.376\ (MF\%) + 0.209\ (P\%) + 0.948$$

$$EV\ (MJ/kg) = 0.406\ (MF\%) + 1.509$$

where MF% and P% are the milkfat and protein concentrations of the milk (g/100g).

For example, the EV of milk with 4.5% milkfat and 3.3% protein is:

$$0.376 \times 4.5 + 0.209 \times 3.3 + 0.948 = 3.33 \text{ MJ}.$$

The equation with both milkfat and protein is considered more accurate than the equation with just milkfat as both constituents are accounted for. (however, the predicted requirement is very similar for these fat and protein concentrations, but will differ for other fat and protein ratios).

If milk contains 4.5% MF and 3.3% P it therefore contains 7.8% milksolids (MS). Thus, 12.8 litres of milk are required to provide one kg of milksolids. From the above equation, the EV is 42.6 MJ (12.8 x 3.33). This is the energy in one kg MS. The k value is used to determine the ME required. In this case, the *ME required to produce one kg MS is 68 MJ (42.6/0.63).*

Requirements for liveweight gain

The recommended energy requirement for liveweight gain and loss by lactating cows has recently been decreased (Alderman and Cotrill 1993). The adopted EV for liveweight change in lactating cows is 19 MJ/kg. Using the k value of 0.60, the *ME required for one kg liveweight (LW) gain is 32 MJ ME (19/0.60).*

The mobilised body reserves can be utilised with an efficiency of 0.84. Therefore, one kg LW loss will supply 16 MJ net energy for milk production or maintenance. If this was used for milk production, enough energy would be supplied for 4.8 l/milk or 0.38 kg MS/kg LW loss (assuming 4.5% MF and 3.3% P).

1.2.2. Theoretical responses to concentrate feeding.

The theoretical milk response to supplements can be determined if the energy concentration of the feedstuff and the energy required for milk synthesis is known. The energy value of some common supplementary feeds for dairy cows is shown below (Table 1.1).

Table 1.1: *Nutritional value of some common supplementary feeds.*

Feed	Energy (MJ ME/ kg DM)	Crude protein (% in DM)	Crude fibre (% in DM)
Wheat	12.6-14.7	11.3-11.6	2.4-2.9
Barley	12.9-14.1	10.8-13.5	5.3-7.1
Maize	13.1-14.5	8-10.0	2.4-2.6
Oats	11.1-13.6	10.9-13.5	12.1-12.3
Triticale	13.8	17.6	4.4
Quality Pasture	10.5-12	24	
Quality silage	10	22	

Sources: Kellaway and Porta (1993), Holmes and Wilson (1987).

The dry matter (DM) content of most cereal grains ranges from 85-90%, and this allows for higher DM intakes than for sole diets of pasture (DM content 10-18%) because they occupy less space in the rumen (Ulyatt and Waghorn 1993).

The theoretical marginal milk response to feeding one kilogram of barley is shown in Table 1.2. It is assumed that maintenance requirements have already been met. Theoretically, the energy in one kilogram of barley is enough to produce 2.2 litres of milk. Similarly, if all the energy in the supplement was used for liveweight (LW) gain, the theoretical response would be 360 g liveweight gain or reduction in LW loss/kg supplement DM (AFRC 1993).

Table 1.2: *Theoretical marginal milk response from feeding one kilogram of barley to lactating dairy cows.*

Energy req'd for one kg MS (MJ ME)	68 MJ ME
Energy in one kg barley @ 85% DM (MJ ME)	13.5 x 0.85= 11.5 MJ ME
Kg MS possible if all of the additional feed is used for milk (MS/kg barley)	0.17 kg MS
Litres milk (@ 4.5% fat and 3.3% protein)	**2.18 litres**

Source: Adapted from AFRC (1993).

Typical responses to feeding concentrates are between 0.5 and 1.5 litres milk/kg (Brookes 1993, Kellaway and Porta 1993). Thus, the theoretical response is seldom achieved. The two main factors affecting the response are nutrient partitioning between liveweight gain and milk production, and the level of substitution of pasture for concentrate (pasture sparing effect). An example best illustrates these points:

Assume a cow is producing 1.75 kg MS/day (1 kg MF) and consuming 17 kg pasture DM/day. It is then offered an extra 2 kg barley DMr. The production response can be calculated as follows:

It is assumed that the barley contains 13.5 MJ ME/kg DM, thus there is an extra 27 MJ ME available. Some *substitution* of pasture is likely to occur; the level will depend on many factors, but say the substitution rate is 0.6. This means that for every kg of concentrate consumed the amount of pasture consumed decreases by 0.6 kg. Thus feeding 2 kg barley DM will reduce pasture intake by 1.2 kg, to 15.8 kg. This is the pasture sparing or substitution effect. If the pasture contains 10.5 MJ ME/kg DM, the energy consumed as pasture will decrease by 12.6 MJ ME but since 27 MJ ME is consumed as barley, the net energy intake is increased by 14.4 MJ. This extra energy is *partitioned* into milk production or liveweight gain. Again, the partitioning ratio depends on several factors but say it is 60:40. This means that 60% or 8.6 MJ is used for milk production and 40% or 5.8 MJ is used for liveweight gain. If 68 MJ ME is required to produce 1 kg milksolids and 32 MJ ME is required for 1 kg liveweight gain, then the response should be 0.13 kg MS and 0.18 kg LW gain/cow/day.

Potentially, the above responses can be determined for all situations, however, the level of substitution and the partitioning ratios are variable and significantly affect the outcome. If these were known with certainty, predicting responses would be more straightforward. However, many factors influence pasture substitution and nutrient partitioning and thus response to concentrate (Figure 1.1).

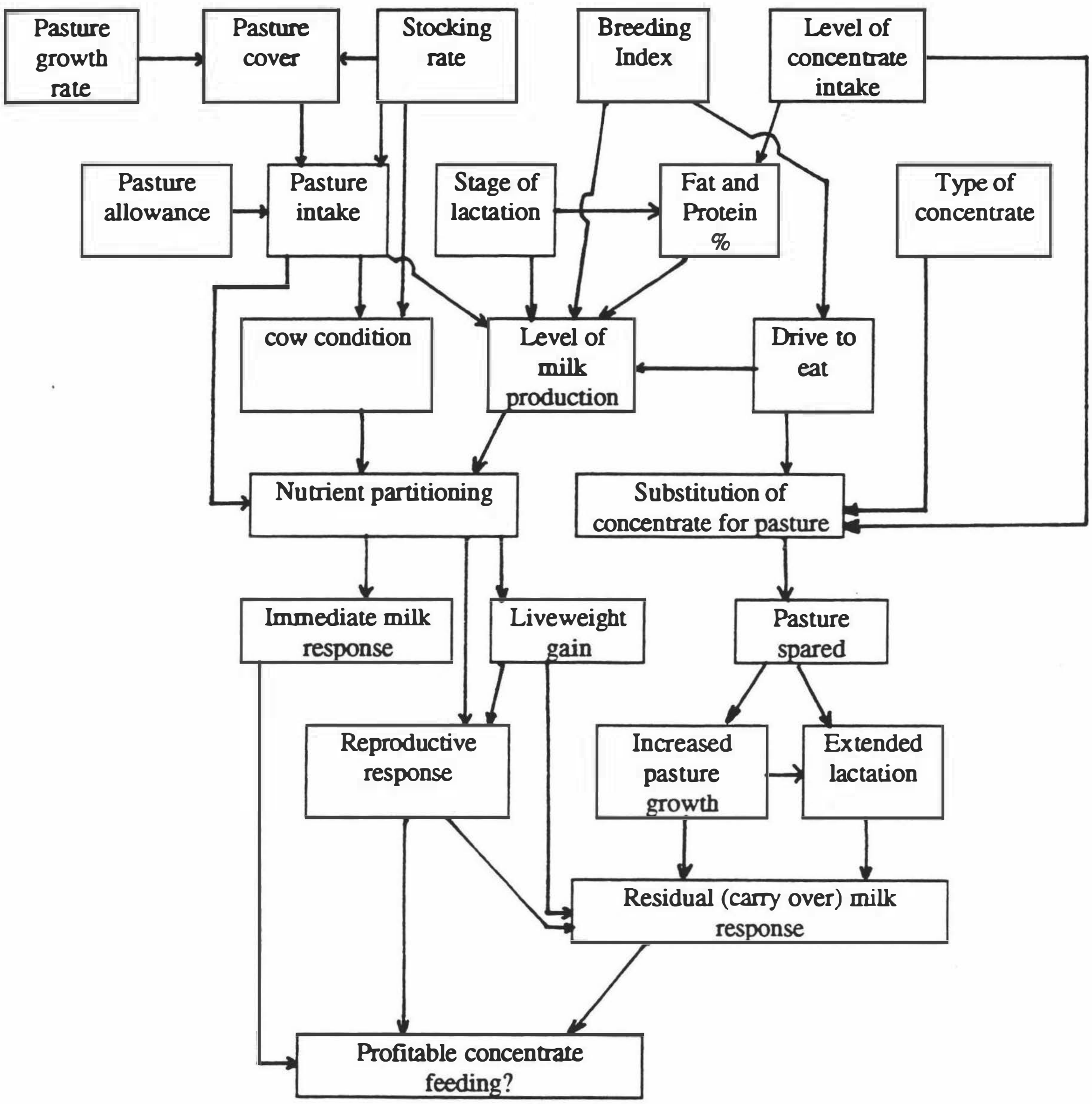


Figure 1.1: *Factors affecting the responses to and profitability of concentrate feeding.*

The proportion of energy used for liveweight gain is influenced by several factors. These include; cow genetic merit (BI), stage of lactation, cow condition and feed quality.The degree of pasture substitution for concentrate is influenced by the level of pasture feeding (pasture allowance), amount of concentrate fed, milk yield, season of the year and pasture quality (either directly or indirectly). Pasture substitution can subsequently give rise to extended lactations or higher production/day because there is more pasture available following the concentrate feeding period (residual/carry over response, Rogers 1985). The liveweight gain may also be used for subsequent production (Steen and Gordon 1980). In addition, feeding concentrates can have an effect on cow reproduction, by increasing energy intake at and before mating (Butler *et al.* 1981, Lean 1992).

In summary, ***assessing the profitability of feeding concentrates requires weighing up all these factors to determine the likely responses, valuing the responses and then comparing them to the cost of providing the extra feed. Thus, it is a complex process.***

1.2.3. Effect of concentrate feeding on milkfat concentration.

The feeding of concentrates can cause a lowering of the milkfat concentration of milk (Rogers and Robinson 1981, Holmes and Wilson 1987, Stockdale *et al.* 1987). This is important in economic terms because the response to concentrates can be overstated if the change in milk yield is quoted without reference to milkfat and protein, since farmers are only paid for milk fat and protein and volume is penalised under the New Zealand milk payment system (Larsen 1991).

One reason milkfat concentration falls when concentrates are fed is because of reduced fibre intake (Stockdale *et al.* 1987, Kelloway and Porta 1993). Varoius estimates suggest that neutral detergent fibre (NDF) intake should be between 280-360 g/kg DM to prevent a reduction in milkfat concentration (Stockdale et al. 1987 after Mertens 1982 and Jorgensen 1984). Low dietary fibre reduces rumenation time and hence the amount of saliva produced. The saliva acts as a rumen buffer, keeping the pH from falling. With less saliva, rumen pH falls and the microbial population of the rumen changes. The result is a change in the products of fermentation and the ratio of propionic acid: acetic acid increases (Meijs 1986). Propionic acid can be used for glucose production but acetic acid cannot be used in this way. Insulin, glucose and acetate levels in the blood rise. Net fat deposition is encouraged (i.e. more energy is partitioned into liveweight gain) because insulin stimulates lipogenisis and decreases lipolysis. This results in decreased amounts of plasma triglycerides being available for fat synthesis by the mammary gland. Greater milk yields are possible because of the increased availability of lactose precursors, thus, the milkfat content of the milk decreases.

In summary, ***milkfat concentration can fall because of lower fibre intakes associated with concentrate feeding. Thus, the effect is related to the amount of concentrate feed and the fibre content of the pasture and concentrate.***

1.2.4. Milk protein percentage.

Milk protein percentage is affected by energy intake. Microbes in the rumen require energy to break down feed proteins into amino acids and ammonia. The microbial protein is used by the cow and excess ammonia is converted into urea and much is excreted in milk and urine (Mackle and Bryant 1994, Figure 1.2). Some protein avoids rumen fermentation. If there is not enough energy in the diet, microbial activity is reduced and the milk protein percentage decreases. However, high energy diets do not lead to an increase in protein percentage, e.g.; when concentrates are fed (Kellaway and Porta 1993, Table 2.3).

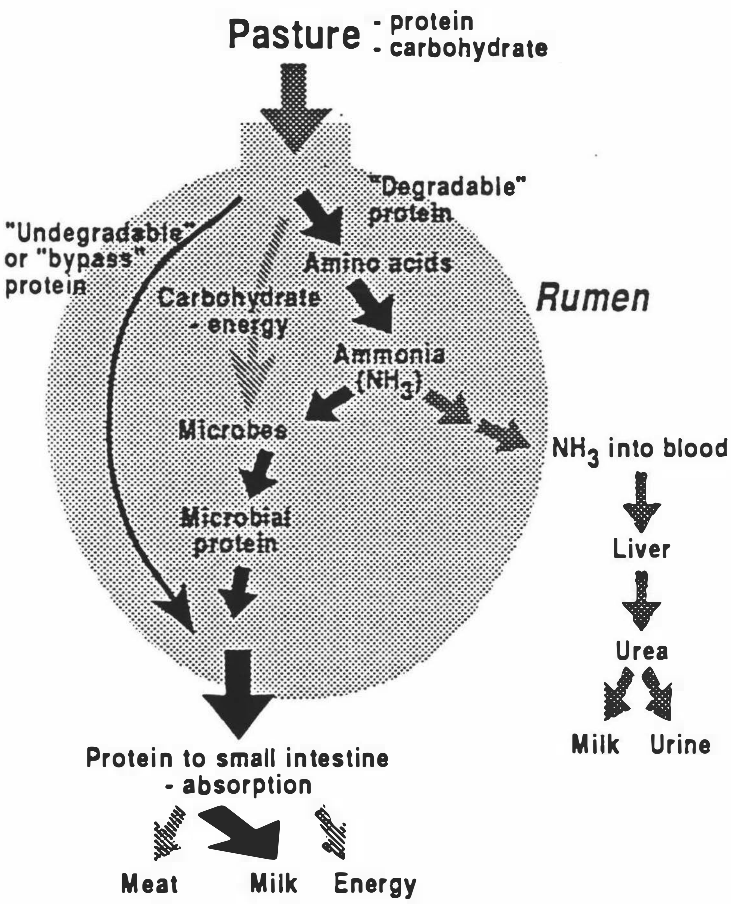


Figure 1.2: *The fate of pasture protein ingested by the cow.*
Source: Mackle and Bryant (1994).

1.3. Objectives and outline of study.

The aims of the study were as follows:

1. To develop a good understanding of the key factors affecting the profitability of concentrate feeding.

2. To review alternative decision support tools in terms of their strengths and weaknesses, and to select an appropriate decision support tool for the concentrate feeding problem.

3. To provide a simple decision support tool to help farmers and their advisors decide if feeding purchased supplements to their lactating dairy cows will be profitable.

4. To establish areas where more research is required to obtain reliable predictions about the likely profitability of feeding concentrates.

In order to determine the profitability of feeding concentrates to pasture-fed dairy cows, the factors that affect the response must be clearly presented and relationships established. The literature is reviewed in Chapter Two and relationships are established in Chapter Three. The principles of decision making and decision support are discussed in Chapter Four and an example decision support model is presented in Chapter Five. The information is presented in a logical and easily interpreted format to support decision making. Chapter Six highlights the main findings, defines areas where further research is required and states what needs to be done to the model in the future before it can be used for decision support.

CHAPTER TWO

RESPONSES TO CONCENTRATES

2.0. Introduction.

Many factors influence the size of the milk response to concentrates. This is one reason why there is a large variation in the response recorded in different experiments. The ability of the cow to increase total intake will depend on how close she is to her maximum intake to begin with. If pasture DM intake is already close to maximum, then extra feed will have little effect on total DM intake. If the cows' udders are close to their maximum output as determined by genetic potential and udder health, they will not produce much more milk in response to extra feed. Similarly, the body condition of the cow affects the way energy is partitioned. If cows are thin the body demands more energy so less can be used for milk production and the response will be lower than if they are fat. In this Chapter, these and other factors are reviewed in relation to many experiments to quantify when and how responses to concentrate feeding are likely to occur.

2.1. Milk responses to concentrates.

Several authors have quantified the milk response to concentrates have been made (Leaver 1968, Cowan and Davidson 1983, Rogers 1985, Kellaway and Porta 1993, Brookes 1993). Reviews on this topic were recently completed by Kellaway and Porta (1993) and Brookes (1993). Brookes (1993) referred to many types of concentrates including silage and hay and relied on information collected from other reviews. Kelloway and Porta (1993) confined their review to concentrate feeding, though feed types ranged from pelletted rations to oats and maize grains. Some of the results used are averages of several experiments. For example, the work quoted by Rogers and Robinson (1981) showed a response of 0.54 litres of milk/ kg concentrate as an immediate response. However, this was an average of seven experiments where the response ranged from 0 to 0.9 litres milk/kg concentrate fed. These data were not presented in the review.

Kellaway and Porta(1993) reported responses to concentrate of *0.5 litres of milk/kg concentrate as an immediate response and an extra 0.5 litres as a residual response.* The mean immediate response to concentrates reported by Brookes (1993) was 0.5 l/kg. No residual response is given. Not surprisingly, these results are similar to those quoted by Phillips (1994), since many of the same experiments were reviewed.

On average, a response of 0.5 l/kg concentrate could be expected as an immediate response. However, responses have varied greatly. Brookes (1993) reported a range of -0.2 l/kg to 1.4 l/kg. Kellaway and Porta (1993) reported a range of -0.2 to 1.0 l/kg as an immediate response and 0 to 2.5 l/kg as a long term response. Other reports have shown even greater responses to concentrates. For example, Wallace (1957) found a long term response of 4.35 l/kg concentrate in an experiment with sets of twins grazed together. One set of twins was fed 2.7 kg concentrate/day for eight weeks. The cows were grazing paddocks out hard for the eight weeks and then given abundant feed. The large response is likely to reflect the effect of liveweight gain during the feeding period. Similarly, Le Du and Newberry (1982) reported a response of 1.9 l/ kg concentrate immediately and 3.5 l/kg concentrate in the long term. Cows were fed 2 kg concentrates/day and restricted pasture (pasture allowance 13.5 kg DM/d) for five weeks (Table 2.1). Part of the high residual response was attributed to poor pasture quality. Many of the reported responses were measured in litres/ kg concentrate (e.g. Kellaway and Porta (1992) main conclusions and Brookes 1993). This may overstate the response (Stockdale *et al.* 1987). Feeding concentrates can lower milk fat percentage as mentioned in section 1.2. Thus, stating the response in litres/kg concentrate may be overstating the value of the response if milkfat has fallen (Figure 2.2). By contrast, protein percentage is not greatly affected by concentrate feeding and may actually increase (Stockdale *et al.* 1987, Table 2.1).

Table 2.1: *The effect of concentrate feeding on milk, milkfat and protein yields.*

Pasture intake (kg DM/cow)	Pellet intake (kg DM/cow)	Milk yield (l/cow)	Milk fat (%)	Protein (%)	Milkfat (kg/cow)	Protein (kg/cow)
6.6	0	13.4	4.49	2.57	0.60	0.34
6.3	1.8	15.1	4.34	2.95	0.68	0.46
6.6	2.7	18.2	4.04	2.80	0.75	0.50
6.5	5.4	20.6	3.76	2.93	0.76	0.58
6.6	9.6	25.0	2.51	3.23	0.64	0.81

Source: Stockdale *et al.* (1987).

Variation in the response to concentrates can be attributed to factors such as the level of feeding of pasture and concentrate, quality of pasture and concentrate, stage of lactation and degree of substitution of pasture for concentrate (Stockdale *et al.* 1987, Rogers 1985). If differences in response can be explained, it should be possible to predict the likely response to concentrate feeding for any given farm situation, and hence estimate whether using additional feed would be profitable. A summary of experiments reporting milk responses to concentrates is shown below (Table 2.2).

Table 2.2: *Summary of experiments which measured milk responses to concentrates.*

Reference	Stocking rate (cows/ha)	Concentrate type	Amount concentrate fed (kg/c/d)	Lactation stage	Pasture feeding level	Length of experiment	Effect on pasture	Condition score or Liveweight change	Milk response (l/kg conc)
Thomas *et al* (1980)	3.5	whole oats	4.2	Early	restricted	20 wks fed for 5 wks	APC increase early	increase 0.2 CS	0.69-2.5
Rogers *et al.* (1983)		crushed oats	3.5	Early	restricted	lactation fed 5-10 wks	N/A	N/A	1.1
Stockdale & Trigg (1989)	stalls	pellets	2.2 4.5	Early	6.8 kgDM	5 weeks	N/A	0.2 0.5	1.18 1.87
					11.7 kg DM			0.5 0	1.5 0.58
Stockdale and Trigg (1985)	N/A	pellets	1.8-6.3	Late	15 kg DM 26 kg DM low quality	8 wks	Low subs Higher subs	↑ 1.1 kg/d ↑0.11 kg/d ave.	0.78 0.81 ave.
McCallum *et al.* (1994)	4.3	pellets	0.5-3.5	whole lactation	high intakes	lactation	higher APC spring	no change	1.5
Dobos *et al.* (1987)	1.65	Wheat milled	3 kg	Early	12 kg DM/c/d	13 weeks	none shown	-0.2 kg/d	0.1
Rogers and Robinson (1983)		pellets	3.5 kg	Early	42 allow RG-WC	5 weeks	+ 150 kg DM residual	+0.1 kg/d	0.0
Robinson and Rogers (1983)	N/A	grain	3.5	Early	14 allow		0	+0.18 kg/d	0.5 l/kg
Taparia and Davey (1970)	N/A	grain mix	2.7 kg 4.0 kg	Early	Ad-lib	12 weeks	N/A	0 0	0.2 0.0
Stakelum (1986b)	N/A	barley molasses	3.8	Early	16 24	16 days	N/A	N/A	0.5 FCM 0.5 FCM
Wallace (1957)	1.hard grazed 2.lax grazed	mixed oats, barley crushed	2.7	Early	high quality	Fed 8 weeks whole lactation	n/a	n/a	1.24-4.35 0.44-1.24
Le Du and Newberry (1982)	N/A	?	3 2	Early	allowance of 13.5 kg DM	Fed 2 wks Fed 5 wks	N/A	↑ 11 kg ↓ 16 kg (7 wks)	1.0-2.9 1.9-3.5

2.1.1. Possible reasons for high and low responses to concentrates.

Thomas *et al.* (1980), reported an initial response of 0.69 l/kg grain in the first 5 weeks of lactation (Table 2.2). The increase to 2.5 l/kg over the next 10 weeks was partly explained by the higher condition score of grain fed cows at week five (4.5 vs 4.2) and the higher pasture cover at the end of week 5 (1258 vs 1090 kg DM/ha).

Many experiments indicated that the *level of pasture feeding* has a large effect on the response to concentrates (e.g. Cowan *et al.* 1975, Davison *et al.* 1982, Robinson and Rogers 1983, Onley and Albertson 1984, Stakelum 1986, Grainger and Matthews 1989, Stockdale and Trigg 1989). The effect of level of pasture feeding was highlighted by Stockdale and Trigg (1989) (Table 2.2). Where the level of pasture feeding was high the milk response to concentrates was much lower (1.87 vs 0.58 l/kg). The cows on the low level of pasture feeding (6.8 kg DM+4.5 kg conc/d) were producing a similar amount of milk to those on a high level of pasture feeding (11.5 kg DM+4.5 kg conc/d). Milk production was similar, 19.2 and 19.3 litres/d of fat corrected milk, despite a large difference in intake (5 kg DM). This result does not demonstrate a substitution effect because the pasture intake level was controlled. Rather, the extra energy was increasingly partitioned into body fat at the high level of intake (0.86 vs 0.57 kg LW gain/c/d). Similarly, Grainger and Matthews (1989) reported that as pasture allowance increased from 7.6 to 33.2 kg DM/cow/day, the milk response decreased from 0.97 to 0.28 litres milk/kg concentrate fed (Milksolids response reduced from 33 to 12 g/kg concentrate but this result was not significant).

Onley and Albertson (1984) reported that cows grazing tropical pastures and stocked at 7/ha produced 1.1 litres solids corrected milk/kg concentrate while those stocked at 5/ha produced 0.6 l SCM/kg concentrate fed (total production was 6 and 9 l/c/d respectively for the unsupplemented cows. All cows were grazing irrigated kikuyu-based pastures and supplemented cows were fed 4 kg barley/day). Pasture on offer on the high stocked farmlets (set stocked) fell by over 1500 kg DM/ha over seven months while on the lower stocked farmlets the amount of pasture increased by 2700 kg DM/ha where concentrates were fed but by 940 kg DM/ha where concentrates were not fed. This indicates that there was more than adequate pasture on the lower stocked farms, and some substitution occurred. The substitution rate was calculated as 0.23 kg pasture DM/kg concentrate fed and was actually slightly negative on the higher stocked farmlets (i.e. the supplemented cows ate more pasture than the unsupplemented cows).

Rogers and Robinson (1983) reported a milk response of 0.5 vs 0.1/kg concentrate for cows allocated 15 kg pasture DM/c/d or fed *ad-libitum* respectively. Milksolids response reduced from 29 to-20.6 g/kg concentrate because of a decline in milkfat percentage at the higher allowance. But the differences in milksolids were not significant. Similarly, Davison *et al.* (1982) reported, for cows grazing tropical pastures and fed 3 kg maize/day, a response of 1.0 l/kg concentrate fed at low pasture availability and a response of 0.3 l/kg concentrate for cows grazing abundant pasture.

There are exceptions to the rule of higher responses to supplements with lower pasture feeding level. Cowan *et al.* (1975) reported that milk and milkfat yields were almost identical (117 vs 119 kg MF/c/yr) for cows stocked at 2.5/ha and fed no supplements or fed 3.6 kg maize/day for the entire lactation, respectively. At lower stocking rates (1.3, 1.6 and 1.9 cows/ha), the response to supplements was apparently much greater, *indicating a higher response with higher pasture allowance.* However, much of this response could be attributed to the extra days in milk for the cows fed supplements which was about 30 days more for all three stocking rates. In contrast there was only five days difference in lactation length at the higher stocking rate. Stakelum (1986b) reported similar intakes and milk production for cows allocated 16 or 24 kg pasture DM. Although feeding 3.8 kg concentrate/day reduced pasture intake (13.8 to 12.4 kg OM/cow, substitution rate of 0.37 kg pasture OM/kg concentrate OM), the reduction was the same for both allowances. This was explained by the presence of low yielding cows (18 l/day) which would substitute more pasture for concentrate.

Low milk responses to concentrates have been reported in a number of experiments (Table 2.2). It is expected that where there was a low milk response to concentrates there would be a high liveweight gain, or pasture sparing response. This in turn should give rise to residual responses (Kellaway and Porta 1993). Other possible reasons for measured low responses are the short term nature of some trials (Figure 2.1) and inaccurate measurements in others. For example, Dobos *et al.* (1987) reported no significant differences at all between cows fed wheat in early lactation at 3 kg/c/d and those fed pasture alone. Milk production, pasture consumption and liveweights were apparently the same for both treatments. However, the cows fed wheat did eat it, but the effect of extra energy intake was not manifested in either milk production or a change in body condition. Pasture intake was estimated at 12 kg DM/c/d for both treatments, by the difference technique using the Ellinbank rising plate meter. Average pasture cover at the beginning of the experiment was 2300 kg DM/ha and increased to 2900 kg DM after 6 weeks. It would be difficult to obtain an accurate measure of intake at these levels of pasture mass using the plate meter. Milk fat yield/cow was 1.1 kg/day. The theoretical intake required to achieve this production is 17 kg DM if the feed consumed has an energy density of 11 MJ ME/kg DM (Brookes 1993). It is therefore probable that the measurements of pasture intake were inaccurate. It is likely that some pasture was substituted for wheat and pasture intake for the unsupplemented group, was much higher than that estimated. Other studies have found complete substitution at high levels of pasture feeding (Taparia and Davey 1970, Grainger and Mathews 1989).

Overall, ***many authors reported higher responses to concentrates at lower pasture allowances/intakes. It seems that the effect is due to a combination of pasture substitution and differences in nutrient partitioning which are affected in turn by many other factors (Figure 1.1).*** These topics are discussed in detail in Chapter three.

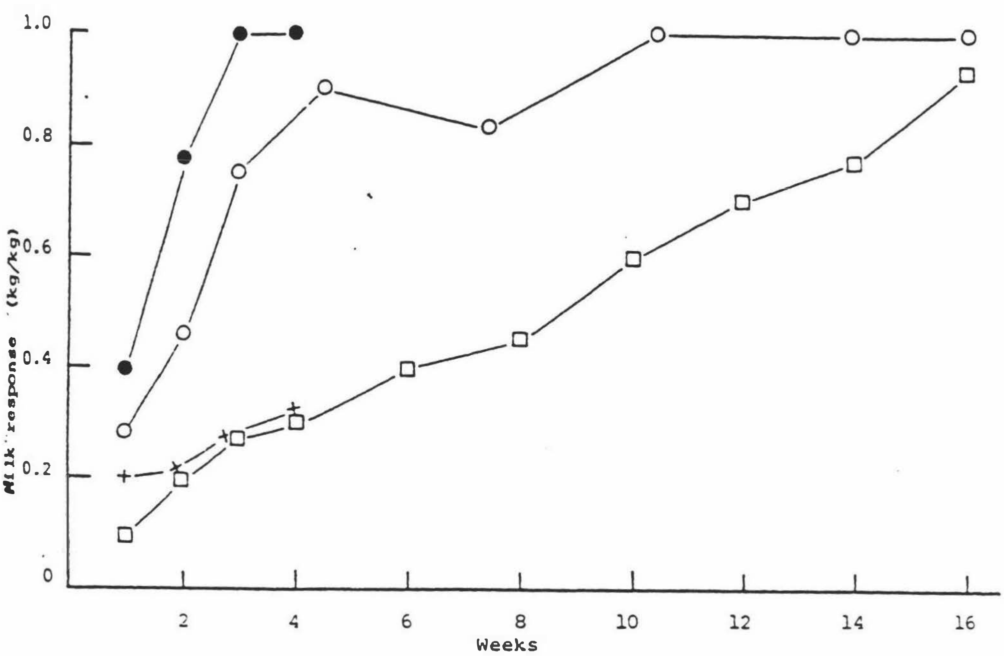


Figure 2.1: *The effect of time on the measured response to concentrates at different levels of pasture feeding (● grain, low pasture allowance;* o *molasses moderate pasture allowance;* □ *grain, moderate pasture yield;* x *grain, high pasture allowance).*
Source: Davidson (1982).

2.1.2. Early versus late lactation responses.

The theoretical response to concentrates expected in late lactation is lower than in early lactation because a larger proportion of the feed consumed is partitioned into liveweight gain (Moe *et al.* 1970, Stockdale and Trigg 1985, Stockdale and Trigg 1989, Figure 2.1). Interpreting results from late lactation experiments is often complicated by seasonal conditions as late lactation coincides with late summer/autumn on seasonal supply dairy farms, when both pasture quantity and quality can be low. Carry-over effects from feeding concentrates in late lactation may not be evident until the following season, by which time many experiments have finished. For example, none of the five late lactation experiments reviewed by Kellaway and Porta (1993) reported residual responses.

Experiments carried out by Stockdale *et al.* (1987, 1989) largely eliminated the seasonal effects by using cows that were in early and late lactation at the same time of the year (spring). The pasture fed to the early lactation cows was of similar quality to that fed to the late lactation cows, eliminating the effect of lower pasture digestibility normally associated with late lactation. The experiments clearly showed the difference between late and early lactation responses (Table 2.3).

Table 2.3: *Effect of stage of lactation on response to concentrates.*

pasture intake (kg DM/cow/day)	pellet intake (kg/cow/day)	milk yield (FCM/cow/d)	LW change (kg/cow/14d)
Early lactation			
6.8	0	12	-5
6.8	2.2	13.6	6
6.6	4.5	19.2	8
Late Lactation			
6.7	0	8.7	15
6.7	2.2	9.9	28
6.7	4.4	12.1	28

Source: Stockdale and Trigg (1989).

In a review of five mid-late lactation experiments, Kellaway and Porta (1993) reported that the immediate milk response ranged from 0.28 to 0.80 l/kg concentrate (average 0.5 l/kg). This is the same average response as the early season experiments examined but with less variation, indicating that there may not be a large difference between marginal partitioning in early and late lactation. Stockdale and Trigg (1989) reported that in early lactation, the marginal response to an extra kg of concentrate was 1.6 l FCM at a pasture intake of 6.8 kg DM/c/d but only 0.64 l/kg at an intake of 11.7 kg pasture DM/c/d. In late lactation the values were 0.77 l/kg and 0.50 l/kg for the low and high pasture allowances respectively. Thus, there is not as much variation in milk response to concentrate in late lactation (Figure 2.2).

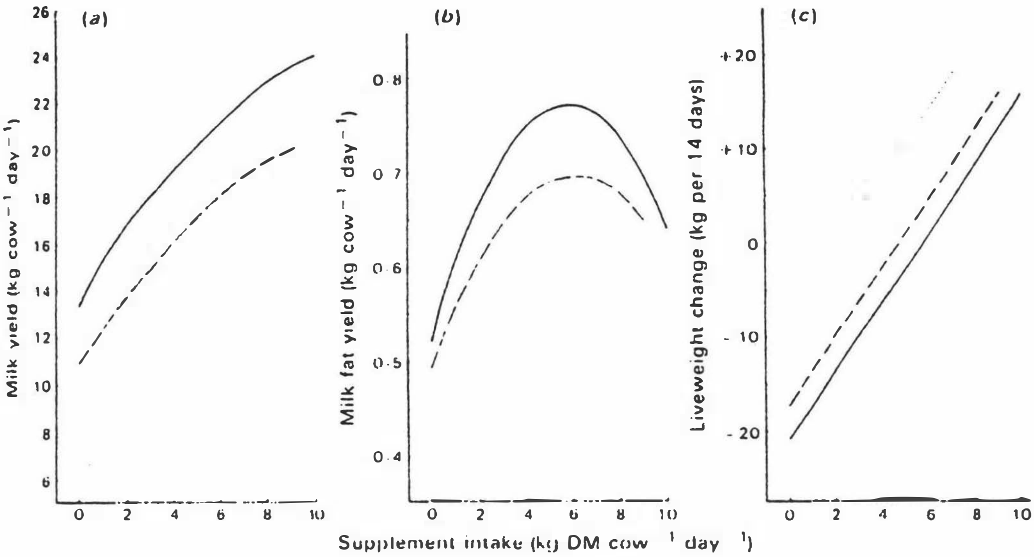


Figure 2.2: *Effect of concentrate intake and stage of lactation on response to concentrates by lactating dairy cows (______50 days into lactation, ------- 100 days into lactation .... 250 days into lactation).*
Source: Stockdale *et al.* (1987).

An important aspect of late lactation feeding is the ability to increase lactation length. If concentrate feeding in late lactation can delay drying off until after autumn rains arrive, the response to concentrates may be very high compared to the case where the herd must be dried off early. This effect has been a major factor in some feeeding trials. For example, McCallum *et al.* (1994) reported an increase of 40 days (240 to 280) in milk for cows fed concentrates because there was more feed available for them (Figure 2.3). The Grassmere demonstration farm at Warnambool, Victoria was able to extend lactation by between 30-60 days as a result of feeding concentrate to fill the late summer feed gap (Rogers 1985). In an experiment with cows grazing ample ryegrass/white clover pasture Laird and Walker-Love (1962), found that those fed additional concentrates did not have longer lactations than those fed pasture alone. This was not surprising because all cows were grazed as one mob.

It is possible that responses obtained through extra days in milk could have been gained by feeding a cheaper form of supplement such as silage. Holmes *et al.* (1994) extended lactation by 35 days by feeding an apple pomace/silage mix. This resulted in an extra 40 kg MS/cow but lower pasture cover (1620 vs 1790) and body condition (4.4 vs 5.2) than the control. Extending lactation in this way was profitable in the short term but the difference in pasture cover and condition score would impact on the next season's production (Grainger *et al.* 1982) (see Chapter 3).

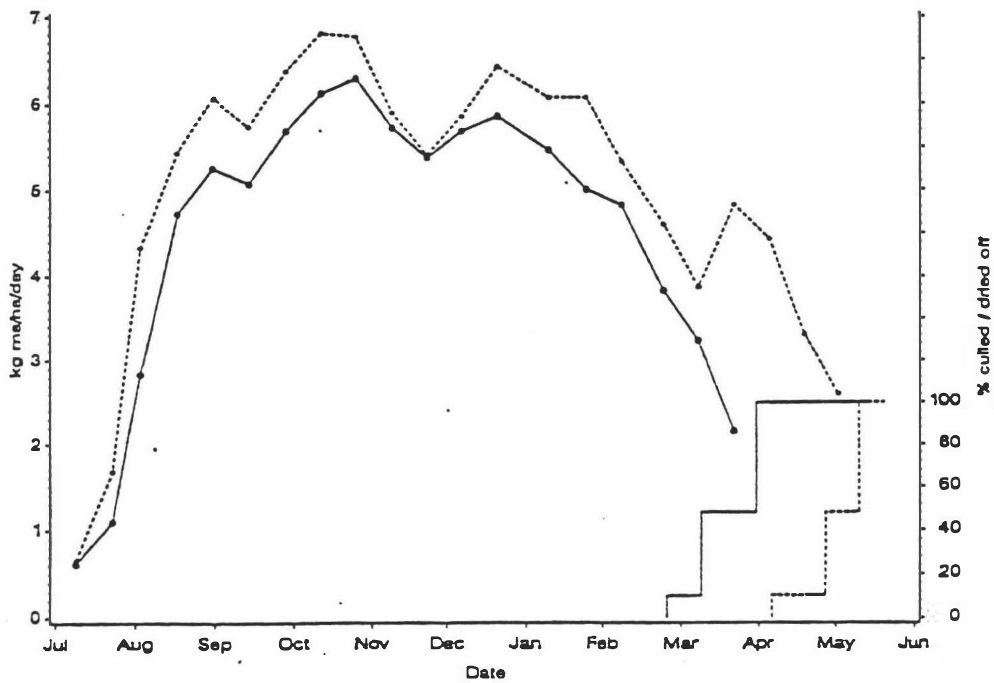


Figure 2.3: *The effect of feeding concentrates throughout lactation on days in milk of two herds stocked at 4.3 cows/ha (........ concentrate fed, ______ no concentrate.* Source: McCallum *et al.* (1994).

2.1.3. The effect of level of concentrate feeding.

Davison *et al.* (1982) reported that cows fed a high level of concentrate (6.7 kg/cow/day) or a lower level of concentrate (3.3 kg/cow/day) for the first 90 days of lactation responded with 0.4 l/kg and 1.3 l/kg concentrate respectively. Apparently, the cows fed the high level of concentrate were not able to consume sufficient protein from the tropical pasture to fully utilise the energy supplement. A less dramatic effect was reported by Steen and Gordon (1980) where cows were fed either 3.8, 5.4 or 7.2 kg concentrates. Milk production was 16.9, 20.4 and 22.8 l/cow/day respectively. The response was therefore 2.2 and 1.7 l/kg concentrate for the 5.4 and 7.2 kg groups, showing a slight reduction in milk response at the higher rate. The weight gain of the 7.2 kg feeding group was greater than the other groups. The cows weighed 29 kg more than the 5.4 group and 41 kg more than the 3.8 group after 72 days. This indicates greater partitioning to liveweight gain at high levels of feeding, supporting the work of Stockdale and Trigg (1989) and Stockdale *et al.* (1987) (Table 2.7). However, although there appears to be a definite effect of high levels of concentrate *per se* on the amount of energy partitioned into milk production. The isssue is confounded by the increase in total energy intake as concentrate intake increases. Total energy intake has a large effect on nutrient partitioning (Chapter 3), so in some cases the effect of concentrate feeding level is probably overstated.

In an experiment with cows grazing tropical pasture, Jeffery *et al.* (1976), found that the level of concentrate fed did not affect milk, milkfat or protein production greatly, even when the level of feeding varied between 3 and 8.3 kg concentrate/cow/day. The low yields of the cows (9.5-11.4 l FCM/day) and the shortness of the treatment period (14 days) probably influenced the results. All cows were grazing as one mob so no pasture substitution effects could be measured and no liveweight responses were measured. It is likely that the low response to concentrates was seen because most of the cow requirements could be met from the grass/clover pasture (because production was so low).

2.1.4. Immediate vs carry over responses.

The immediate response to concentrates is normally measured during the period the concentrates are being fed. Carry-over milk responses due to either increased pasture growth, liveweight gain or improved fertility occur after the concentrate has been fed and may take the entire lactation or longer to be fully revealed. The carry over response is important when calculating the profitability of feeding concentrates. If, for example, it leads to a doubling of the response, as some experiments showed (Kellaway and Porta 1993), the price that can be paid for concentrates is significantly increased. Differences between immediate and carry over responses vary greatly (Table 2.4).

Table 2.4: *Summary of experiments showing immediate vs carry over milk responses to concentrates.*

Reference	Immediate response (l/kg concentrate)	Whole lactation response (l/kg concentrate)
Wallace (1957)	1.20	4.35
	0.44	1.24
Thomas (1980)	0.69	2.50
Rogers and Robinson (1981)	0.54	1.10
Blair *et al.* (1982)	0.77	1.5
Robinson and Rogers (1983)	0.5	0.5 (i.e. no residual response)
Le Du and Newberry (1982)	1.0	2.9
	1.9	3.5

Carry-over responses can be related to pasture growth. For example, following a period of concentrate feeding to dairy cows and subsequent greater weight gain in the concentrate fed group, Rogers (1985) reported that liveweight difference between high and low producers was unaltered for the entire lactation. However, milk production remained higher in the group that was supplemented (Figure 2.4). This implies that *a pasture effect enabled cows to be fed better*. However, Steen and Gordon (1980) reported significantly higher weight gains in dairy cows fed 7.2 kg concentrates/day compared to those fed 3.8 kg/day. (533 vs 492 kg LW by the end of a 72 d feeding period). This extra liveweight was later used for milk production. The response was 300 l milk for 35 kg difference in liveweight gain. Thus, the response was 8.6 l/kg LW gain. The theoretical response calculated in Chapter one was similar at 5.6 l/kg for milk containing 4.5% milkfat and 3.3% protein. This suggests that the residual response to concentrate was due to the *extra liveweight gain* of the cows fed more concentrate during the feeding period. These cows subsequently did not partition as much energy into liveweight gain.

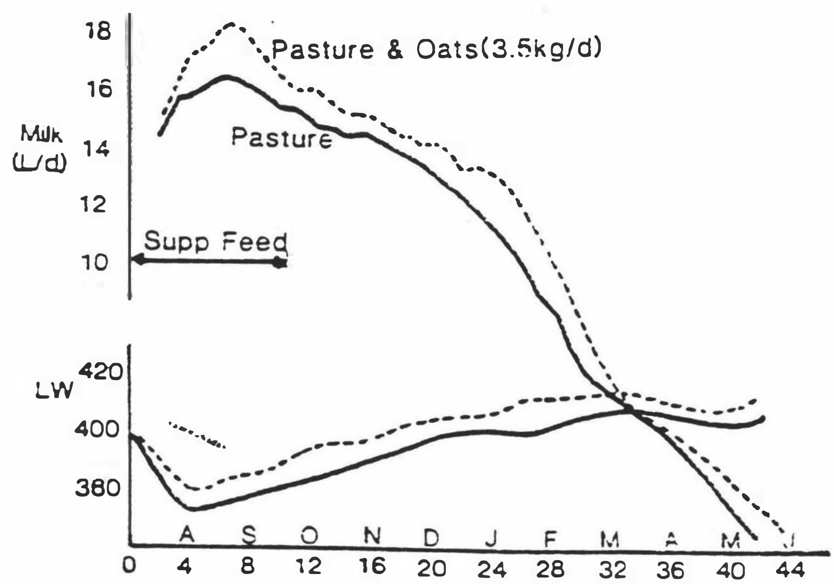


Figure 2.4: *Effect of concentrate supplementation in early lactation on subsequent milk production and liveweight (LW) change (------- fed concentrate, _____ no concentrate fed).*
Source: Rogers(1985).

In an experiment in which no carry over response to concentrate feeding was reported (Rogers and Robinson 1983), all cows were fed *ad-libitum* on pasture after the feeding period. This suggests that the residual response is at least partly *pasture related*. Not surprisingly, Laird and Walker-Love (1962) found there was no residual response when cows fed concentrates had not shown a liveweight response and were grazed with cows not fed concentrates after the feeding period.

In summary, ***there is evidence that the carry-over responses reported are either due to liveweight gain being converted into milk or a pasture response whereby pasture spared or extra pasture growth was later used for milk production.***

2.2. Liveweight responses.

The liveweight response to the feeding of concentrates to lactating cows is variable (see Table 2.1). The extra liveweight gained from feeding concentrates can be used for milk production in the future, though this is less efficient than direct conversion to milksolids (Geenty and Rattray 1987). Liveweight responses by dairy cows to concentrates are higher in late lactation and responses are related to the level of feeding (Table 2.5).

There appears to be a larger liveweight response to concentrates at low levels of feeding, even though there are also greater milksolids responses (Table 2.5). This is an apparent anomaly. Pasture substitution was not possible in this experiment as cows were stall fed, indicating an apparent loss of energy from the system. Stockdale and Trigg (1985) reported a less controversial response for cows in *late lactation*. Cows allocated 16 kg pasture DM/day produced similar levels of milksolids (0.95 kg/day) regardless of concentrate feeding level. However, those fed the high level of concentrates (6.3 kg/day) gained much more weight than the others (1.04 kg/day vs 0.49 kg/day for those fed 3.6 kg conc/day). By contrast, cows allocated more pasture (26 kg/cow/day) did not gain as much weight and substituted more pasture for concentrate indicating that they were already adequately fed on pasture.

Table 2.5: *Effect of feeding level on liveweight response of lactating dairy cows to concentrates in early lactation.*

Pasture intake (kg DM/c/d)	Concentrate intake (kg DM/c/d)	Milk production (kg MS/c/d)	LW change (kg/cow/14 d)	MS/kg conc (kg)	LW change /kg conc (kg)
6.8	0	0.81	-5	N/A	N/A
6.8	2.2	0.94	6	0.06	0.36
6.8	4.5	1.34	8	0.12	0.32
11.6	0	1.18	6	N/A	N/A
11.8	2.2	1.39	10	0.10	0.13
11.5	4.5	1.40	12	0.05	0.10

Source: Stockdale and Trigg (1989).

Rogers and Robinson (1981), reported a liveweight response of 0.03 kg/kg concentrate for cows in *early lactation*. This occured with cows grazing restricted pasture and eating 3.5 kg oats/day. The immediate milk response was 0.54 litres/kg concentrate. Similarly, Olney and Albertson (1984) reported that for cows stocked at 7/ha and fed 4 kg barley/day, the liveweight gain was 291 g/day compared to 104 g/day for the unsupplemented group. Milkfat yield was also higher (0.42 vs 0.25 kg MF/cow). Interestingly, cows stocked at 5/ha in the same trial showed no difference in liveweight gain regardless of whether they were fed supplement or not, although, there was a significant difference in milkfat yield (0.36 vs 0.46 kg MF/c/d for the unsupplemented and supplemented groups respectively). This indicates that when cows are not severely underfed on pasture, the liveweight response is low, i.e. liveweight response is lower 'priority' than milk response.

Stockdale *et al.* (1987) found that when concentrate feeding level was very high, fat percentage of the milk decreased so that even when there appeared to be a large milk response to concentrates, the increase in milksolids yield was not great. However, at the same time liveweight increased rapidly (Table 2.6). *This is an expected response to high concentrate diets because fat deposition is encouraged as a result of a change in rumen products* (see Section 1.2).

Table 2.6: *The effect of high levels of concentrate feeding to pasture fed cows on their milk and liveweight response.*

Pasture intake (kg DM/c/d)	concentrate intake (kg DM/c/d)	Milkfat (%)	Milk production (MS /cow/d)	LW change (kg/14 d)	LW change (kg/kg conc)
6.5	5.4	3.76	1.34	4	0.053
6.6	9.6	2.51	1.45	15	0.11

Source: Stockdale *et al* (1987).

A summary of liveweight responses to extra concentrates and extra feed is shown below (Figures 2.5 and 2.6). Figure 2.5 shows that the marginal response to extra concentrate is similar in both early and late lactation because the slopes of the lines are similar. Figure 2.6 shows a similar response to total feed intake though a curve has been fitted to the early lactation data. Interestingly, the marginal milk response in early lactation seems to be greater than late lactation at low intakes but is similar at higher intakes (> 10 kg DM/c/d).

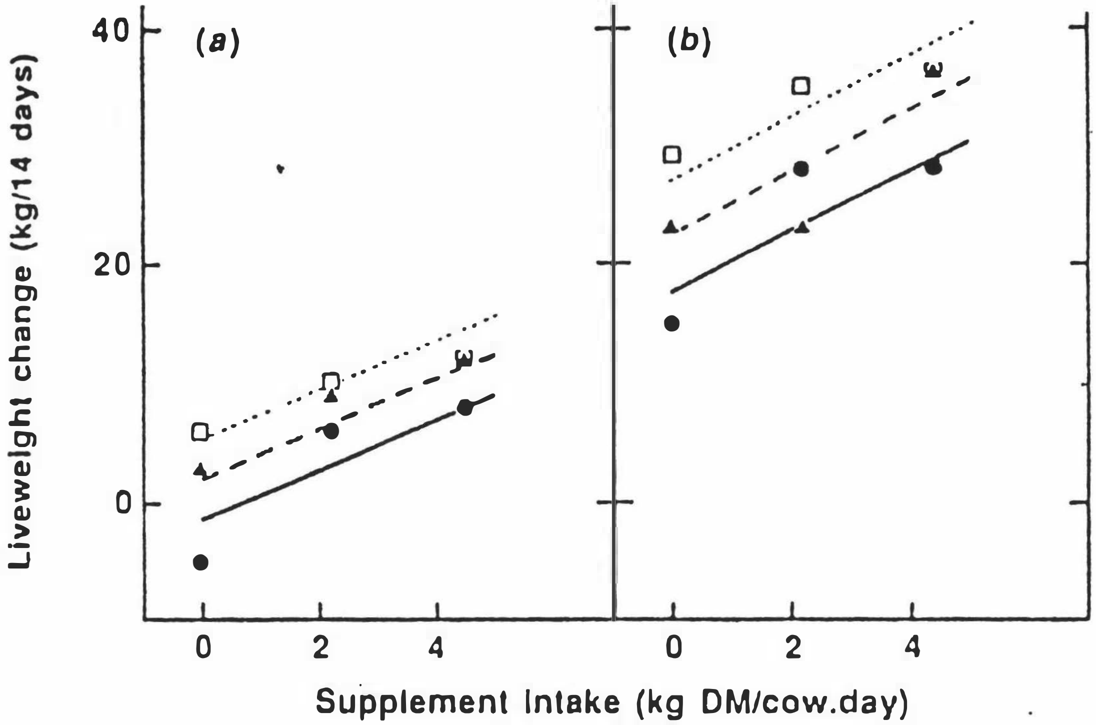


Figure 2.5: *Liveweight response of pasture fed cows offered different levels of concentrates in early (a) and late (b) lactation (● low pasture feeding, Δ medium pasture feeding, □ high pasture feeding).*
Source: Stockdale and Trigg (1989).

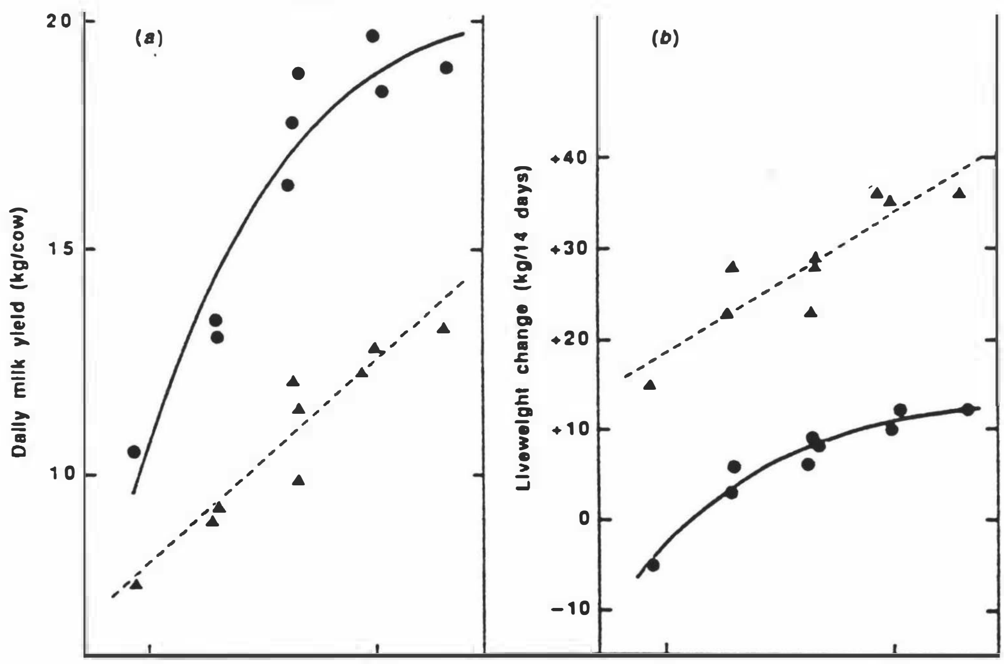


Figure 2.6 : *Effect of total dry matter intake on milk yield and liveweight gain (● early lactation, Δ late lactation).*
Source: Stockdale and Trigg (1989).

To summarise this section, ***the liveweight response to concentrates depends on energy being channelled away from milk production into liveweight gain (partitioning). This is more likely to occur when high levels of concentrate/feed are consumed because of either higher total energy intake or change in rumen fermentation or cows are in late lactation. Cows in light condition or of lowgenetic merit will tend to divert more energy towards liveweight gain.*** These aspects are discussed further in Chapter 3.

2.3. Fertility responses to concentrates.

A delay in calving of one day can result in a reduction equivalent to one day's production during the peak (average 0.7 kg MF, MacMillan *et al.* 1984). Thus, a five day delay in mean calving date can result in a reduction in production of 0.7 x 5 = 3.5 kg MF/cow, or 350 kg MF per 100 cows (provided there would be enough feed for the cows). Wilson (1988) reported feeding 2 kg/c/d of high protein concentrates in early lactation to underfed cows resulted in a 35% increase in cow milking days in the following year, equivalent to a response of 1.5 l/kg concentrate. Thus, improving fertility through feeding concentrate can be very worthwhile.

Reported New Zealand conception rates are among the highest in the world at 60-65% (Williamson and Fernandez-Baca 1992), despite cows being apparently underfed in early lactation (indicated by relatively low milk yields and cow condition). Conception rates in the U.S., where feeding levels are much higher than in New Zealand, are currently only 50% or lower (MacMillan 1994, Figure 2.7), whereas, they were 66% in 1951 when production was lower (Butler and Smith 1989). Possible reasons for the observed differences in conception rate are; that New Zealand cows are selected for an ability to get in calf quickly because of the seasonal pattern of production and the associated short time in which to conceive, U.S. cattle produce more milk and therefore remain in negative energy balance for longer, or the U.S system of management may make heat detection more difficult. Conception rates in U.S heifers have remained high, and conception rates in lower producers are higher than for high producers, indicating that the lower conception rates are related to the metabolic demands of milk production (Butler and Smith 1989, Figure 2.7). There is also lower perceived need for high conception rate with year round milk production (MacMillan 1994).

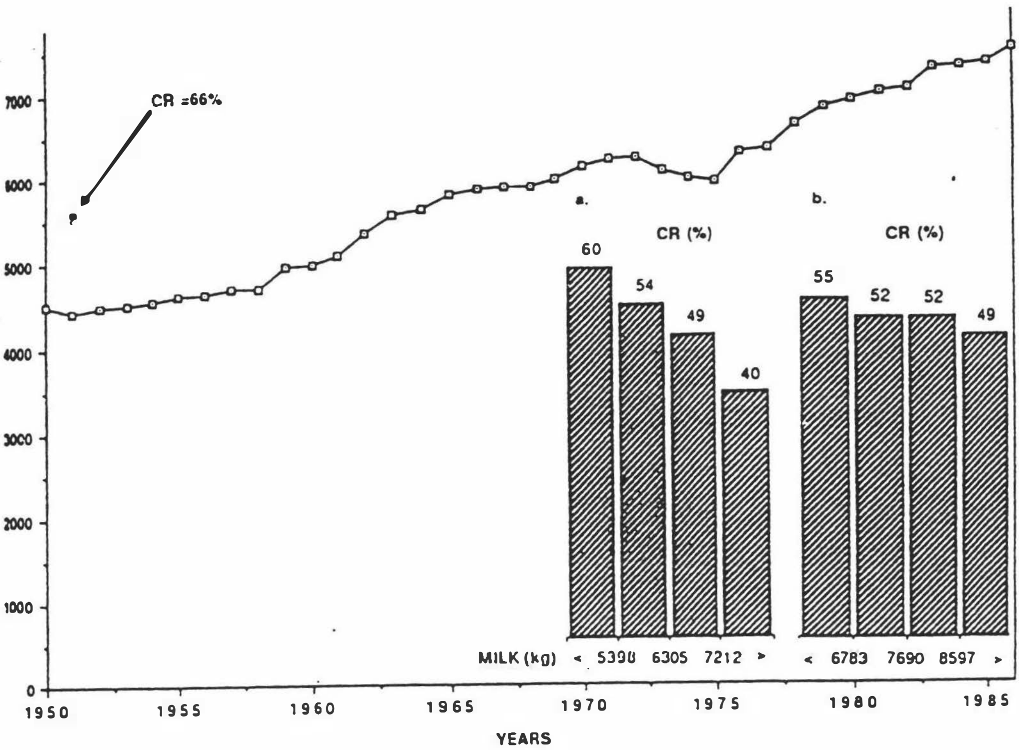


Figure 2.7: *The relationship between milk production and conception rate for U.S dairy cows. Conception rate (CR = 66%) for lactating cows in 1951 is compared to a. CR in 1973 (mean 50%) and b. CR in 1985 (mean 51%).*
Source: Butler and Smith (1989).

2.3.1. Nutritional effects on reproductive performance.

Nutrition is only one factor that can affect reproductive performance. Cow condition, milk production, infection, heat detection and artificial insemination influence reproductive performance (Hunter 1977). McDougal (1992) reported a high correlation between herd condition score at calving and interval to first ovulation and oestrus. However, the cows in low condition score at calving were at a higher stocking rate and losing condition much faster than the cows in higher condition score at calving which complicated the outcome but Wilson *et al.* (1985) reported similar findings. In that experiment, cows above condition score 4.3 at calving had significantly higher pregnancy rate than cows below 4.3 at calving (58% and 39% vs 10%). The relationship between nutrition and reproductive performance is likely to be complex and thus the effect of nutrition difficult to predict (Ducker 1986).

Reproductive performance is different to milk production and liveweight gain in that there is not a continuous response. Cows either become pregnant or they do not. Many experiments have shown that nutrition does affect reproductive performance (e.g.

McClure 1970, Hunter 1977, Ducker *et al.* 1985, 1985b, Ducker 1986, McDougal 1993) but there is conflicting evidence about the relationship (Ducker 1986).

Some research has shown that increasing milk yield leads to decreased fertility, and that excessive liveweight loss in early lactation was associated with poor reproductive performance (McClure 1970, Ducker and Morant 1984). Although Ducker and Morant (1984) found no effect of energy intake on reproductive performance, the cow intakes for both treatments were high at 193 and 175 MJ ME/c/d for the 'high' and 'low' energy intake groups respectively. It is therefore likely that energy intakes were above some 'critical' level. In another similar experiment, Ducker *et al.* (1985) found a 10.1 MJ difference in net energy output at insemination time (i.e. energy used for milk production less energy intake and liveweight loss) decreased number of days to successful pregnancy by 12.6 days, 95% of the time. This is related to energy balance (the difference between energy intake and energy leaving the animal). Lean (1992 p113) stated that **'The critical factor in the period from calving to mating would appear to be change in condition score.'**

Recent work suggests that energy balance, or more specifically change in energy balance, in cows has a large effect on fertility and that changes in blood constituents merely reflect changes in energy balance (Butler *et al.* 1981, Canfield and Butler 1990, Lean 1992, MacMillan 1994). However, the relationships between energy balance and fertility have not been precisely defined. Others have reported that the *rate* of body condition loss post partum, which must be highly correlated to energy balance, is important. Butler and Smith (1989) reported that cows which lost more weight in early lactation were slower to cycle and had lower conception rates than those which lost less weight (Table 2.7).

Table 2.7: *The relationship between body condition loss in the first five weeks of lactation and reproductive performance.*

	Loss <0.5 CS units	Loss 0.5-1.0 CS units	Loss >1 CS units
No. Samples	17	64	12
Days to first ovulation	27	31	42
Days to first oestrus	48	41	62
Days to first service	68	67	79
First service conception rate(%)	65	53	17
Services per conception	1.8	2.3	2.3
Pregnancy rate (%)	94	95	100

Source: Butler and Smith (1989).

In one New Zealand trial (McDougal 1993), non-cycling cows were in negative energy balance for longer than cycling cows which resumed cycling about 10 days after the lowest energy balance was reached. Butler *et al.* (1981) also found that cows resumed cycling 10 days after the lowest energy balance and Canfield and Butler (1990) reported a similar figure of seven days. This indicates that if cows are underfed post partum, the interval between calving and first oestrus will be delayed. Also, high producing cows are likely to be in negative energy balance for longer than low producers if they are underfed. Butler and Smith (1989) reported one example where a lower producing cow (7131 kg milk/305 d) was in negative energy balance for five weeks after calving and cycled 22 days after calving. A higher producing cow (9386 kg milk/305 d) took 76 days to cycle and was in negative energy balance for 12 weeks. These results may not necessarily apply to pasture fed cows if higher producers are able to consume more feed than lower producers by grazing longer or faster. It also indicates a possible role for concentrates to lift the energy balance of high producing cows.

There are conflicting opinions as to the effect of weight loss at the time of mating. Lean (1993 after Youdan and King 1977) reported that cows gaining weight for the 14 days around mating, had higher percentage of successful services. No such relationship was observed by McClure (1970) who found that weight loss at the time of mating was not well correlated with reproductive performance. Two cow groups lost considerable weight (7.7 and 9.9 kg/c/wk) but achieved normal fertility (67 and 69% pregnancy rate to first service). Other cow groups that exhibited poorer reproductive performance, lost more than 1% body weight/wk, but also had significantly ($P < 0.001$) lower blood glucose levels than fertile groups (28.2 vs 38.5 mg/100 ml). Feeding dairy meal enabled blood glucose levels to be maintained even when feeding levels were low and cows lost weight (7.7 kg LW/c/wk). The conclusion was that reproductive performance was inhibited when blood glucose levels fell below 30 mg/100 ml, but the base ration in this experiment was forage oats, a poor quality feed. This may not reflect the situation with pasture.

A similar result, to the above, was found by Hunter (1977). Cows with a blood glucose level of 25 mg/100 ml or less had a reduced pregnancy rate (46% vs a mean of 66% for 971 cows). Reproductive performance was improved in cows that had increasing blood glucose levels at the time of mating. The above results have implications for concentrate feeding. It seems likely that blood glucose levels would increase when concentrates are fed because of the increase in propionate production in the rumen (glucose precursor). Thus, there may be reproductive benefits of feeding concentrates at mating, even if intake levels of pasture are high (if blood glucose level affects reproductive performance).

There is some evidence to the contrary; for example, Canfield and Butler (1990) reported that there was correlation between blood glucose levels and energy balance but that glucose levels did not actually affect reproductive performance. Ducker *et al.* (1985b) found no such relationship between blood glucose levels and reproductive performance, but the levels reported were all above 30 mg/100 ml. However, a correlation between *B*-hydroxy-butyrate levels and reproductive performance was reported (higher levels were associated with better reproductive performance, but higher levels normally reflect fast rates of body tissue mobilisation, so this result is surprising). These differences, between experiments, led Ducker *et al.* (1985b) to conclude that metabolic profiles were of little value for predicting reproductive performance, in agreement with others (e.g. Parker and Blowey 1976).

2.3.2. Effects of concentrate feeding on reproductive performance.

The fertility response of dairy cows to concentrate feeding *per se* is not well documented as most experiments have only reported milk production responses and/or liveweight responses. The research that has been done, indicates that ***underfeeding in early lactation affects reproductive performance*** (Wilson 1988, MacCallum *et al.* 1994). McCallum *et al.* (1994) reported that the mean calving date was five days later in a herd which had been underfed on pasture in early lactation, compared to a supplemented herd (Table 2.8). Johnson (1979) reported a significantly ($P<0.01$) lower number of days to first service (84 to 75) for cows fed higher levels of concentrate (10.6 vs. 9.3 kg/c/d). The milk yields of the high and low nutrition group were very similar in this experiment (2373 vs 2253 l SCM in weeks 9 - 20 of lactation) which is not surprising considering that the intake difference between the high and low nutrition groups was small. Wilson (1988) outlined three cases where mean calving date was brought back by between 7 and 10 days as a result of feeding a high protein (18% crude protein (CP)) concentrate at 2 kg/d for four weeks prior to mating. These experiments indicate feeding level and feed quality can have a large effect on fertility.

Table 2.8: *The effect of underfeeding at mating on reproductive performance.*

	Feeding level	
	9 kg pasture DM	3.2 kg conc + 8.8 kg pasture DM
4 week in calf rate	43	68
Cows calving after 6 weeks (%)	24	11
Mean calving date	19/7	14/7

Source: McCallum *et al.* (1994).

McDougal (1993) found that friesian cows grazed at a higher stocking rate (4.0 cows/ha) took 20 days longer to reach first ovulation than cows that were provided higher pasture allowances at a lower stocking rate (3.0 cows/ha). Jerseys at the higher stocking rate (4.5 cows/ha) took only seven days longer to ovulate than those at the lower stocking rate (3.5 cows/ha). This trial was complicated by cow condition as cow groups were at a different condition score at the commencement of the trial, but it indicates a possible effect of underfeeding in early lactation.

Ducker *et al.* (1985) reported that cows well fed after calving took longer to conceive than cows that were less well fed (first insemination pregnancy rates of 42% and 63% respectively). Intakes for the two groups were 150 and 120 MJ ME respectively. Milk yield and liveweight loss were correlated with time to get in calf so the cows with higher intakes also produced more milk and were probably in negative energy balance for longer. This result is unusual in that the better fed cows exhibited poorer reproductive performance and provides some confusion as to the benefits of concentrate feeding.

There is some evidence to suggest that lower conception rates achieved overseas are related to high dietary rumen degradable protein levels (Jordan and Swanson 1979, Williamson and Fernandez-Baca 1992). Jordan and Swanson (1979) indicated that crude protein intakes above 16% of total intake may affect fertility. Excessive protein intakes require energy to be broken down to urea from ammonia in the liver, decreasing efficiency of feed utilisation. This can exacerbate the negative energy balance related to infertility. The urea enters the blood and some is discharged in the uterus and vagina which can decrease sperm and embryo viability, reducing fertility. However, dietary protein levels in New Zealand spring pastures are high and yet official records suggest that conception rates are also high. There is some evidence that pastures high in protein decrease fertility in New Zealand (Williamson and Fernandez-

Baca 1992).There are many factors affecting plant nitrogen levels. High pasture nitrogen levels can be induced by applying nitrogen fertiliser.Immature pasture has higher nitrogen levels than mature pasture (Santamaria and McGowan 1982, Moller 1993), so rapid rotations in early spring may cause a problem.

In summary, ***the exact relationship between fertility and nutrition is unclear, but the research indicates that feeding concentrates would improve fertility when cows are underfed on pasture and in low condition score (< 4.5). This may become an important role for concentrate feeds, especially for high yielding cows run at high stocking rates, or calving at a time when pasture growth does not meet herd requirements. However, though most research suggests benefits from feeding concentrates in these situations would be beneficial, the quantity required and length of time they need to be fed for has not been clearly established.***

2.4. Pasture responses to concentrate feeding.

The pattern of pasture growth after grazing depends on the plant carbohydrate reserves and the severity of grazing (Hodgson 1990, Chapman and Lemaire 1993). Early leaf growth depends on reserves in the plant. When these are high and the period of stress is not long such as in rotational or lax grazing, plants may not experience any decline in growth rate after grazing. When reserves are low, growth rate after grazing will be slow. Very hard grazing results in a lag in growth until new tillers develop to provide leaf for photosynthesis (Figure 2.8).

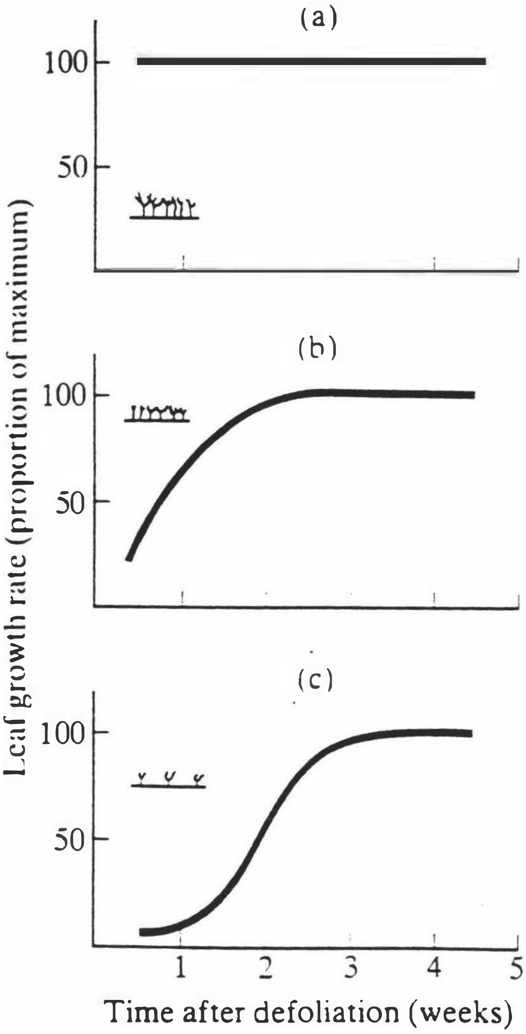


Figure 2.8: *Alternative patterns of leaf growth over time in harvested swards.*
Source: Hodgson (1990).

Generally, it is considered that keeping sward heights above 5-6 cm will result in higher pasture growth rates and that to maximise pasture net accumulation rate, almost all of the light falling on the pasture should be intercepted by leaf (Chapman and Lemaire 1993). One exception to this rule was the work by Brougham (1960). He reported that pasture growth rates during the winter were enhanced by hard grazing in winter. Pasture growth rates were 70% higher (1015 vs 1805 kg DM/ha total yield) during this period when pastures were grazed hard. This was attributed to greater tillering and possibly higher temperatures at the soil surface. However, this was a one-off experiment. Leaving a higher residual after grazing can result in higher pasture growth rates at least at certain times of the year (Figure 2.9, Santamaria and McGowan 1982, Hodgson 1990, Matthew pers. comm. 1995). Recent analysis of a large amount of pasture growth rate data at Massey University showed a highly signifiicant (P<0.001) increase in pasture growth rate as pasture residuals increased from 700 to 1800 kg DM/ha (Matthew pers comm. 1995). The regression equation predicted an increase in pasture growth of 2.6 kg DM/ha/d for every 100 kg DM increase in pasture cover (Figure 2.9). Santamaria and McGowan predicted increases of 1.1-1.6 kg DM/day for every 100 kg DM extra pasture cover.

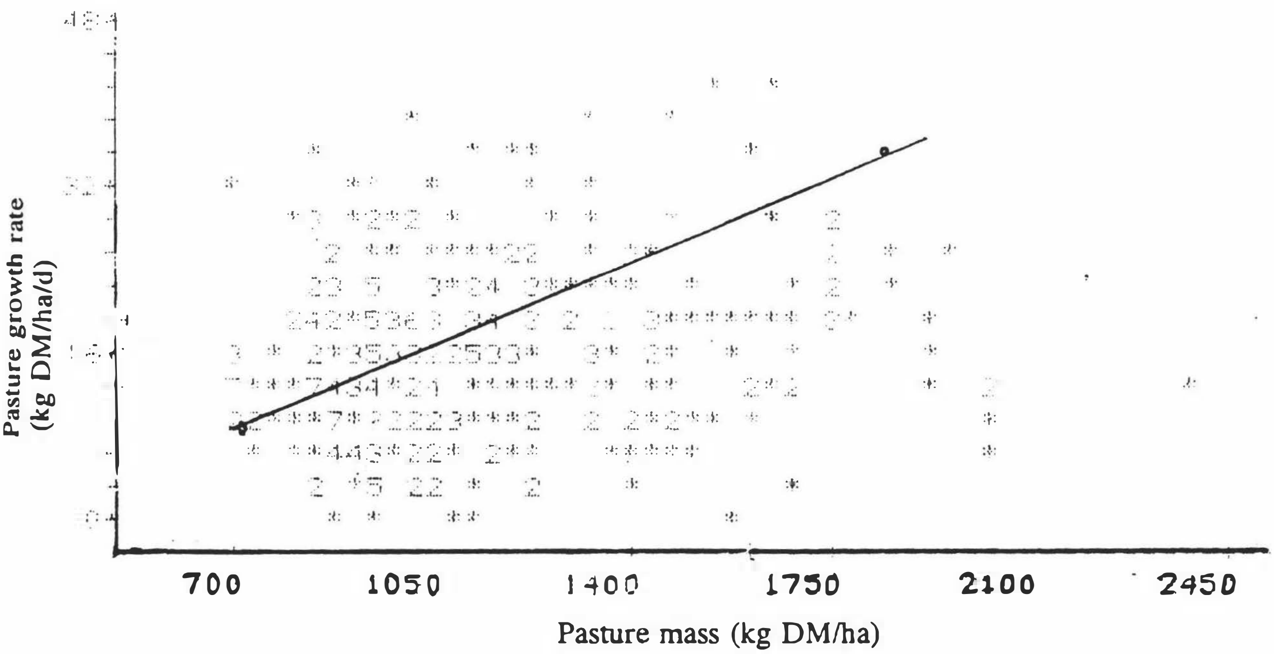


Figure 2.9: *The effect of residual pasture mass on pasture growth rate in winter and early spring.*
Source: Matthew unpublished

Hoogendoorn *et al.* (1988) observed higher net pasture growth rates in spring in swards that were laxly grazed (residual 2000-2500 kg DM/ha) compared to those grazed hard (1000-1500 kg DM/ha). Others found that pasture growth rate decreased above a pasture mass of about 1000 kg DM/ha because of an increase in leaf death (Bircham and Hodgson 1983, Hodgson 1990, Matthews 1994). However, the work by Bircham and Hodgson (1983) involved set stocked sheep and may not directly apply to rotationally grazed dairy pasture. However, the concept explained by Bircham and Hodgson (1983) is a valid one. As pasture mass increases, there is an increase in senescent material and eventually a point is reached where senescence equals growth and the net accumulatrion rate is 0 kg DM/d (Figure 2.10). The argument is with the quantitative relationships rather than the concept. Some data from Massey University (Matthew unpublished) showed that the point at which the rate of senescence began to increase was much higher (3500 kg DM/ha) than shown below (Figure 2.10). Thus, rate of net herbage accumulation *could* continue to increase until the pasture mass reached 3500 kg DM/ha.

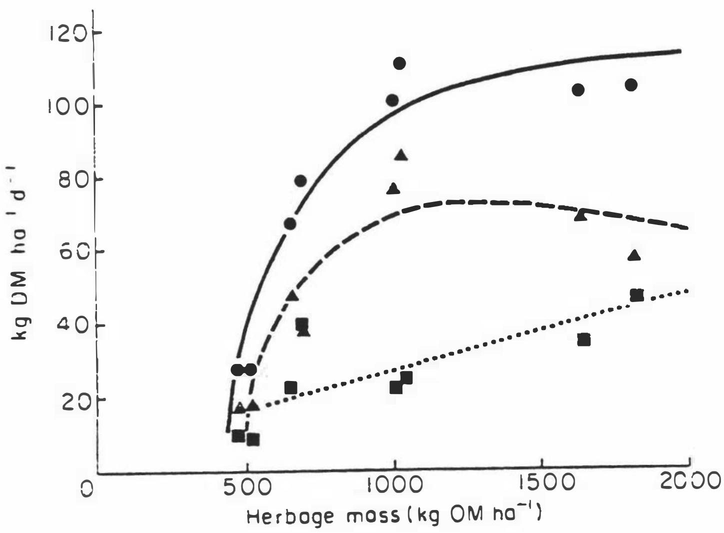


Figure 2.10: *The effect of pasture mass on pasture growth and senescence for a continuously stocked sward (● total growth, ■ senescence, Δ net production)* .
Source: Bircham and Hodgson (1983).

In summer and autumn pasture growth rates are also affected by residual pasture heights. Brougham (1960) reported significantly higher growth rates for pasture that was lax rather than hard grazed during summer and autumn.

In the longer term, if pasture masses remain high, dead material can build up, and a reduction in tiller numbers can result in lower subsequent growth (Hoogendoorn and Holmes 1988, Hodgson 1990). Several authors have observed partial compensation for reduced growth under hard grazing through a greater utilisation of available pasture (Bircham and Hodgson 1983, L'Huillier 1987, Hoogendoorn *et al..* 1988). Hoogendoorn *et al.* (1988) reported that lax grazing in the spring resulted in a reduction in herbage quality and subsequent reduction in summer pasture growth and milk production. Their conclusion was that residual pasture mass in the spring should be kept below 1500 kg DM/ha to maintain pasture quality and milk production. However, no intermediate pasture residual levels (between the extremes of 1500 and 2200 kg DM/ha) were assessed. A better compromise may have been reached at a slightly higher residual.

Results from the ongoing 'late control' experiment at Massey University showed, even under hard grazing, 61% of the daughter tillers surviving after flowering came from reproductive stems, indicating that management to minimise reproductive growth may be self-defeating (Matthew *et al.* 1993). 'Late control' not only resulted in higher pasture production during the spring but also an increase in pasture production of around 1000 kg DM/ha during the summer. This led to higher milk production of about 10 kg MS/c (Da Silva *et al.* 1994). Pastures still had to be grazed hard to prevent the build up of dead material and maintain pasture quality, but this occurred after seed head development. Surprisingly, this did not result in a reduction in milk production during the late control period (Da Silva *et al.* 1994). ***Overall, it seems that higher residuals will result in higher pasture growth for post grazing residuals lower than 1800 kg DM/ha. Above 1800 kg DM/ha, the situation is less clear but there may be increased plant senescense.*** Whether extra pasture growth results in increased milk production will depend on pasture supply and demand following the feeding period. Milk production could be increased if pasture supply is low relative to animal demand.

2.5 Summary of main points.

Some of the different responses to concentrate feeding were examined in this Chapter. Nutrient partitoning and substition rate are important key factors determining the response to concentrates. These factors are examined in detail in Chapter three. The pasture and reproductive responses are important for determining the long term response. Substitution of pasture for concentrate can result in higher pasture growth rates because of higher post grazing residuals. This extra feed may be used for subsequent milk production. There may be a role for concentrates to improve energy balance in early lactation if cows are in poor condition and losing weight.

CHAPTER THREE

FACTORS AFFECTING NUTRIENT PARTITIONING AND SUBSTITUTION RATE.

3.0. Introduction.

Possible responses to concentrates include increased milk production, increased liveweight gain, improved fertility and higher pasture growth. In the previous Chapter it was established that at different levels of pasture feeding and stage of lactation, the response to concentrates varied. In this Chapter the factors affecting nutrient partitioning and substitution rate are examined because they determine the response to concentrate. If substitution rate is high, a residual milk response may occur as a result of extra pasture being available for consumption, but immediate milk response normally will be low. Similarly, if much of the extra energy consumed is used for liveweight gain, the immediate milk response will be low but fertility could be improved and a residual milk response may occur through tissue catabolism at a later time. Specific factors affecting nutrient partitioning and substitution rate are discussed below and responses are quantified.

3.1. Factors affecting nutrient partitioning.

Nutrient partitioning describes the way in which energy intake, above a theoretical maintenance requirement, is divided between liveweight gain and milk production by the cow. Cow genetic merit (3.1.1.), cow condition (3.1.2.), stage of lactation (3.1.3.), type of concentrate (3.1.4.) and level of concentrate feeding (3.1.5) may affect partitioning. *Gross nutrient partitioning* refers to the way in which total energy consumed is used. *Marginal partitioning* describes what happens to the *extra* energy consumed (e.g. as concentrate). These are clearly different. The emphasis is on factors affecting marginal partitioning because this is more important when considering the effects of extra feed inputs.

3.1.1. Genetic merit.

Several authors have reported that cows of high genetic merit (BI) produce more milk than cows of low genetic merit (Bryant and Trigg 1979, Grainger *et al.* 1981, Bryant 1982, Davey and Grainger 1982, Davey *et al.* 1983, Holmes *et al.* 1985, Grainger 1990). The difference in production appears to be due to higher intake or greater partitioning of nutrients towards milk production (Bryant 1981, Grainger *et al.* 1981, Davey and Grainger 1982). It has been reported that high BI cows eat significantly more pasture than low BI cows (Bryant 1981, Grainger *et al.* 1981). In some cases, however, high BI cows were also heavier than low BI cows and this influenced intake and production. When this factor was accounted for differences in intake still occurred(Bryant 1981). Grainger *et al.* (1981) reported high BI cows also partitioned significantly more energy towards milk production in late lactation, but in early lactation the difference was not significant.

Some authors found that genetic merit (BI) did not affect marginal partitioning (Bryant 1981, Rogers 1985 after Robinson and Rogers 1982), although it did influence gross efficiency because high BI cows ate more than their low BI counterparts (Table 3.1). Grainger (1990) reported greater marginal milk response by cows of high initial milk yields (1.2 vs 0.8 kg MF/c/d), but not necessarily different BIs. For instance, cows of low initial yield did not show any milk response to extra feed once intake reached 15 kg DM/c/d. The cows of high initial yield were still producing an extra 35 g MF/kg extra feed at this level of intake. Grainger (1982) found that high BI cows exhibited higher marginal efficiencies than low BI cows, partitoning between 7 and 10% more of the extra energy consumed into milk production. In two out of the three experiments reported, low BI cows gained more weight that high BI cows (Table 3.2). However, none of these results were significant. In contrast, Johnson (1979) reported a different response when barley and pellets were fed to cows of high (> 22 *l/d*) and low (< 22 *l/d*) milk production. The response/kg concentrate was lower for the high producers (0.74 vs 0.92 *l*/kg concentrate) but interpretation of this result is complicated by the fact that the low producers received 22% less concentrate than the high producers, and again, there was no certainty that those with high milk yields were also of high genetic merit.

Table 3.1: *The effect of high or low genetic merit (HBI vs. LBI) on liveweight, intake and feed conversion efficiency in early lactation (average of 3 experiments).*

	HBI	LBI
Liveweight (kg)	375	335
Intake (kg DM/c/d)	14.0	12.2
Milk fat yield (kg/c/d)	0.87	0.70
Efficiency (g MF/kg DM consumed)	64	58

Source: Bryant (1981).

Table 3.2: *The effect of high or low genetic merit (HBI vs. LBI) on nutrient partitioning (within each column the values are the difference between two levels of feeding).*

Stage of lactation	Early	Early	Late	Late	Early	Early
	HBI	LBI	HBI	LBI	HBI	LBI
Increase in pasture intake (kg DM/c/d)	5.5	6.1	5.6	6.9	4.9	4.8
Increase in milk production (g MS/c/d)	268	203	210	144	308	240
Increase in LW gain (kg/c/d)	0.64	0.36	-0.28	0.04	0.46	0.68
Extra energy intake (MJ ME/c/d)[1]	58	64	59	72	51	50
Energy required for extra milk (MJ ME)[2]	18	13	14	10	20	16
Marginal partitioning (% extra energy intake used for milk)	31%	20%	23%	14%	39%	32%

[1] Assumes 10.5 MJ ME/kg pasture DM.

[2] Assumes 68 MJ ME required to produce 1 kg MS.

Source: Adapted from Grainger (1982).

Holmes *et al.* (1985) also showed greater marginal partitioning of energy to milk by cows of high BI compared to cows of low BI. However, again the difference was not significant (Table 3.3). ***Overall, there was some evidence of difference in marginal partitioning between cows of high and low genetic merit, however the differences were not significant. Therefore, it cannot be assumed that differences will exist in commercial situations.***

Table 3.3: *The effect of genetic merit (BI) on marginal partitioning to milk and liveweight gain.*

Breeding Index (BI)	H[1]	H	L	L
Pasture allowance (kg DM/c/d)	50	15	50	15
MF yield (kg/d)	1.08	0.86	0.87	0.73
Marginal increase in MF (kg/c/d)	0.22	N/A	0.14	N/A
Condition score change (CS units/8 weeks)	-0.08	-0.4	+0.32	+0.18
Marginal change in condition score (CS units/8 wks)	+0.32	N/A	+0.14	N/A

[1] H = BI 125, L = BI 105.

Source: Holmes *et al.* (1985).

3.1.2. Cow condition at calving.

The effect of cow condition at calving on subsequent milk production is well documented (Rogers *et al.* 1979, Grainger 1980, Grainger 1982, Grainger et al. 1982, Garnsworthy and Topps 1982, Garnsworthy and Jones 1993, Kellaway and Porta 1993). Experiments in the late 1970's showed that one extra condition score unit at calving increased milkfat production by 8.5 kg MF/cow and cow condition by 0.2 units after 20 weeks of lactation (Grainger 1980,1982; Table 3.4). Thus, cows in low condition score at calving gained weight while those in high condition score at calving subsequently lost weight and produced an extra 8.5 kg MF over 20 weeks. In the first five weeks, the cows in condition score five at calving produced 3.5 kg MF more than those in condition score four.

Table 3.4: *Effect of an extra condition score (CS) unit at calving on milkfat production (MF) and subsequent condition score.*

	CS 4	CS 5
MF (kg 1st 5 weeks)	25.2	28.7
CS @ week 5	4.2	4.8
MF (kg 1st 20 weeks)	100.1	108.6
CS @ 20 weeks	4.7	4.9

Source: Grainger (1980).

Grainger *et al.* (1982) examined the effect of different feeding levels and condition scores on milk production in early lactation (Table 3.5). The results showed that ***cows in condition score six partitioned 40% more, of the extra energy consumed, into milk production than cows at condition score three.*** The cows used in the experiment may have been of low genetic merit because the reported milkfat yields were relatively low despite measured intakes of 14 kg DM/c/d. Similarly, Stockdale *et al.* (1987), in a set of experiments observed the effects of different condition score on milk production and liveweight gain in late lactation. Fatter cows consistently produced more milk and partitioned more energy (1.4 times) into milk production than their thinner counterparts (Table 3.6). However, it was not possible to complete a marginal analysis with this data because there was only one level of feeding. Thus, the work by Grainger *et al.* (1982) provides the only Australasian data for pasture-fed cows on the effect of condition score on marginal nutrient partitioning.

Table 3.5: *The effect of cow condition score on marginal partitioning in early lactation (20 weeks).*

	Cow	condition	score	
	Low		High	
	3	3	6	6
Cow pasture intake (kg DM/c/d)	8	14	8	14
Milk production (kg MF/c/d)	0.36	0.52	0.48	0.71
Marginal increase in milk production (kg MF/c/d)	-	0.16	-	0.23
Marginal increase in energy intake (MJ ME/c/d)[1]	-	64.8	-	64.8
Marginal partitioning (% extra energy used for milk production)[2]	-	30%	-	43%

Source: Adapted from Grainger *et al.* (1982).

[1] Assumes pasture contains 10.8 MJ ME/kg DM.

[2] Assumes 115 MJ ME required to produce one kg MF.

Table 3.6: *The effect of cow condition score (CS) on gross nutrient partitioning in late lactation.*

	CS 5.9	CS 4.6
Pasture Intake (kg DM/c/d)	6.6	6.7
Milksolids production (MS/c/d)	0.79	0.58
Liveweight change (kg/c/d)	-0.07	0.93
Nutrient partitioning (% energy intake used for milk production)[1,2]	73%	52%

1 Assumes pasture contains 10.8 MJ ME/kg DM.

[2] Assumes 68 MJ ME required to produce 1 kg MS.

Source: Adapted from Stockdale *et al.* (1987).

Some research pertaining to cows consuming feeds other than grazed pasture, does not support the view that cows in fatter condition at calving produce more milk. Work in the U.K. with cows fed silage and concentrates showed that thinner cows at calving had higher intakes and produced more milk than their fatter counter parts (Garnsworthy and Topps 1982, Garnsworthy 1988). Garnsworthy (1988) concluded that cows in lower condition, fed high quality feeds *ad libitum*, were able to out produce fatter cows due to their higher appetite. This conclusion is surprising since it implies that the thinner cows are able to eat enough to sustain high early season production as well as gain weight. This is not supported by work in Australasia (e.g.

Grainger et al 1982, McDougal 1992) where all cows lost some weight in early lactation and thinner cows partitioned more energy into liveweight gain. Kellaway and Porta (1993) concluded that on occasions where pasture intake was restricted, milk production was higher in cows calving in high condition score (Kelloway and Porta 1993).

There is some evidence that fat cows will lose weight and thin cows gain weight to arrive at a common condition at the end of lactation when fed well (Garnsworthy and Topps 1982, Holmes *et al.* 1985). Holmes *et al.* (1985) found high BI cows that were either fat or thin at the start of lactation were all about condition score 4.8 at the end of lactation. However, low BI cows were fatter at the end of lactation (CS 5.8 and 5.5 for initially fat and thin cows respectively). Feeding levels for these cows were not recorded but they all grazed together. Similar results were reported by Grainger (1980, Table 3.4). Garnsworthy and Topps (1982) showed three groups of cows converging on the same condition after 15 weeks. The rate of condition gain or loss depended on the initial condition score (Figure 3.1). The cows in low condition score gained weight immediately after calving while those in high condition score lost weight for 15 weeks. However, the rate of gain or loss of condition will also depend on cow energy intake and genetic merit as discussed elsewhere. Thus, ***high BI cows (BI 125) above condition score 4.8 at calving are likely to lose condition over the lactation and partition more energy towards milk production while those below condition score 4.8 are likely to gain condition and partition less energy towards milk production. Low BI cows (BI 100) tend to converge to somewhat higher condition scores (5.5). Very high BI cows (BI 140) may converge to even lower condition scores (e.g. 4.3).***

The above results imply that, ***the response to concentrates is likely to be higher in the immediate term if cows are in good condition at calving.*** After calving thin cows may partition more energy from concentrates into liveweight gain. However, over the whole year, the benefits of high condition score at calving may be eroded because the high condition cows lose weight and must regain it. The benefits may remain high if the liveweight can be regained at low cost (e.g. through grazing).

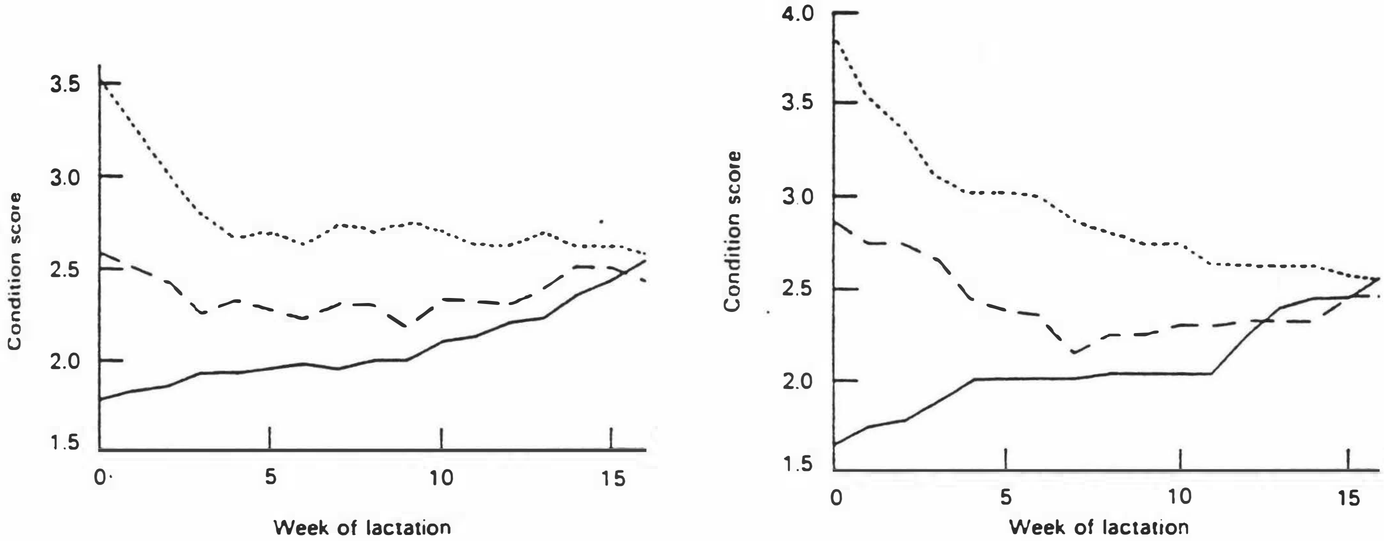


Figure 3.1: *The effect of initial condition score on subsequent condition change of lactating cows (______ low, ------- medium, ... high initial condition n.b. British condition score units, to convert to Australian/ New Zealand units multiply by 2)*. Source: Garnsworthy and Topps (1982).

3.1.3. Stage of lactation and energy intake.

Cows partition more energy into liveweight gain in late lactation than in early lactation (Section 2.2). Stockdale and Trigg (1985) reported different marginal partitioning rates for cows offered high or low levels of low quality pasture (58% digestible) and concentrate in late lactation. Others found that partitioning in early lactation was affected by the amount of pasture and concentrate fed (Rogers 1985, Grainger and Matthews 1989, Grainger 1990). Figure 3.2 shows that the level of energy intake affects marginal nutrient partitioning.

Tables 3.7 and 3.8 summarise nutrient partitioning responses from several experiments for early and late lactation respectively. The main effect shown in these tables is that cows offered low levels of pasture partitioned proportionately more of the extra energy supplied into milk production, and therefore showed a greater immediate milk response to concentrates, than cows offered high levels of pasture. For example, Trigg *et al.* (1983) reported that cows fed high levels of concentrate (9.6 kg/d in addition to 6.5 kg DM/d pasture) in early lactation gained 21 kg LW while those that were fed less concentrate (5.4 kg /d) lost 1 kg LW. At the same time, milksolids production was 1.43 and 1.31 kg/c/d respectively, indicating that at high intakes the effect on milk production can be minimal, with much of the extra energy being partitioned into liveweight gain. This response may also reflect a change in rumen product resulting from high starch intakes (Section 3.1.5).

There is a distinct difference in gross energy partitioning to milk production between early and late lactation (average 63 and 50% respectively from Tables 3.7 and 3.8) but there is little difference between marginal partitioning in early and late lactation (average 39% for both, from Tables 3.7 and 3.8). This has important implications as it *means that the response to extra feed in early and late lactation will be similar,* This relationship is shown clearly in Figure 3.2.

Table 3.7: *Summary of marginal nutrient partitioning responses in early lactation.*

Experiment	Pasture intake (kg DM/c/d)	Concentrate intake (kg DM/c/d)	Energy intake(1) (MJ ME/c/d)	Milk production (MS/c/d)	Marginal increase (MS/c/d)	Energy for milk prod (2) (MJ ME/c/d)	Increase in energy for milk(2) (MJ ME/c/d)	Energy partitioned to milk (%)	Marginal partitioning to milk(%)
Opatpatanakit *et al.*	15.5	0	173	1.15	0	75.9	0	44%	N/A
`(1993)	13.2	4	193	1.21	0.06	79.86	3.96	41%	20%
	11.3	8	207	1.27	0.12	84	7.92	40%	23%
Stockdale and Trigg	6.8	0	71	0.81	0	53	0	75%	N/A
(1989)	6.8	2.2	97	0.94	0.13	62	9	64%	33%
	6.8	4.5	125	1.34	0.53	88	35	71%	65%
	9.4	0	99	1.01	0	67	0	67%	N/A
	9.3	2.2	124	1.25	0.24	83	16	67%	63%
	9.4	4.5	152	1.32	0.31	87	20	57%	39%
	11.6	0	124	1.18	0	78	0	63%	N/A
	11.8	2.2	150	1.39	0.21	92	13.86	61%	53%
	11.5	4.5	175	1.40	0.22	92	14.52	53%	28%
Rogers (1985)	10.8	0	119	1.45	0	96	0	80%	N/A
	10.7	3.6	161	1.54	0.09	102	5.94	63%	14%
	14.5	0	160	1.71	0	113	0	71%	N/A
	13.4	3.5	189	1.60	-0.11	106	-7.26	56%	-25%
Grainger and Matthews (1989)	6.3	3.2	108	1.28	0	84	0	78%	N/A
	11	3.2	159	1.65	0.37	109	24.42	68%	48%
	13.7	3.2	189	1.76	0.48	116	31.68	61%	39%
Tapara and Davey	9.1	0	100.1	0.67	0	70.35	0	70%	N/A
(1970)	8.1	1.8	110.7	0.69	0.02	72.45	2.1	65%	20%
	7.6	2.7	116	0.67	0	70.35	0	61%	0%
Stockdale *et al.*	6.6	0	72.6	0.94	0	62.04	0	85%	N/A
`(1987)	6.3	1.8	90.9	1.16	0.22	76.56	14.52	84%	79%
	6.6	2.7	105	1.25	0.31	82.5	20.46	79%	63%
	6.5	5.4	136.3	1.34	0.4	88.44	26.4	65%	41%
	6.6	9.6	187.8	1.45	0.51	95.7	33.66	51%	29%
	7	0	77	0.71	0	46.86	0	61%	N/A
	7	3.6	120.2	1.12	0.41	73.92	27.06	61%	63%
	6.9	8.7	180.3	1.19	0.48	78.54	31.68	44%	31%
	6.8	0	74.8	0.82	0	54.12	0	72%	N/A
	6.8	2.2	101.2	0.89	0.07	58.74	4.62	58%	18%
	6.8	4.4	127.6	1.35	0.53	89.1	34.98	70%	66%
Trigg *et al.* (1983)	6.5	0	71.5	0.95	0	62.7	0	88%	N/A
	6.5	1.8	93.1	1.18	0.23	77.88	15.18	84%	70%
	6.5	2.7	103.9	1.31	0.36	86.46	23.76	83%	73%
	6.5	5.4	136.3	1.31	0.36	86.46	23.76	63%	37%
	6.5	9.6	186.7	1.43	0.48	94.38	31.68	51%	28%

[1] Assumes pasture contains 10.5 MJ ME/kg DM and concentrate contains 12 MJ ME/kg DM.

[2] Assumes 68 MJ ME/kg milksolids.

Table 3.8: *Summary of marginal nutrient partitioning responses in late lactation.*

	Pasture intake (kg DM/c/d)	Concentrate intake (kg DM/c/d)	Energy intake (1) (MJ ME/c/d)	Milk production (MS/c/d)	Marginal increase (MS/c/d)	Energy for milk prod (2) (MJ ME/c/d)	Increase in energy for milk (2) (MJ ME/c/d)	Energy partitioned to milk (%)	Marginal partitioning to milk (%)
Trigg *et al.* (1983)	8	0	86.4	0.68	0	44.88	0	52%	N/A
	8.1	1.8	109.08	0.94	0.26	62.04	17.16	57%	76%
	8	3.6	129.6	0.95	0.27	62.7	17.82	48%	41%
	6.5	6.3	145.8	0.94	0.26	62.04	17.16	43%	29%
	10.6	0	114.48	0.88	0	58.08	0	51%	N/A
	8.9	1.8	117.72	0.93	0.05	61.38	3.3	52%	102%
	9.1	3.5	140.28	1.02	0.14	67.32	9.24	48%	36%
	8.7	6.2	168.36	1.08	0.2	71.28	13.2	42%	24%
	6.5	0	70.2	0.77	0	50.82	0	72%	N/A
	6.5	1.8	91.8	0.9	0.13	59.4	8.58	65%	40%
	6.5	3.6	113.4	1.05	0.28	69.3	18.48	61%	43%
	6.5	6.1	143.4	0.93	0.16	61.38	10.56	43%	14%
	7	0	77	0.72	0	47.52	0	62%	N/A
	7	3.6	120.2	1.12	0.4	73.92	26.4	61%	61%
	7	5.6	144.2	1.17	0.45	77.22	29.7	54%	44%
	7	3.6	120.2	1.13	0.41	74.58	27.06	62%	63%
	7	8.7	181.4	1.21	0.49	79.86	32.34	44%	31%
Stockdale and Trigg	8	0	72	0.68	0	45	0	62%	N/A
(1985)	8	3.6	115	0.94	0.26	62	17.16	54%	40%
	6.5	6.3	134	0.95	0.27	63	17.82	47%	29%
	10.6	0	95	0.88	0	58	0	61%	N/A
	9.1	3.5	124	1.02	0.14	67	9.24	54%	32%
	8.7	6.2	153	1.08	0.2	71	13.2	47%	23%
Stockdale and Trigg	6.7	0	70	0.58	0	38	0	55%	N/A
(1989)	6.7	2.2	96	0.74	0.16	49	10.56	51%	41%
	6.7	4.4	122	0.87	0.29	57	19.14	47%	37%
	9.2	0	97	0.7	0	46	0	48%	N/A
	9.2	2.2	123	0.94	0.24	62	15.84	50%	61%
	8.8	4.4	151	0.98	0.28	65	18.48	43%	34%
	11.8	0	124	0.84	0	55	0	45%	N/A
	11.7	2.2	149	1.02	0.18	67	11.88	45%	48%
	11.3	4.4	172	1.03	0.19	68	12.54	40%	26%
Stockdale *et al.* (1987)	6.5	0	71.5	0.79	0	52.14	0	73%	N/A
	6.6	1.8	94.2	0.81	0.02	53.46	1.32	57%	6%
	6.6	3.6	115.8	1.03	0.24	67.98	15.84	59%	36%
	6.3	6.1	142.5	1	0.21	66	13.86	46%	20%
	6.7	0	73.7	0.58	0	38.28	0	52%	N/A
	6.7	2.2	100.1	0.73	0.15	48.18	9.9	48%	38%
	6.7	4.4	126.5	0.78	0.2	51.48	13.2	41%	25%

[1] Assumes pasture contains 10.5 MJ ME/kg DM and concentrate contains 12 MJ ME/kg DM

[2] Assumes 68 MJ ME/kg milksolids.

Separate equations were generated for early and late lactation from the data in Tables 3.7 and 3.8:

$$MPe = 80 - 0.301\ EI \qquad R^2 = 18.5\%\ \ NS,$$

$$MPl = 71 - 0.244\ EI \qquad R^2 = 8.4\%\ NS,$$

where MPe and MPl are marginal partitioning in early and late lactation respectively and EI is energy intake (MJ ME/c/d). However, because of the similar range points they were combined to generate a single significant relationship:

$$MP = \underset{(+/-\ 13.6)}{85.5} - \underset{(+/-\ 0.095)}{0.331}\ EI \qquad R^2 = 19.9\% \qquad P < 0.001$$

where MP is marginal energy partitioning to milk production.

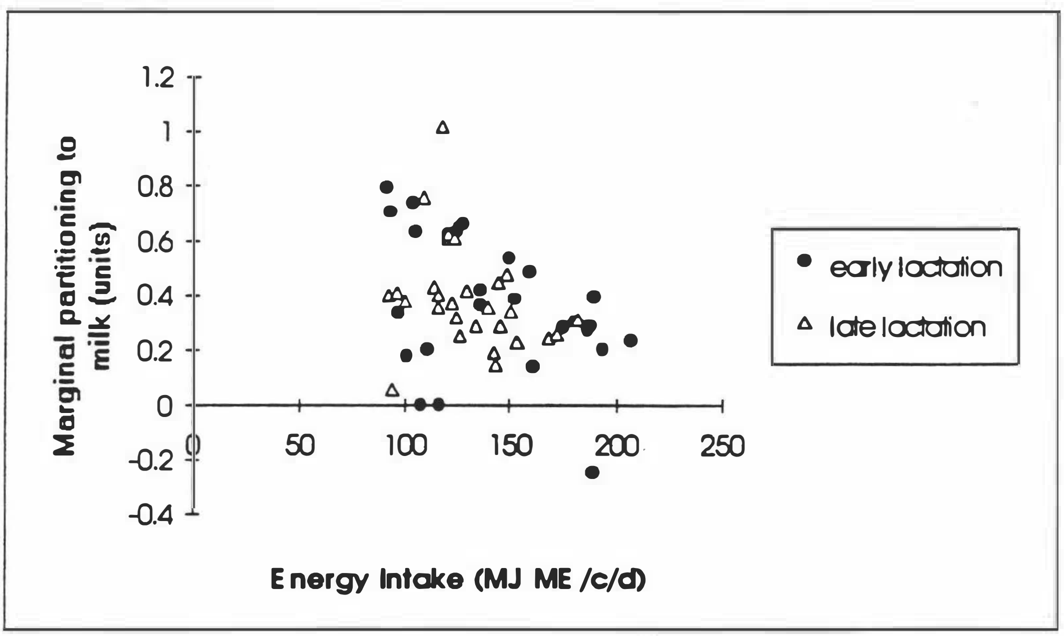


Figure 3.2 *:The effect of energy intake on marginal nutrient partitioning in early and late lactation.* Source: Adapted from Tables 3.7 and 3.8.

3.1.4. Effect of type of concentrate.

Trigg *et al.*(1983) reported that when cows were fed wheat or commercial pellets (4 kg/cow/day) milk responses were similar, however the response was slightly different when they were given *ad libitum* access to concentrates. The cows fed pellets ate more than those fed wheat (8.7 vs 5.6 kg/d) but produced similar amounts of milksolids

(1.17 vs 1.21 kg/c/d) because of a reduction in milkfat concentration associated with the high concentrate intake. The cows fed pellets gained more weight (Table 3.9), but this was probably because total intake was higher; they had reached maximum yield and partitioned the remaining into liveweight gain (Figure 3.2). The main differences between the wheat and pellets were lower kjeldahl nitrogen content in the wheat (1.67% vs 2.67%) and higher fibre content in the pellets (14.1% vs 6.9%). Kelloway and Porta (1993), in a review of several experiments, reported that there was no difference in response to concentrate type at low levels of feeding but suggested that responses at high levels of feeding would be influenced by fibre content. ***Concentrates containing a high level of fibre, such as oats (12% crude fibre) are likely to cause a smaller reduction in milkfat percentage when fed to lactating dairy cows.***

Meijs (1986) reported that cows grazing pasture and fed high fibre (100 g starch and sugars/kg DM) concentrates (5.4 kg OM/c/d) produced 0.5 l FCM/d more than those fed the same amount of high starch concentrates (350 g/kg DM starch and sugars). This could be explained, partly by the greater reduction in pasture intake associated with the high starch concentrates (see Section 3.2.2), and partly by the fact that the cows fed high starch concentrates gained more weight (0.17 kg/d more), indicating that there was a difference in nutrient partitioning between the different types of concentrate. However, the difference was small and the higher milk production of the high fibre consumers can be attributed mainly to a higher intake (Table 3.9). There is some evidence that, feeding high starch concentrates increases the ratio of propionic acid/acetic acid in the rumen, resulting in high blood insulin levels and more energy being used for liveweight gain (Meijs 1986 after Buekelen) (Section 1.2). ***Thus, feeding high fibre concentrates resulted in a greater immediate milksolids response than feeding high starch concentrates of the same energy density; the difference could be explained by higher intakes associated with high fibre concentrates.***

Table 3.9: *Effect of type of concentrate on intake and nutrient partitioning in lactating dairy cows.*

	Wheat	Pellets	Wheat	Pellets	High starch	High fibre
Pasture intake(kg DM/c/d)	7	7	7	7	12.5	14.2
Concentrate Intake (kg DM/cow/d)	3.6	3.6	5.6	8.7	6.1	6.0
Milksolids yield (kg/c/d)	1.12	1.13	1.17	1.21	1.88	1.99
Liveweight change (kg/c/d)	0.2	0.33	1	1.13	0.28	0.11
Estimated energy intake (MJ ME/c/d)[1]	120	120	144	181	204	221
Marginal Increase in energy intake (MJ ME/c/d)	-	-	24	61	N/A	N/A
Energy req'd for milk production (MJ ME/c/d)[2]	74	75	77	80	124	131
Marginal increase in energy required for milk (MJ ME/c/d)	-	-	3	5	N/A	N/A
Energy req'd for liveweight gain (MJ ME/c/d)[3]	6	11	32	36	9	4
Marginal partitioning (% extra energy intake used for milk production)	-	-	12.5%	8.2%	N/A	N/A
Gross partitioning (% total energy intake used for milk production)	62%	63%	53%	44%	61%	59%

[1] Assumes pasture contains 11 MJ ME/kg DM (spring 74% dig.) and concentrate contains 12 MJ ME/kg DM.

[2] Assumes 68 MJ ME/kg milksolids.

[3] Assumes 32 MJ ME/kg LW gain.

Sources:Trigg *et al.*(1983), Meijs (1986).

3.1.5. Level of concentrate feeding

At higher energy intakes proportionately less energy is partitioned into milk production (Figure 3.2). Thus, for a given pasture intake, increasing concentrate intake will indirectly affect marginal partitioning anyway. To distinguish between the effects of concentrate feeding level and energy intake required taking a predetermined level of energy intake and plotting the partitioning for different levels of concentrate feeding (and by default different levels of pasture feeding). ***Concentrate intake had no effect on marginal partitioning, for the range of energy intakes of 160-200 MJ ME/c/d, however at lower total energy intakes there appeared to be an effect*** (Figures 3.3 and 3.4). This *could* be attributed to concentrate making up a greater proportion of total intake and therefore having a larger effect on rumen function. However, in the experiments reported, this was not the case. Broster *et al.* (1985) reported that milkfat content started to decline quickly when the proportion of concentrate in the diet exceeded 0.60. However, this would depend on the fibre content of the forage, for example; Stockdale *et al.* (1987), found milkfat concentration decreased for cows fed pasture, when pellets made up 40 - 50% of the diet. In the experiments reported in Tables 3.7 and 3.8, it was difficult to tell at what level of concentrate feeding milkfat percentage fell because there are few cases with very high concentrate proportions in the diet (Figure 3.5). The critical proportion of concentrate in the diet will vary depending on the fibre content of the concentrate and that of the base feed. For example, research in the U.K. did not indicate a drop in milkfat percentage until concentrate made up more than 60% of the diet when cattle were fed silage as a base ration (Broster *et al.* 1978).

In a stall feeding experiment, Stockdale *et al.* (1987) reported a change in partitioning as concentrate intake was increased above 6 kg/c/d, due to a large reduction in milkfat concentration. This was considered to be related to a reduction in fibre intake to about 250 g/kg DM NDF causing a change in the VFA ratio in the rumen. Thus, ***fibre intake seems to have an important role in maintaining milkfat concentration and therefore, the amount of energy partitioned into milk production.***

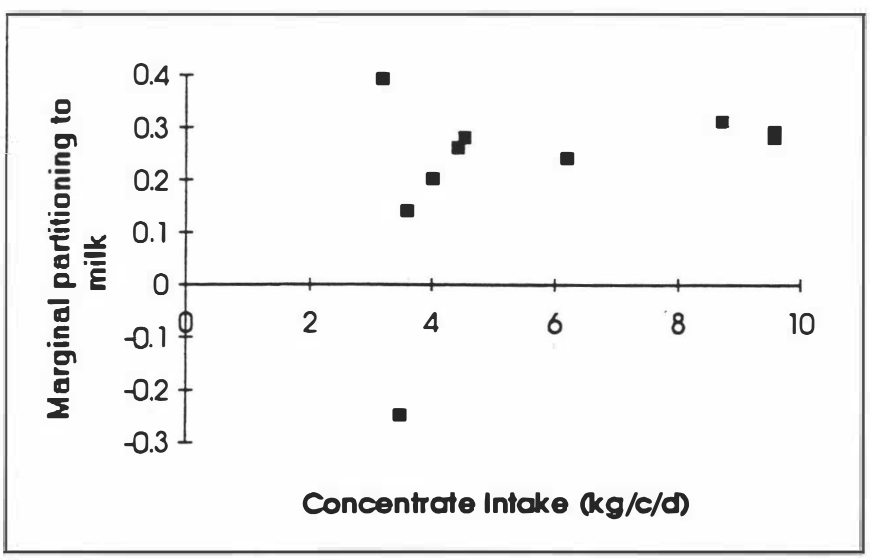


Figure 3.3 : *Marginal nutrient partitioning to milk production for energy intakes of between 160 and 200 MJ ME/c/d.*
Source : Tables 3.7, 3.8.

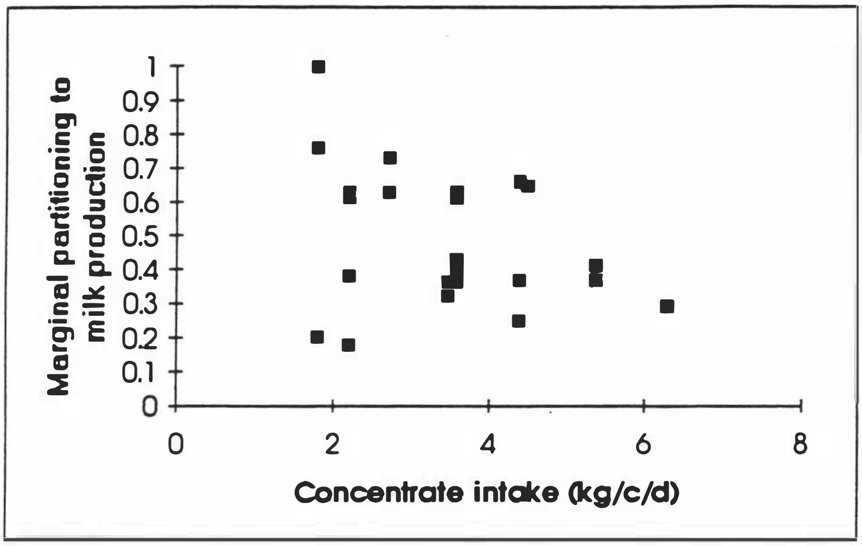


Figure 3.4. : *Marginal nutrient partitioning to milk production for energy intakes of between 100 and 140 MJ ME/c/d.*
Source: Tables 3.7, 3.8.

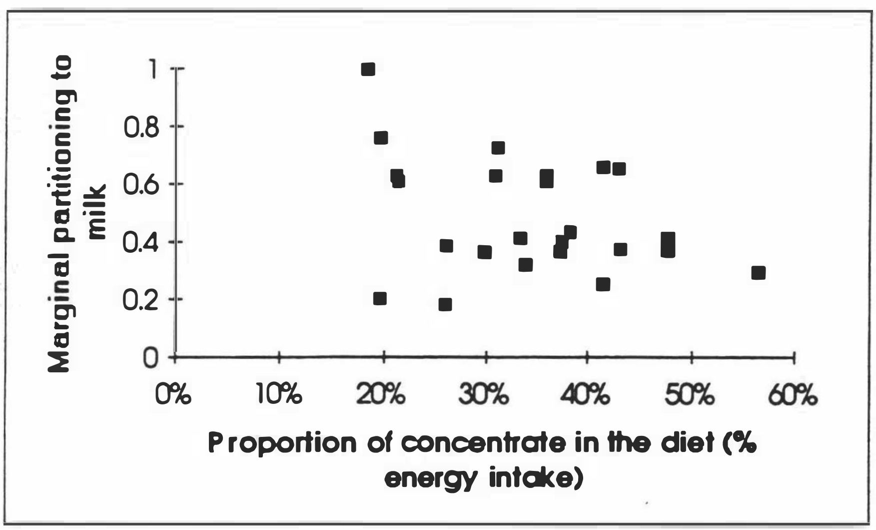


Figure 3.5: *The relationship between proportion of diet as concentrate and marginal nutrient partitioning for energy intakes between 100 and 140 MJ ME/c/d.*
Source: Tables 3.7, 3.8.

3.2. Factors affecting substitution rate.

Substitution seems to occur via a reductioin in grazing time (Sarker and Holmes 1974, Rook *et al.* 1994b). Sarker and Holmes (1974) reported that grazing time decreased from 495 min/day when two kg concentrates were fed, to 359 min when 8 kg concentrates were fed. Rook *et al.*(1994) reported similar figures.

Many authors have reported that different factors affect substitution rate (e.g. Stakelum 1986, Thomas 1987, Opatpatanakit *et al.* 1993). Thomas (1987) in a review of the factors influencing substitution rate, pointed out that factors affecting substitution rate range from the characteristics of the forage and the concentrate to animal factors such as the drive to eat of fat vs thin cows. Often it is difficult to distinguish the effects of the different factors, because in any particular experiment several factors are compounding. It is with this in mind that the factors affecting substitution rate are discussed.

3.2.1 Effect of pasture allowance, pasture intake and level of concentrate feeding on substitution rate.

Most experiments to determine the causes of substitution when concentrates are fed indicate that pasture allowance and/or pasture intake have a large effect (Table 3.10). For example, Grainger and Mathews (1989) derived the following regression equation from five experiments depicting this relationship:

$$SR = -0.445 + 0.315\ PI,$$

where PI is the pasture intake/100 kg liveweight before supplements were introduced and SR is substitution rate.

The data fromthis equation applied to pre grazing pasture yields ranging from 2300 to 5100 kg DM/ha and stage of lactation ranging from 1 to 8 months. A very similar equation was derived from the combined data in Table 3.10 (see also Figure 3.7):

$$SR = -0.480 + 0.313PI \qquad R^2 = 44\% \qquad P < 0.02$$

where PI is the pasture intake/100 kg liveweight before supplements were introduced and SR is substitution rate.
(note: data from experiments with low digestibility pasture or high fibre concentrate was excluded from the regression because these affect substitution rate)

Table 3.10: *Effect of pasture allowance and pasture intake on substitution rate.*

Reference	Pasture allowance (kg DM/c/d)	Conc. intake (kg DM/c/d)	Base pasture intake (kg DM/c/d)	Cow liveweight (kg)	Base pasture intake/ 100 kg LW (kg)	Substitution rate (kg DM/kg concentrate)
Robinson and Rogers	14	3.6	10.8	N/A	N/A	0
(1983) high fibre (oats)	40	3.5	14.5			0.26
Grainger and Mathews	8	3.2	6.0	454	1.3	0
(1989)	17		11.8		2.6	0.25
	33		15.9		3.5	0.69
Stockdale and Trigg	16	1.8	8.0	427	1.9	0
(1985) low digestibility		3.6				0
pasture (58%)		6.3				0.23
	26	1.8	10.6		2.5	0.94
		3.5				0.43
		6.2				0.30
Meijs and Hoekstra	18 above 4	0.9	12.3	579	2.1	N/A
(1984)	cm ht	2.7				0.00
		4.3				+0.09
	27	0.9	16.2		2.8	N/A
		2.7				0.33
		4.3				0.62
	18	0.9	12.9		2.22	N/A
		3.6				+0.07
		6.2				0.19
	27	0.9	16.8		2.9	N/A
		3.6				0.70
		6.2				0.58
Opatpatanakit *et al.*	48	3.6	15.5	547	2.8	0.64
(1991)	47	6.6				0.63
Taparia and Davey	*Ad libitum*	2.3	9.1	227	4.0	0.63
(1970)		3.4				0.66
Rook *et al.* (1994)	4 cm ht	3.4	13.9	498	2.8	0.5
	6 cm ht	3.4	15.3	542	2.8	0.44
	8 cm ht	3.4	16.8	531	3.1	0.09
	6 cm ht	3.4	13.5	552	2.4	0.00
	8 cm ht	3.4	14.1	540	2.6	0.06
Stakelum (1986c)	16	3.9	11.6	532	2.2	0.26
	16	3.9	12.5		2.3	0.38
	24	3.9	13.6		2.6	0.64
	24	3.9	16.6		3.1	0.66
Stakelum (1986b)	15	3.9	11.7	493	2.4	0.36
	15	4.0	12.7		2.6	0.40
	22	4.1	15.1		3.1	0.30
	23	4.1	15.7		3.2	0.57

The effect of increasing concentrate intake *per se* on substitution rate is unclear. Some researchers have reported higher substitution rates with increased levels of concentrate feeding (Laird *et al.* 1981, Meijs and Hoekstra 1984, Phipps *et al.* 1988, Faverdin *et* *al.* 1991, Figure 3.6). Sarker and Holmes (1974) showed a *decrease* in substitution rate as concentrate feeding level increased and others using a wide range of concentrate feeding levels (3.3 to 9.6 kg/c/d) could find no curvilinearity in response (Thomas 1987 after Kristensen 1983, Gordon 1984). The issue is complicated by the fact that increased concentrate intake will result in an increase in total feed intake.

Stockdale and Trigg *et.al.* (1985) reported a lack of substitution at the low pasture allowance (16 kg DM/c/d) which is consistent with the findings of others. Interestingly, at the allowance of 26 kg DM/c/d, substitution was high at low concentrate intake and decreased at high levels of concentrate intake (Table 3.10). Rook *et al.* (1994) reported similar findings; greater substitution by cows grazing on shorter pasture, which is the opposite to what is normally expected. It appeared that cows on short pasture were reluctant to graze after a threshold level of intake had been achieved (grazing time was reduced for the supplemented group on short (4 cm) pasture, Rook *et al.* 1994b) The reason for this is unclear, but it is in contrast to most other reports, where increased herbage availability lead to greater substitution (Figure 3.7).

There is a large variation in the substitution rate for a given pasture allowance or intake, for example, at a pasture allowance of 16 kg DM/c/d the substitution rate varies from 0 to 0.3 units (Figure 3.8). This variation exists because there are factors other than the pasture allowance which influence substitution rate, and pasture allowance is not a perfect predictor of intake. It would therefore not be appropriate to calculate substitution rates from pasture allowance or intake data alone.

Over a range of grazing experiments, level of concentrate feeding does not appear to affect substitution rate in any consistent way (Figure 3.8). Thomas (1987) in a review of 27 experiments, concluded that there was ***little evidence to support the view that increased levels of concentrate feeding resulted in higher substitution rates. The same conclusion must be drawn here.***

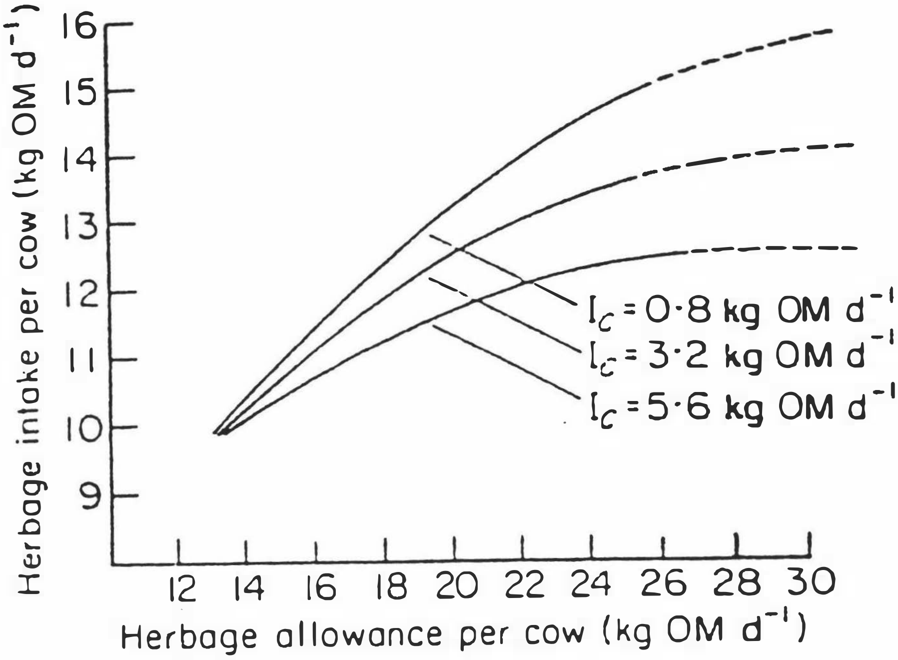


Figure 3.6: *The effect of herbage allowance on herbage intake at three different levels of concentrate intake (I_c).*
Source: Meijs and Hoekstra (1984).

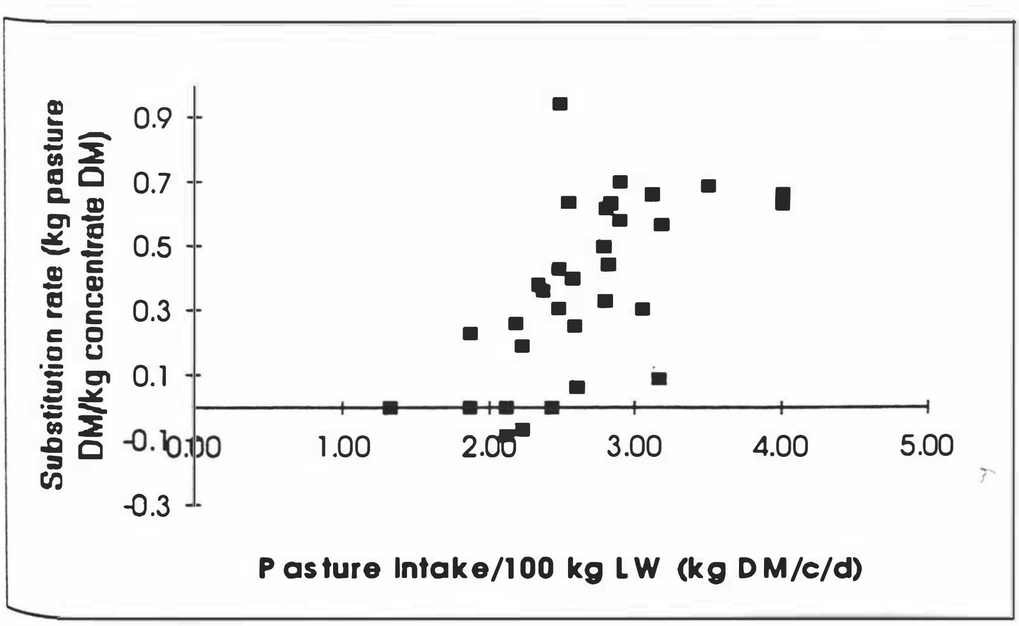


Figure 3.7: *The effect of pasture intake on substitution rate.*
Source: Data in Table 3.10.

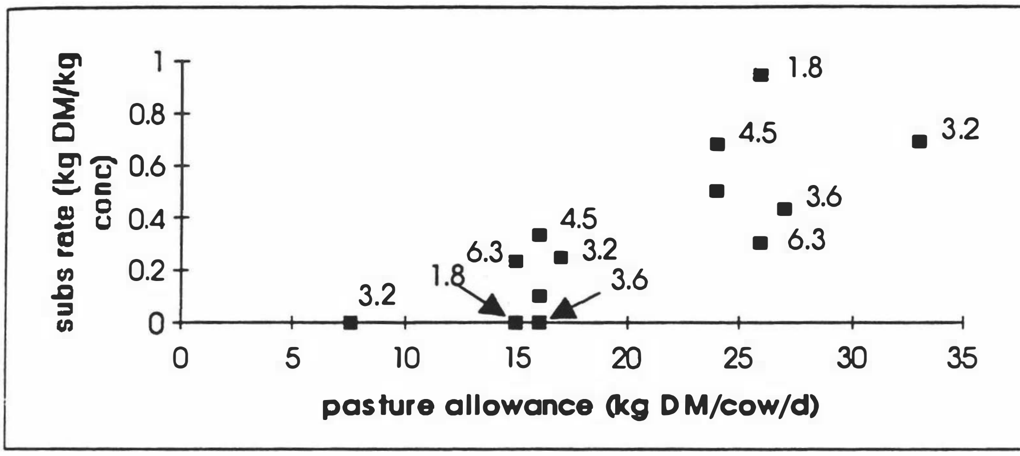


Figure 3.8: *The effect of pasture allowance on substitution rate, adapted from several experiments, showing the prevailing level of concentrate feeding.*
Source: Data in Table 3.10.

3.2.2. Type of concentrate.

Several authors report a reduction in substitution when high fibre concentrates are fed (Trigg *et al.* (1983), Meijs 1986, Thomas 1987; Table 3.10) Thomas (1987) in a review of several experiments, reported that silage intakes were higher for cows supplemented with fibre rather than starch based concentrates (indicating lower substitution) in two experiments, but in others the effect was inconsistent. Faverdin *et al.* (1991) showed a lower substitution rate for cows fed high fibre concentrates compared to those fed high starch concentrates. Forage intake (11.1 to 13.2 kg DM/c/d) was higher for cows eating high fibre concentrate (8.1 and 8.8 kg DM/d of low and high fibre concentrate respectively) and substitution rates were 0.76 and 0.60 respectively. However, the higher intakes did not result in increased milk yield. In a similar experiment, Meijs (1986) reported that cows fed a high fibre concentrate produced more milksolids than others fed a high starch concentrate (1.99 vs 1.88 kg MS/c/d). There was also higher substitution by the cows fed the high starch concentrate (0.45 vs 0.21 kg DM/kg conc) resulting in higher intakes for cows fed the high fibre concentrate (Table 3.10).

A reduction in intake can be caused by high levels of easily fermentable substances (sugars and starch) reducing rumen pH, increasing VFA concentration and lowering the rate of breakdown of fibrous particles in the rumen. Entry of more feed is restricted because of greater rumen fill. This has occurred in stall feeding experiments for cows fed more than 50% of their diet as concentrate (Meijs 1986 after Visser and Groot 1981). It may be more of a problem for cows grazing pasture because the sugar content of fresh pasture is higher than that of silage. This is supported by the results of a trial using oats, a high fibre grain, as a supplement. Substitution rates of 0 and 0.26 for pasture allowances of 14 and 42 kg DM/c/d, respectively were reported (Robinson and Rogers 1983). These are low compared to other trials (Table 3.10).

There is some evidence that grains which are easily digested are associated with higher substitution rates because of a more rapid lowering of the rumen pH (Hulme *et al.* 1986, Kellaway and Porta 1993). This implies that processed pellets will be associated with high substitution rates because they are easily digested however, the evidence is not conclusive. Hulme *et al.* (1986) incorporated a relative substitution factor into the CAMDAIRY model to reflect thedifferences in degradability of different concentrates. ***In summary, it appears that feeding high fibre concentrates results in lower substitution rates because of the ability of the rumen to continue functioning normally at higher concentrate intakes and therefore allow a more rapid through put of feed.***

3.2.3. Stage of lactation.

There are few reports showing stage of lactation affecting substitution rate. However, in a study reported by Phipps *et al.* (1987), substitution rate declined as lactation progressed, possibly due to decreased energy intake, according to the following equations:

Good silage, $SR = 0.972 - 0.051w - 0.0016w^2$

Average silage: $SR = 0.516 - 0.015w$

w= week of lactation and SR = substitution rate.

These equations indicate that substitution rate was initially much higher for the good quality silage (0.97 vs 0.52) but declined more rapidly as lactation progressed, However, the equation for good quality silage predicted that positive substitution occurred in late lactation (because of the shape of the curve), which was not reported in the paper. The general applicability of these equations is unclear and the results are not supported by other authors.

Generally, there is little difference between substitution rate in early and late lactation or with non-lactating cows. For example, Sarker and Holmes (1974) reported a substitution rate of 0.54 kg pasture OM/kg concentrate OM consumed for *dry cows* grazing pasture and consuming between 2 and 8 kg concentrates/day. Pasture intake varied between 9.9 to 7.4 kg OM/d for the high and low concentrate groups respectively. Similarly, Wills and Holmes (1988) found that for herbage allowances of 9 and 14 kg DM/c/d substitution rates for cows fed hay were 0.28 and 0.4 kg pasture DM/kg hay DM respectively. Thomas (1987) stated:

> 'It would appear that information on the animal factors which affect substitution rate is limited... Separation of feed and animal effects in these trials is clearly difficult, but nevertheless this could change the interpretation of the effects.'

Overall, ***from the evidence available, it can be concluded that the stage of lactation has little affect on substitution rate.***

3.2.4. Digestibility of pasture and season of the year.

Bines (1985), in a review of several experiments, showed that substitution rate was affected by the quality of the forage. When cows were fed forage *ad libitum* substitution rate when concentrate was fed ranged from 0.17 for poor hay to 1.00 for quality pasture (Table 3.11). However, since they were fed *ad libitum*, there may also be an associated effect of increased intake of high quality feeds. Leaver (1968) reported that substitution depends on voluntary pasture intake, which in turn depends on the digestibility of the pasture, Thus, the effect of digestibility may simply be a restriction of intake. It follows that for cows fed generous amounts of pasture, ***substitution should be highest in the spring and lowest in the summer/autumn if pasture quality is low because of seasonal conditions.***

Table 3.11: *Reduction in intake of forage per unit of additional concentrate (kg/kg DM) when forage fed ad libitum.*

Forage	Substitution rate
Poor hay	0.17
Poor grass silage	0.32
Lucerne hay	0.44
Medium grass hay	0.63
Maize silage	0.63
Good grass silage	0.68
Lucerne Wafers	0.78
Spring grass	1.00

Source: Bines (1985).

There is some evidence that digestibility of pasture *per se* affects substitution rate even when intake is restricted. Stockdale and Trigg (1985) found relatively low substitution rates for cows grazing low quality pasture (58% dig.) (Table 3.10). Conversely, Grainger and Matthews (1989) and Rogers (1985) showed higher substitution rates for cows grazing restricted high quality pasture (>70% dig.). Others have compared high and low quality base feeds and found different substitution rates. Phipps *et al.* (1987) reported a substitution rate of 0.63 for cows fed good quality silage (10.8 MJ ME/kg DM) and 0.27 for those fed average quality silage (9.4 MJ ME/kg DM), respectively. Similarly, Moisey and Leaver (1984 cited by Thomas 1987) reported substitution rates of 0.75 vs 0.63 and 0.54 vs 0.45 for high and low digestibility silages, respectively (i.e. about 20% lower for low digestibility). However, these results pertain to silage fed *ad libitum*, so undoubtedly there is an intake affect.

Intuitively, the reduction in rumen pH associated with starch based concentrates (Section 3.2.2), is likely to be less severe when cows are eating poor quality pasture because they must ruminate more. Rumination increases the amount of saliva entering the rumen. Saliva, being alkaline, acts as a buffer reducing the fall in pH. Thus, when cows are grazing pastures of low digestibility the substitution rate should be lower than when grazing pastures of high digestibility (Meissner *et al.* 1991 after Vadiveloo and Holmes 1979). Thus, ***many of the reports relating pasture digestibility and substitution rate are confused by intake. However, there is some evidence to suggest a reduction in substitution rate at lower pasture digestibilities.***

3.3. Summary of main points.

The major factors affecting substitution rate are pasture intake, digestibility of the pasture and the type of concentrate fed . Stage of lactation and level of concentrate feeding as such do not appear to affect the substitution rate in any consistent way.

Marginal nutrient partitioning is affected by level of energy intake, cow condition, and type of concentrate fed. The level of concentrate feeding appears to affect nutrient partitioning when concentrates make up a large proportion (> 50% on high quality pasture) of the diet. Cow genetic merit may have some influence on marginal partitioning but experimental results to date have not been significant. Stage of lactation affects gross nutrient partitioning but does not appear to affect marginal nutrient partitioning.

Substitution rate and marginal nutrient partitioning are the two key factors affecting responses to concentrate feeding. Thus, the relationships established in this Chapter form the basis of the model developed in Chapter five.

CHAPTER FOUR

DECISION MAKING AND DECISION SUPPORT TOOLS.

The purpose of this Chapter is to identify the steps involved in decision making and outline alternative forms of decision support. An appropriate decision support tool is chosen taking into account the nature of the information available with which to make the decision and the need for a simple, easy to follow format.

Decision support system (DSS) is a broad term used to describe anything that helps people make better decisions. Stuth *et al.* (1994) defined a DSS as consisting of '*any and all data, information, expertise and activities that contribute to option selection.*' Similarly, Sprague and Carlson (1982) consider a DSS to be a '*computer based system that helps decision makers confront ill-structured problems through direct interaction analysis*'. Gillard and Moneypenny(1988) define DSS as ' *attempts to model the inputs, outputs and parameters which are likely to affect which alternative is implemented*':

Examples of DSS are: Computer simulation models such as UDDER (dairy farm model, Larcombe 1990), expert systems such as Pasturepak (a pasture renovation guide DPIF 1993), Linear programming models such as CAMDAIRY (a dairy feeding optimisation model, Hulme *et al.* 1986) graphical information systems, discussion groups and structured thought processes. Most often though, when referring to DSS, some type of computer model is implied.

4.1 Decision making.

Decisions are being made all the time by different people for different reeasons. Stuth *et al.* (1994) provided a useful definition of decision making : 'A *complex process which requires humans to perceive and evaluate a problem relative to their personal experiences, level of internalised formal knowledge, cultural values, social constraints, current needs and stage of life...'*

McCall and Kaplan (1990) argued that normally decisions are not made in a logical step by step manner, but alternatives are weighed up against something that is known. Similarly, Stoner and Freeman (1992 after Herbert Simon); stated that decision makers are not machines and will use rules of thumb (heuristics) and satisfice, or accept the first satisfactory alternative they find rather than look for the optimal solution each time. Similarly, Gladwin (1976) suggested that people tend to use procedures to simplify decision making. Nevertheless it is useful to look at the possible steps in the decision making process (Figure 4.1). This view of the decision process is supported by many authors (e.g. Huber 1980, Sonka and Patrick 1981, Cooke and Slacke 1991, Stoner and Freeman 1992).

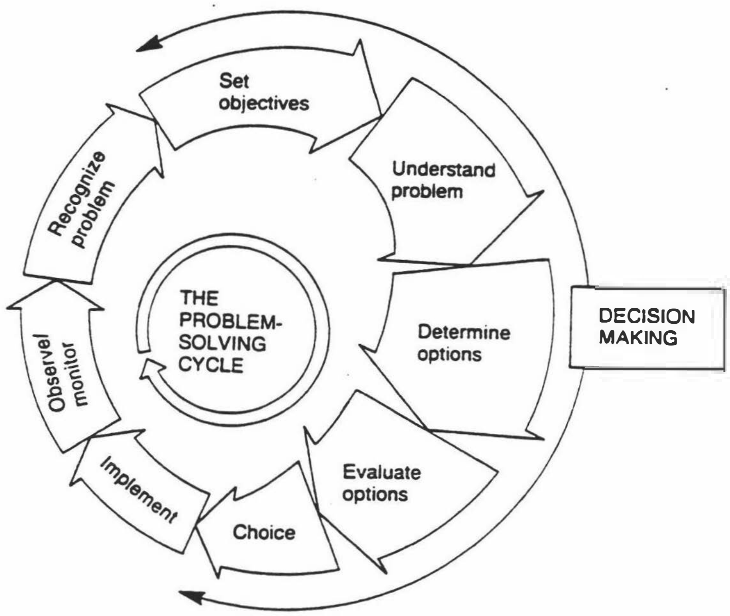


Figure 4.1: *The problem solving cycle showing decision making as part of the cycle.* Source: Cooke and Slack (1991).

Making a decision in reality will never be as smooth or regimented as outlined in Figure 4.1; it is more likely to be stop/start with frequent backtracking. However, it is useful to look at Figure 4.1 in the context of concentrate feeding.

The farmer's apparent 'problem' could be that the cows are not producing as much milk as desired. Alternatively the farm may be generating insufficient income. Are these the problems or is the problem really that there is not enough feed being grown or there are too many cows? ***Working out what the problem really is, can be more difficult than making a decision once the problem is known.***

A decision support tool can compliment several parts of the decision process. It can help with determining or evaluating options and enable a more effective decision to be made because of better information or the ability to complete complex calculations quickly (Turban 1988). It can also help with decision implementation. A U.S. survey reveiled that managers primarily used computers for explaining, justifying and communicating decisions. Thus, decisions were supported by improving communication between decision makers (Turban 1988 after Mittman and Moore). Understanding the real problem and making the decision is still up to the manager. Thus, decision support tools can be used to provide information or make complex calculations quickly so that better decisions can be made.

4.1.1. Elements of decisions.

Decisions have several key components. Stoner and Freeman (1992) defined a rational decision making process as one where the situation is investigated, alternatives are developed and evaluated, and the decision is implemented. Cooke and Slacke (1991) suggested that the key elements of a decision are: the decision maker, the decision options, the uncontrollable factors and the consequences. These are explained in turn.

The decision maker

Normally, on a dairy farm the decision maker is an individual or couple but it can be a commitee or other large group. This can greatly influence the nature of the decisions made as the decision maker's own biases influence which options are considered and the importance placed on them (Cooke and Slack 1991). Decisions are also influenced by outside parties such as family members and sales representatives (O'Keefe 1990). The decision makers are therefore the most important element of any decision and the decision made will vary depending on who is making it.

Decision options

Decision options represent the range of possible decisions that could be made. Without options there can be no decision. With concentrate feeding, there may only be two apparent options; to feed concentrates or to not feed concentrates. The options soon expand to how much concentrate to feed, when to feed it and so on. Thus, even with an apparently simple decision there can be many options.

The uncontrollable factors.

The uncontrollable factors are factors not able to be affected by those making the decisions but which influence the end result. For example, the price of milk and the amount of rainfall are two such factors. Some prediction regarding the uncontrollable factors needs to be made. A range of scenarios can be used to determine the impact of a change in any of the factors. There will be a certain level of risk associated with any decision which has uncontrollable factors. The risk associated with different options can be formally assessed by programmes such as target MOTAD (Hazell 1971).

The consequences

For any decision combined with the prevailing uncontrollable factors, there will be an outcome or consequence. The consequences can be measured in terms of what actually happened or alternatively be evaluated against some criteria. In the second case the decision makers' own opinions and expectations will influence the evaluation. For example, increased milk production following supplementary feeding is an actual outcome. One decision maker may be happy with that result while another may wish to know whether the milk response was profitable. Thus, whether the outcome of a decision is considered favourable or not depends largely on the criteria used to value the outcome.

4.1.2. Uncertainty in decision making.

A destinction between risk and uncertainty was originally made by Knight (1921) and maintained by other authors (e.g. Sonka and Patrick 1981, Stoner and Freeeman 1992). The distinction made is that there are objective probabilities associated with risk but not with uncertainty. For example, when a coin is tossed, the probability of it falling heads is 0.5. The risk of it falling tails is therefore also quantifiable. Uncertainty is defined as a decision situation with subjective probabilities. For example, a farm worker may quit but it is difficult to put a probability on this event occurring. However, as Sonka and Patrick (1981) point out, there is little distinction between risk and uncertainty in common usage. They will be taken to mean the same thing here as there seems little point in making the distinction in this case.

Stoner and Freeman (1992) suggested that uncertainty can come from two sources. The first is from elements over which managers have no control, such as the weather, and the second arises from a lack of information. As McCall and Kaplan (1990) say:

> 'One reason for putting off action on problems is that it is often difficult to know what one is getting into. Problematic situations are often only vaguely understood at the start, decision opportunities are often ambiguous and it is often hard to estimate the significance of a particular problem.'

Decision making under uncertainty largely involves placing probabilities on different outcomes (Anderson *et al.* 1977, Huber 1980, Stoner and Freeman 1992, Dake and Squire 1994). This can be a difficult task. However, with years of experience farmers have gathered much information which enables them to make judgements on the likelihood of certain events occurring. Methods such as the 'strength of conviction' and 'triangular distribution' enable probabilities to be derived from limited farmer data but they may not be very accurate (Sonka and Patrick 1981).

Risk associated with concentrate feeding

Some authors argued that feeding supplements reduced the risk of underfeeding and therefore increased farmer confidence (Parker and Edwards 1994). However, farmers may still face the risk of reduced profit if they feed supplements and waste pasture or under utilise other feed sources as a result. This risk can be reduced if the farmers are fully aware of the responses to feeding concentrates in different situations.

4.2. Characteristics of a good decision support tool.

In Chapter 1 it was established that a systems approach to modelling is useful. This section explores what is required to make a useful model incorporating a systems approach.

4.2.1. The process of modelling.

A model is a simplified representation of reality which may or may not be realistic depending on the purpose for which it is built and how well it has been put together. Managers frequently use mental models to make decisions (Turban 1988). A formal model is an extension of the mental model which incorporates more information or performs complex calculations which the mental model cannot process. Modelling is not an exact science. Mihram (1972) defines it as '*the art of mimicry*'. Wilson and Morren(1992) define modelling as:

> 'a mental construction process used to make sense out of phenomena that are made explicit to others through the use of one or more symbolic languages, narrative, pictures, mathematical equations, charts, diagrams, replicas, games.'

Three groups of models were defined by Cleland and King (1972) and Turban (1988). *Iconic* models are the most realistic. They are scale models such as a model aeroplane. *Analog* models behave like the real system but do not look like it. They are normally flat charts or diagrams. Examples are a thermometer, charts and maps with different colours for water and mountains. *Mathematical* models are more abstract but are able to represent complex relationships relatively simply. These are frequently used in decision support systems because a large amount of data can be analysed quickly and the model can be manipulated easily by changing input data. Analog models (charts) may also be used in decision support systems to show main points clearly.

Decision support systems (DSS)

Stafford Smith and Foran (1990) offered some good advice to modellers:

> 'A decision support system must supplement not supplant the decision makers own thinking or the decision is taken out of their hands'

Stuth and Stafford Smith (1993) suggested that a decision support system will only be useful if it provides more objective, consistent or timely information than that which is already available to the decision maker. They outlined the attributes of a good DSS as being *integrated* (i.e. information and relationships between pieces of information form the basis of good decision making), *flexible* (each decision is unique so decision methods must be flexible) and *people orientated* (decisions must be important to people's lives; there is no point trying to influence a decision that no-one makes!)

Developing models

Three essential prerequisites for developing a decision model were described by Cooke and Slack (1991) and, Dent and Blackie (1979):

i. An understanding of the *key variables* in the decision. There are two types of variables; those which can be affected by the decision maker, such as the level of grain cows are given, and those which cannot be influenced such as the price of milk. There are both input and output variables.

ii. Knowledge of the *cause-effect relationships* between the variables. This is simply the way the variables link together. This can be shown by the use of a simple *cause-effect diagram* which uses arrows to show the direction of influence. Generating reliable response curves from limited data is a major problem for modellers. If experiments have not been designed to show relationships required for the model then assumptions may be required which can decrease the accuracy of the model (Dent and Blackie 1979).

iii. *System dynamics/mathematical relationships*. These give a description of the form of the relationships between the variables. A more sophisticated diagram is useful here to show the relationships. The steps in model building are shown diagramatically (Figures 4.2a and 4.2b).

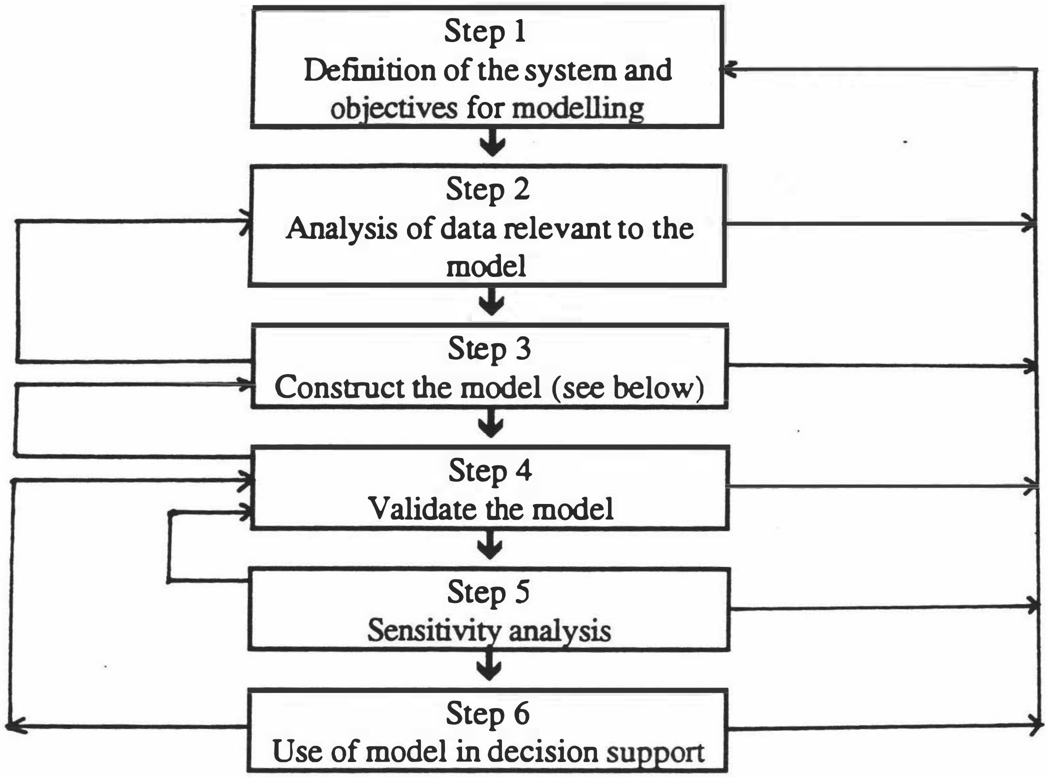


Figure 4.2a: *Steps in systems simulation.*
Source: Dent and Blackie (1979).

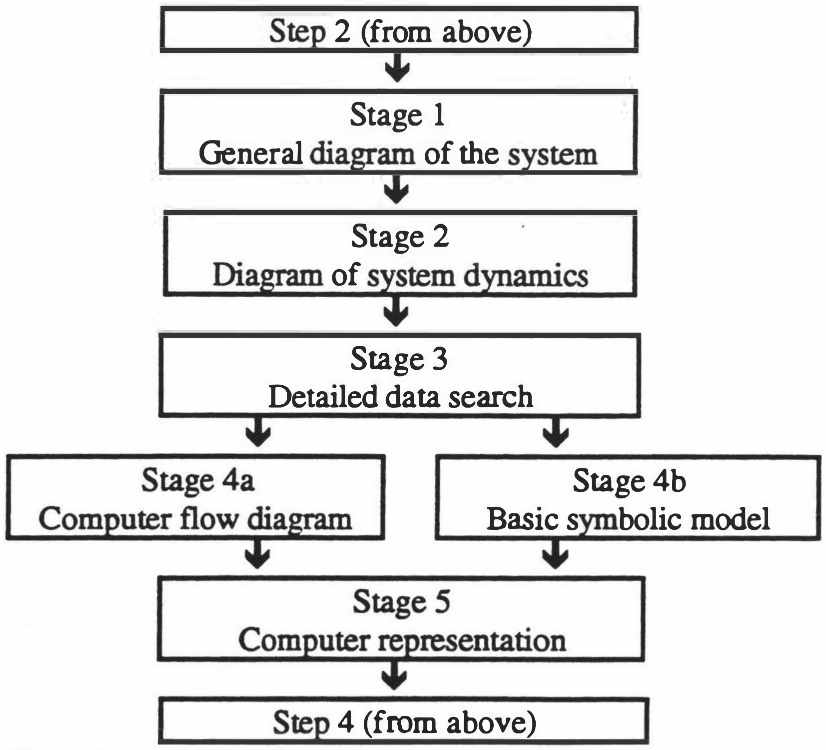


Figure 4.2b: *Steps in model building.*
Source: Dent and Blackie (1979).

Part of the model building process involves determining what data is required and what is available. Often data is not available in the form required as mentioned above. In the absence of a team of researchers able to generate new data by experimentation, the only options are to adapt the available information subjectively, redesign the model or abandon the project. If there is only a small amount of unknown data then making estimates can be less imprecise than it sounds, particularly if the model is not highly sensitive to changes in that variable (Dent and Blackie 1979). Generally though, if there is an absence of good data in the form required, there is little point in building an applied model for the purpose.

The importance of involving the users of the model in the planning phase has been stressed by several authors (e.g. Dent and Blackie 1979, Stafford Smith and Foran 1990, Cooke and Slack 1991, McCall *et al.* 1991). McCall *et al.* (1991), when developing 'Stockpol,' a decision support model for livestock farms, determined the prioritities of consultants from a series of workshops attended by 48 people, before the modelling process began. Stafford Smith and Foran (1990), when developing RANGEPACK, used a survey of 100 people and a workshop of 18 people to determine the aspects of management where most assistance was needed. Thus, defined user groups were heavily involved in the planning stages in both cases.

Validating the model

Models require validation prior to being used (Figure 4.2a).
The model can be tested by comparing predicted responses to actual responses (Murray-Prior and Wright 1994). However, this may be difficult to assess in the field as a control group of dairy cows is required. Validation would need to be achieved in conjunction with research stations. In the case of concentrate feeding in New Zealand, often the decisions are being made by, or in conjunction with advisors(e.g. Agriculture New Zealand, Interlact). Thus, advisors could be used to test the model to see how easy it is to use and how well the predictions correlate with what they believe. A problem with this approach is that their responses will be subjective and they may not know what response to expect. However, there is certainly a case for using them to ensure the model is in appropriate format.

4.2.2. Types of models.

It is useful to look at a range of different decision support tools to determine which is most appropriate for the proposed decision support tool. The two major types of models are optimisation and simulation models. Optimisation models find a discrete optimum quantity but are best suited to a structured problem. In this sense they are not accurate if the data varies from the structure set out. Simulation model give the outcome for a given set of inputs and are usually more flexible than optimisation models. The problem with simulation is that there is no guarantee that the selected quantity is the best one. Some simulation models include an optimisation function as well. An example of this is UDDER, the dairy management model (see Larcombe 1990).

Mental Simulation model.

Perhaps the most simple model of all is the mental simulation model. A person will often form a model in their mind of what will happen, given a situation, and act accordingly. For example, a farmer sees that it is raining and the cows are in a paddock. The farmer moves the cows off the paddock to avoid pugging damage. The mental model is that pugging damage will occur if the cows remain on the paddock, however it is not necessarily accurate. Any other model must be able to provide better information than the mental model to facilitate better decision making (Stuth and Stafford Smith 1993).

Linear programming

Linear programming (LP) aims to optimise a linear function subject to a number of constraints (Harsh *et al.* 1981). It gives a discrete answer quickly. For these reasons it is favoured by some researchers (e.g. McFarlane and Dillon 1956, Black and Hlubick 1980, Bath and Strasser 1990,Yuretich 1992). The strength of LP lies with analysing a large number of limiting factors which could be put to a large number of potential uses. The full range of alternatives can be considered using LP.

The value of LP as a research tool is undisputed as it enables the study of changes to model farms to be carried out quickly and effectively (Malcolm 1990). However, there has been much criticism of LP over the years because it is only ever going to provide a partial description of the individual farming system (Malcolm 1990 after Cocks 1963). The reality of decreased diversity on farms and greater uncertainty of prices has meant that LP is very seldom used on farms as a planning tool. However, it has found a niche for determining least cost rations for intensive farming systems and may be useful for determining 'maximum profit' rations (Lara and Romero 1994).

Linear programming is also used for risk analysis. Target MOTAD (minimisation of total absolute deviations) is an LP model designed to aid decision making under uncertainty. It uses historical information to determine the likelihood of being able to meet target incomes given different strategies (Hazell 1971, Sonka and Patrick 1981, Dake and Squire 1994). For example, if an income target is $50/stock unit/yr, the target MOTAD technique could be used to show the probability of income being less than $50 for different enterprise mixes. It might be less than $50, 20% of the time for sheep and cattle but only 10% of the time if some bull beef were run as well. One limitation is that it relies on past information which may not be applicable to the current situation. However, variables can be modified to allow for this.

Simulation models

Simulation models are attempts to duplicate a real system. Dent and Anderson (1971) describe simulation as the process of setting up a model and running experiments with it. Simulation models describe what will happen rather than optimising. They are run, not solved (Dent and Blackie 1979).

Examples of simulation models are UDDER (Larcombe 1990), Stockpol (McCall *et al.* 1991) and CAMDAIRY (Hulme *et al.* 1986). These simulation models are large integrated system models.

Simulation models have had very wide use, reflecting several advantages of these models viz: they allow the study of systems which do not exist or would be very costly to set up, long term effects can be looked at easily and the model builder must look at information in a critical way which can be very enlightening (Dent and Blackie 1979) Simulation assesses options chosen by the user. The simulation model merely carries out the calculations required. The decision maker is still responsible for the decision, but often the user does not see the calculations performed and therefore cannot assess the validity of the assumptions used (e.g. CAMDAIRY and UDDER).

There are several problems with simulation models. They can be costly and time consuming to build. Moreover, the data used in them can be inadequate for the purpose and simplifying assumptions may be required. If there is a paucity of research data the modellers own experience may be incorporated into the model. This may provide less than objective information. There can also be problems validating the model because of undeleted flaws and biases in the model (intentional or unintentional) (Dent and Blackie 1979).

Large simulation models have been criticised by Malcolm (1990) for being so highly detailed as to be inaccurate because of the nature of the biological system modelled. Similarly, Stafford Smith and Foran (1990) criticised complex optimisation models as 'reducing the opportunities for assessment by the user' and because they do not give perfect results, the limitations of the model may be hidden. For example, a model suggesting the optimum stocking rate is five cows/ha may not have accounted for pugging damage and consequent loss of pasture productivity. They suggest it may be better to allow successive approximations 'creep up on an answer' to give the user many opportunities to assess the reliability of the model.

Expert systems.

Expert systems are designed to emulate the decision making process of experienced people. For example, the program Pasturepak developed by the Tasmanian Department of Primary Industry and Fisheries (DPIF 1993) takes the knowledge of experienced agronomists and uses to to help others decide on what pasture species to sow in their situation. Similarly Gray *et al.* (1992) discussed using the knowledge of 'expert' farmers to aid the drying off decision on dairy farms and Crandall (1973) outlines the use of an extensive data base and expert system to aid decision making on dairy farms. The data base is continually updated as new information becomes available..

Hierarchical decision models

Heirarchical decision models require the use of simplifed rules to cope with an uncertain environment. They are based on the notion that decision makers 'do not make complex calculations of the overall utility of each alternative but use procedures that simplify their decision making calculations' (Gladwin 1976). Generally, they take the form of a flow diagram or decision tree with decision criteria at the branching points of the tree, but may take the form of a set of decision rules or be algebraic (Gladwin 1976).

Murray-Prior and Wright (1994) and Murray-Prior (1994) used a heirarchial decision model to predict the decisions made by wool producers regarding type of sheep to run and wool to produce. Gladwin (1976) used the model to view a plan to increase maize yields in Mexico (Plan Puebla), through the eyes of the proposed adoptors- the farmers. Heirarchical models were used to predict decisions about fertiliser and planting density. Gray *et al.* (1994) used a heirarchical model (in the form of a decision tree) to highlight alternatives and simple rules for each step in the drying off decision of dairy farmers.

Heirarchical decision models involve a two stage process. First, decision makers narrow down choices to a subset of two or three choices based on a set of criteria. For example, a person looking to purchase a used car may look at a paper with hundreds of cars. If a four door sedan costing less than $5000 is required, all other cars can be eliminated from the list very quickly. Secondly, a more detailed look at the options that fit the criteria is made and they are ordered but not eliminated (Murray-Prior 1994). For example, the engine capacity and the colour may be looked at and the cars ranked in order of preference.

The theory assumes that an alternative has a set of characteristics (Gladwin 1976 after Lancaster and Tversky). Characteristics that are similar between alternatives are eliminated from the list and not referred to again. The ordering of characteristics in a decision model is therefore very important to ensure that the correct decision is made. For example, Gray *et al.*(1994) ordered alternatives from least cost/most flexible (Cull low producing cows), to high cost/least flexible (Dry off the herd). If the order was reversed and the decision was taken to dry off the herd then the other potentially less costly options could not be considered.

The theory also requires that alternatives are discrete. Continuous variables such as price must therefore be treated as constraints (e.g. price of grain > $250/tonne) or ordered (e.g. price barley < price wheat).

To produce a heirarchical model, the specific characteristics of decision alternatives and constraints applicable to these need to be determined. The information used to make decisions also needs to be assessed. Establishing the criteria used by the decision makers has been described by Gladwin (1976) as the most difficult part of the modelling process and involves 'producing an hypothesis about the specification of the decision criteria and testing of the hypothesized criteria against the choice behaviour of the sample of decision makers'. An advantage of the heirarchical approach is that decision criteria are elicited from the decision makers so there is no danger of using criteria or terms that they do not use.

Murray-Prior and Wright (1994) suggest that a major weakness of the model is that ' it does not incorporate an adequate theoretical explanation of the underlying motivation for behaviour and for the aspects included in the decision trees'. However, they overcame this by using 'personal construct psychology', which is essentially the notion that farmers behave as scientists and develop hypotheses which they continually test against what they believe has occurred. people end up making similar decisions because different experiences have led them to the same hypothesis about the results of various actions (Murry-Prior 1994).

Decision trees outline alternative decisions in a diagramatic form and show the possible consequences of different choices. They are a useful way of representing decision options under uncertainty. Magee (1964) describes them as being helpful in identifying choices, risks, gains and goals. .To use a decision tree the probability of certain events occuring must be assessed. This is a potential source of error and is a major problem with decision trees. If a decision tree is used, a decision can be made based on the best expected outcome (Figure 4.3) or other criteria such as miniminum loss. In the example below (Figure 4.3), the expected outcomes of buying 1000, 1200 or 1600 cattle are $12200, $11700 and $10100 respectively. Thus, the preferred option using expected outcome criteria, would be to purchase 1000 cattle.

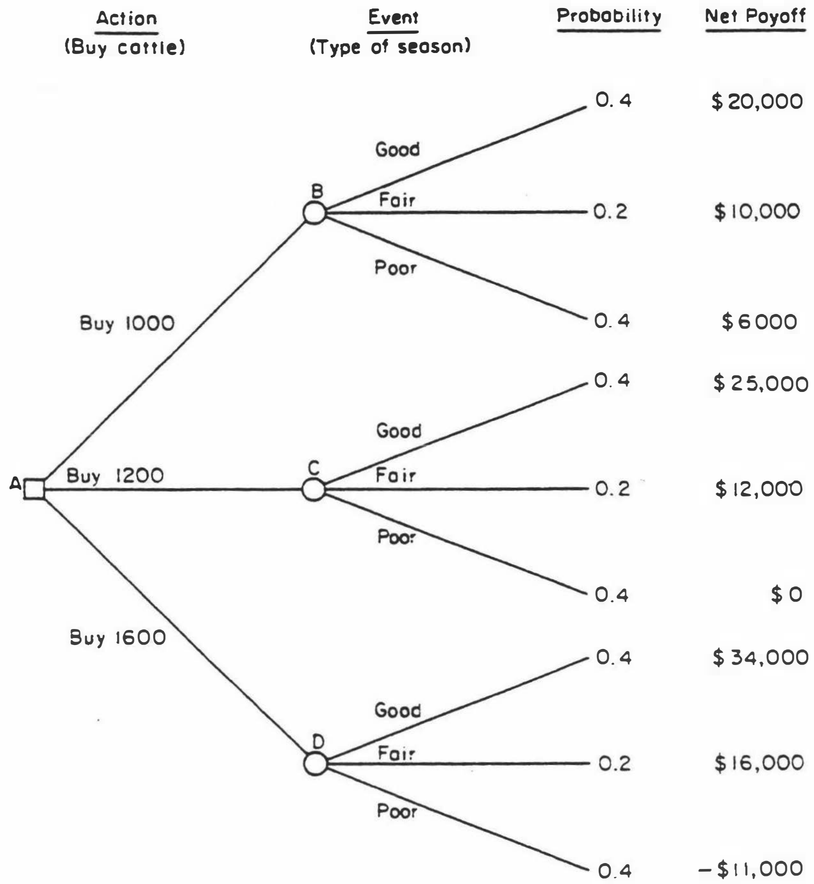


Figure 4.3 *Example of using expected outcome from a decision tree. The decision which gives the highest expected outcome is considered better.*
Source: Anderson *et al.* (1988).

Application of decision trees to concentrate feeding is difficult because the issue is too complicated for the format of a decision tree. Many possible branches are quickly established, which become confusing (Figure 4.4). The inclusion of yes/no questions soon makes the decision tree large and difficult to follow. A discrete answer is not possible because a range must be specified. It would be simpler for a farmer or advisor to use a model where discrete values were given which could be used in further calculations. For these reasons, ***a decision tree is considered inappropriate for aiding concentrate feeding decisions***

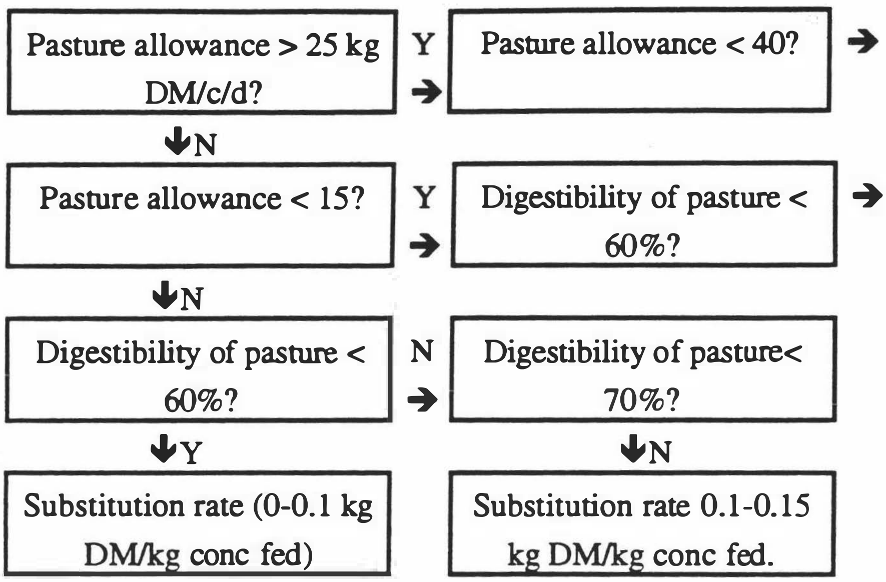


Figure 4.4: *An example of the application of a heirarchical decision model to predict substitution rate of dairy cows fed concentrate.*
Source: Hypothetical data.

4.3. The choice of decision support tool.

The decision concerning concentrate feeding involves assessing the farm situation and then deciding if it would be profitable to feed concentrates given the situation. A model which facilitates evaluation of a situation is preferable to one than gives an optimum solution, because the dynamic nature of the system makes it very difficult to predict the optimum amount of concentrate to feed (section 4.2.2). What is required is a model which will provide the information to enable farmers or their advisors to assess for themselves whether it will be profitable for them to feed concentrates. As their situation changes the decision support model can be applied to reassess the situation.

A computer model is best suited to situations where there are a large number of calculations to complete which otherwise would inhibit evaluation of options or where there is a large data base of information is available to draw on (Crandall 1973, Stuth and Stafford Smith 1993). A computer model is not desirable in this case as the model is to provide a quick and easy reference for farmers, and there is not a large number of calculations or a large data base to draw from.

A heirarchical model has already been eliminated as being inappropriate. The chosen model is a simple simulation type which uses a set of graphs and equations to predict the response to concentrates for a given situation. The advantages of this type of model is that discrete answers are possible which makes the process easier to follow. The user must follow the process through which potentially makes the model a greater educational tool than computer based models. One disadvantage is that some calculations are required which may deter some potential users. This model is set out in Chapter Five.

CHAPTER FIVE

A MANUAL DECISION SUPPORT TOOL FOR CONCENTRATE FEEDING

In the previous Chapter alternative approaches to modelling the information regarding responses to concentrate feeding were reviewed. A simulation model incorporating graphs and tables was considered the best choice, given the data available and requirements for the decision. Substitution rate and nutrient partitioning between milk production and liveweight gain are the two key factors influencing the response to concentrate use (Chapter Two). Once they are known, the immediate responses can be estimated. The long term milk response resulting from saved pasture, liveweight gain and fertility improvement can then be determined and from this the expected total return calculated.

This Chapter puts the factors discussed in Chapters Two and Three into a framework to aid decisions regarding concentrate feeding. Figure 5.1 shows the steps taken to determine the profitability of concentrate feeding.

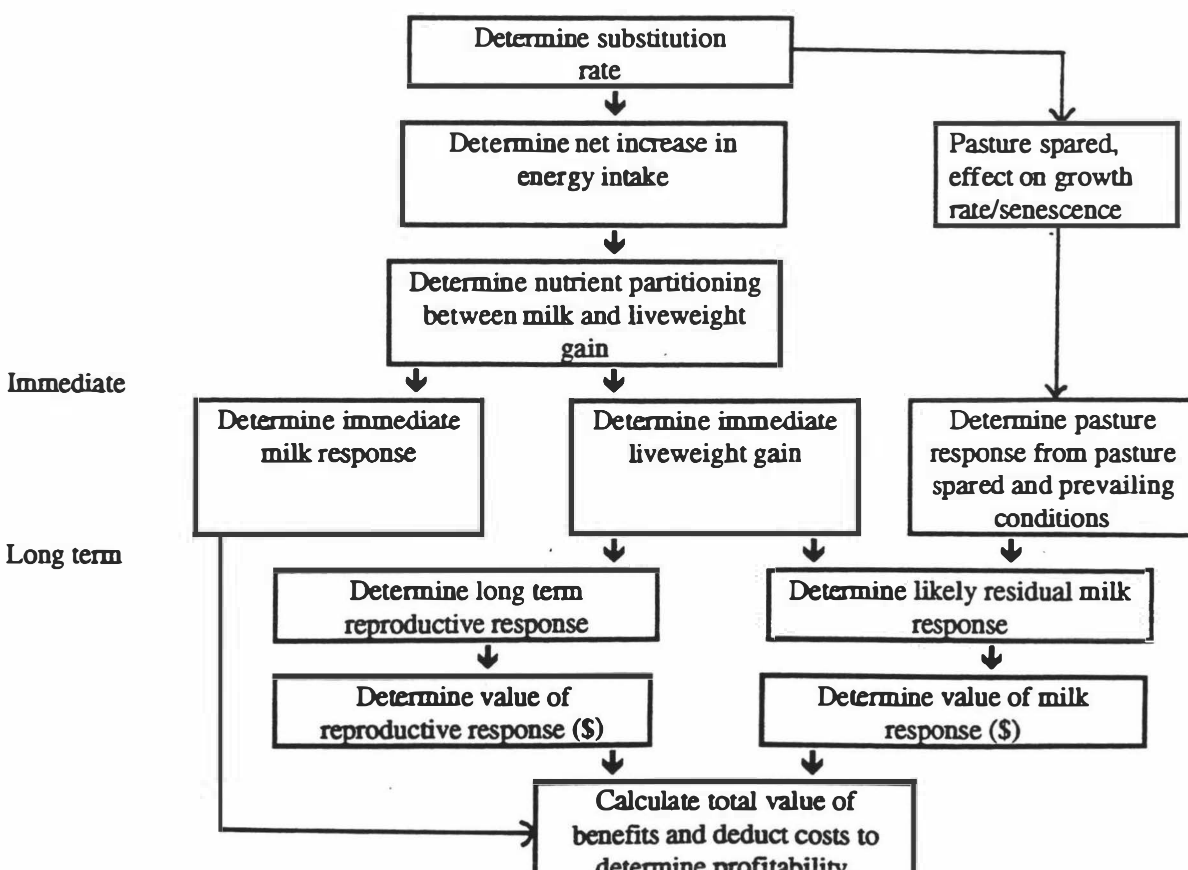


Figure 5.1: *Steps taken to determine profitability of feeding concentrates.*

5.1 Determination of substitution rate.

5.1.1. Calculation of pasture intake.

Pasture intake is required to determine expected substitution rate. An estimate of pasture consumption can be calculated from pre-and post-grazing residuals, the area grazed and the number of cows grazing.

For example,

-100 cows graze a 2 ha paddock with a pre-grazing pasture cover of 2200 kg DM/ha, for 24 hours.

- They graze it down to 1500 kg DM/ha: 700 kg DM is consumed/ha, a total of 1400 kg DM consumed (700 x 2).

-Intake/cow is 14 kg DM/c/d (1400/100).

If the pasture intake is changing because of management decisions or varying pasture conditions, the expected average intake for the coming month should be used. This could be determined from a feed budget or in the way outlined above. If concentrates were fed, a realistic minimum period of feeding would be one month after which the situation could be reassessed. The choice of one month is somewhat arbitrary, however it is a sufficiently long time frame for the situation on the farm to change but not so long that the initial calculations do not apply towards the end of the period.

5.1.2. Calculation of substitution rate.

The substitution rate is determined from pasture intake/ 100 kg LW to enable the calculations to be carried out for cows of different size. A regression equation was calculated from data in Table 3.11. The data used pertains only to experiments where high starch concentrates, such as barley and pellets, were used and the digestibility of the pasture was high (> 70% digestible). This gives the base substitution rate:

$$SR = 0.313\,PI - 0.48 \quad \text{for } 1.5 < PI < 4 \qquad \text{(Equation 5.1)}$$

where PI is pasture intake/ 100 kg LW.

This relationship is shown graphically in Figure 5.2 and presented as a ready reckoner in Table 5.1.

The initial estimate of substitution rate is adjusted for the type of concentrate and pasture digestibility. Where high fibre concentrates have been fed, the substitution rate decreases relative to the situation when high starch concentrates are fed. From the information available, it is expected that high fibre concentrates reduce the substitution rate by 20% (Section 3.2.2, Table 5.1).

Feeding low digestibility pasture also decreases substitution rate (Section 3.2.4). Thomas (1987) developed an equation for estimating substitution rate from the digestibilities of the concentrate and the forage based on the theory that substitution rate is related to gut fill, viz:

$$SR_d = (100 - \text{conc. dig.})/(100 - \text{pasture dig.}) \quad \text{(Equation 5.2)}$$

where SR_d is a multiplier to adjust Equation 5.1 for substitution rate.
This equation applied when cows were fed forage *ad libitum*. It implies that as the digestibility of the forage approaches that of the concentrate, the substitution rate approaches one. The equation is used to adjust the expected substitution rate for the digestibility of the pasture (Table 5.1). In calculating the difference, it was assumed from figures given in experiments used to determine the regression equation, that the base equation reflected a pasture digestibility of 70% and a concentrate digestibility of 85%. Given these values, the 'substitution rate' calculated from Equation 5.2 is 0.5 (0.15/0.30). If the pasture digestibility was 60%, the value would be 0.375, a difference of 0.125. Thus, the substitution rate is adjusted downward by 0.125 for the lower digestibility pasture and similarly for higher digestibility pasture.

The case where both high fibre concentrates and low digestibility pasture are fed has not been reported in the literature. However, it would be reasonable to assume that they would both affect the substitution rate simultaneously

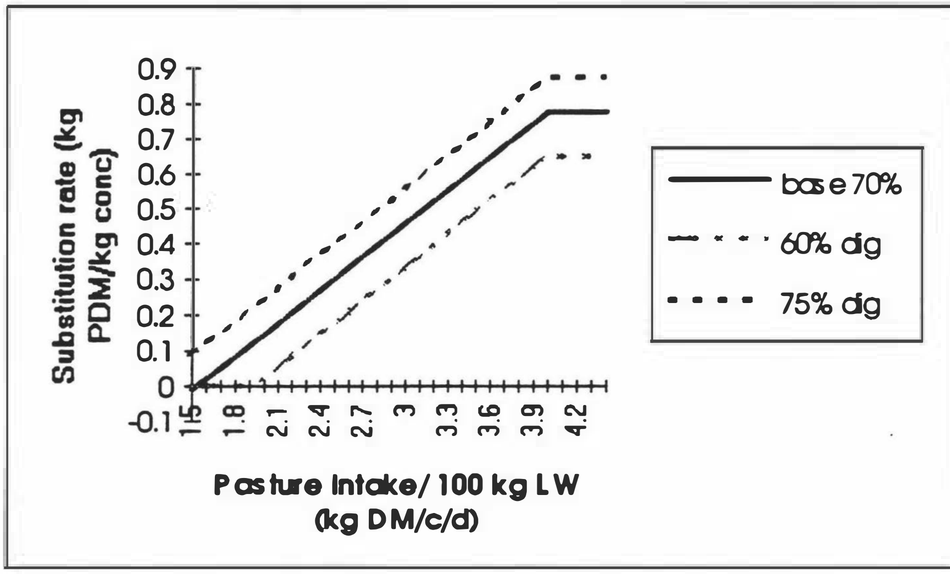


Figure 5.2: *Effect of pasture intake and pasture digestibility on substitution rate.*

Table 5.1: *Ready reckoner to determine substitution rate from pasture intake for different pasture digestibilities and fibre level of the concentrate.*

Pasture intake/100 kg LW (kg DM/c/d)	Pasture Intake (500 kg cow kg DM/c/d)	Digestibility of pasture % DM: 60%	70%	75%	High fibre conc (e.g. oats)
			Low fibre conc.		70% dig.
1.5	7.5	0.00	0.00	0.09	0.00
1.7	8.5	0.00	0.05	0.15	0.04
2.0	10.0	0.02	0.15	0.25	0.12
2.2	11.0	0.08	0.21	0.31	0.17
2.5	12.5	0.18	0.30	0.40	0.24
2.7	13.5	0.24	0.37	0.47	0.29
3.0	15.0	0.33	0.46	0.56	0.37
3.2	16.0	0.40	0.52	0.62	0.42
3.5	17.5	0.49	0.62	0.72	0.49
3.7	18.5	0.55	0.68	0.78	0.54
4.0	20.0	0.65	0.77	0.87	0.62
4.4	22.0	0.65	0.77	0.87	0.62

5.2 Determining nutrient partitioning between milk production and liveweight gain.

The extent of nutrient partitioning between milk production and liveweight gain was determined using response curves. *Gross nutrient partitioning* was found to be influenced by stage of lactation, cow condition, cow genetic merit, level of concentrate fed and type of concentrate fed (Chapter 3). Cows will partition more energy towards liveweight gain than they otherwise would if they are in late lactation, poor condition, low genetic merit, or fed a starch based concentrate. However, analysis of the data showed that *marginal nutrient partitioning* was not significantly affected by stage of lactation, genetic merit, or type of concentrate. Thus, the factors affecting marginal nutrient partitioning are level of energy intake, cow condition and the level of concentrate feeding if concentrates make up a large proportion of the diet. The way in which nutrient partitioning is determined is shown diagramatically below (Figure 5.3).

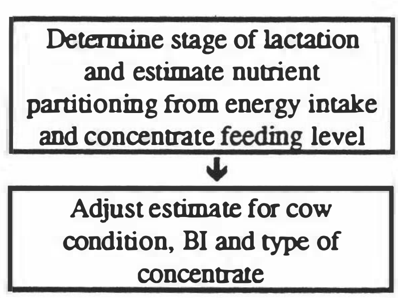


Figure 5.3: *Calculation of nutrient partitioning.*

5.2.1. Estimating marginal nutrient partitioning from energy intake.

It was established in Section 3.1.3 that energy intake affected marginal nutrient partitioning. An increase in energy intake resulted in decreased marginal partitioning to milk production, as shown below in Figure 5.4. This relationship can be shown mathematically:

$$MP = 85.5 - 0.331 \times EI_{100} \qquad \text{(Equation 5.3)}$$

where MP is the marginal partitioning to milk production and EI_{100} is energy intake/ 100 kg LW.

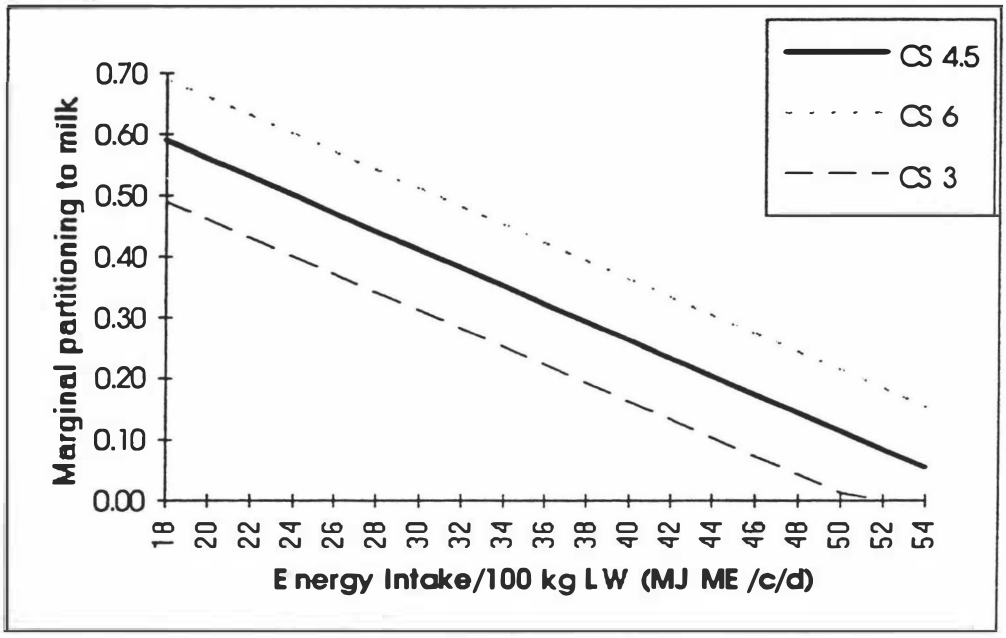


Figure 5.4: *Proportion of marginal energy intake used for milk production at three cow condition scores (CS), for cows of medium/high genetic merit (BI 125).*

Pasture energy content must be estimated before marginal nutrient partitioning to milk can be established. The equation used to estimate the energy value of the pasture is as follows:

$$\text{MJ ME/ kg DM} = 0.16 \times \text{DMD} - 0.77 \qquad \text{(Equation 5.4)}$$

where DMD is the dry matter digestibility of the pasture (MAFF 1975). The digestibility of the pasture must also be estimated from composition of pasture as shown below (Table 5.2). The length of time between grazing also affects digestibility. For example, Waghorn and Barry (1987) reported that the digestibility of white clover fell from 82% three weeks after cutting to 70% 11 weeks after cutting.

Table 5.2: *The effect of stage of maturity on the digestibility of dried perennial ryegrass.*

Stage of maturity	Digestibility of DM (%)
Young Leafy	86
Late Leafy	83
Head Emergence	79
Seed Setting	62

Source: Waghorn and Barry (1987).

The effect of level of concentrate feeding on marginal nutrient partitioning was established in Section 3.1.5. An effect of increasing concentrate feeding level *per se* is not expected unless the concentrate makes up more than 40% of the diet on lush pasture with low fibre content or 60% of the diet when poor quality pasture is fed.

5.2.2. Adjustment of marginal nutrient partitioning for differences in cow condition and genetic merit.

It was proposed in Section 3.1.2 that high genetic merit cows above condition score 4.8 would partition more energy into milk production than cows in poorer condition. Although it was concluded that genetic merit did not affect marginal nutrient partitioning directly, it seems to have an indirect effect via cow condition. Low genetic merit cows (BI 100) seem to converge to an equilibrium condition score of about 5.5. It was established that high genetic merit (BI 125) cows at condition score 3 partitioned 40% less marginal energy into milk production than cows at condition score 6. However, as genetic merit increases, it is likely that the convergent condition score will be lower (Table 5.3). The relationship between cow condition score (CS), genetic merit (BI) and marginal nutrient partitioning can be shown mathematically:

$$M_{csbi} = 0.003 \times (BI - 125) + 0.066 \times (CS - 4.5) \qquad \text{(Equation 5.5)}$$

where M_{csbi} is the adjustment for cow condition and breeding index.

Table 5.3: *Estimated effects of genetic merit (BI) and cow condition (CS) on marginal nutrient partitioning towards milk production relative to the values shown in Figure 5.4 for a cow in CS 4.5 (values in units).*

	Breeding index		
Cow condition	BI 110	BI 125	BI 140
CS 6	+0.05	+0.1	+ 0.15
CS 4.5	-0.05	0	+ 0.05
CS 3	-0.15	-0.1	-0.05

5.2.3. Summary of steps used to determine nutrient partitioning (details shown in Section 5.7).

1. Determine pasture DM intake before concentrates offered from paddock measurements.
2. Calculate the net increase in energy intake as a result of feeding concentrate using the substitution rate calculated above.

3. Calculate total energy intake with concentrate.
4. Use total energy intake to calculate marginal energy partitioning.
5. Adjust for cow condition score and genetic merit and adjust if concentrate intake is high relative to pasture intake.
8. Determine the amount of extra energy used for liveweight gain and milk production from the value so obtained.
9. Determine the likely increase in milk and liveweight gain.

5.3. Determination of pasture growth response.

It was established in Section 2.4 that when substitution occurs, the extra pasture remaining after grazing can lead to an increase in pasture growth rate. An extra 2.6 kg DM/ha/d is expected for each extra 100 kg DM/ha residual yield on the paddock in the range 700 - 1800 kg DM/ha (Table 5.4). The amount of extra pasture on a paddock at next grazing can be represented as an equation:

$$EP = ER + (0.026 \times ER \times d) \qquad \text{(Equation 5.6)}$$

where EP is the extra pasture at next grazing, ER is the extra residual after grazing and d is the days between grazings.

If, for example, an extra 50 kg DM/ha remains after grazing because of substitution, pasture growth rate is expected to be 1.3 kg DM/ha/d (2.6/2) more than it otherwise would. Thus after 30 days there would be 39 kg DM/ha extra pasture growth, and a total of 89 kg/ha of extra pasture will be available at the next grazing. Whether the extra pasture growth will result in extra milk production will depend on the pasture supply and demand conditions which prevail in the future. If cows are already fully fed it is unlikely that an immediate milk response will be obtained.

Table 5.4: *Expected increased pasture growth as a result of substitution for different increases in residual pasture mass (for masses between 700 and 1800 kg DM/ha).*

Increased residual pasture mass due to substitution (kg DM/ha)	Expected increase in pasture growth rate (kg DM/ha/d)
50	1.3
100	2.6
150	3.9
200	5.2
250	6.5

Source: Matthew unpublished.

5.3.1. Valuing extra pasture production.

It is difficult to place a value on the benefits from extra pasture production because they depend on how much of the extra pasture is actually eaten by animals and what it is used for (Doyle and Elliott 1983). The value of extra pasture will therefore change over the year as pasture supply and animal demand change (Rogers 1985). In the context of concentrate feeding, there seems to be two possible effects; animal intake and therefore production can be increased, or the need for supplements can be reduced (Doyle and Elliott 1983). Feeding concentrates may well allow an increase in stocking rate, but in this case there is unlikely to be an effect on pasture growth because post-grazing residuals will probably not be any higher. Of course, if extra pasture growth results in pasture wastage and a decrease in pasture quality, there may be negative effects such as a reduction in pasture quality through shading of clover plants and a build up of dead material (O'Conner 1982, Holmes and McMillan 1982, Hodgson 1984).

If animal intake increases, the value of the pasture will depend on nutrient partitioning, which in turn depends on energy intake. Thus, determining the value of the extra pasture will be difficult. It could be assumed that all pasture spared is consumed and eventually used for milk production. This would probably not be too unrealistic in late spring or autumn when the extra pasture is carried over into a period of low pasture growth relative to requirements. However, this assumption will undoubtedly overvalue the extra pasture.

Valuing the pasture by the cost of replacement feeds is easier, but an assessment of the utilisation of the extra pasture grown is required. It does not necessarily assume that other feeds would be fed in the absence of pasture as the value used can be taken to be an opportunity cost. Pasture utilisation must be assessed for individual situations, but would depend on pasture supply and demand at the time. If, for example, pasture growth exceeded demand it is unlikely that extra pasture growth will be utilised at all, unless it is conserved in which cases adjustments for losses associated with conservation and feeding out would be necessary (Marsh 1978). Estimation of the value of extra pasture as a replacement for supplements is shown in table form (Table 5.5) and mathematically:

PV = (CA x U/100) x EP (Equation 5.7)

where PV is the value of the extra pasture growth, CA is the cost of alternative feed U is the expected utilisation of the extra pasture grown and EP is the extra pasture grown (Equation 5.6).

Valuing pasture in this way requires using the value of the next best available feed, not necessarily the concentrate being fed. For example, pasture should not be valued at 40 c/kg DM if silage is available for 20 c/kg DM.

Table 5.5: *Value of one kg DM of extra pasture growth ($/kgDM) for different pasture utilisations and costs of alternative feeds (assuming perfect substitution of extra pasture for a supplement).*

Cost of alternative feed ($/kgDM)	Utilisation of extra pasture DM grown (%)				
	0%	50%	60%	70%	80%
0.10	0	0.05	0.06	0.07	0.08
0.15	0	0.075	0.09	0.11	0.12
0.20	0	0.10	0.12	0.14	0.16
0.30	0	0.15	0.18	0.21	0.24
0.40	0	0.20	0.24	0.28	0.32
0.50	0	0.25	0.30	0.35	0.40

One way to estimate pasture utilisation is to generate a feed budget and determine whether pasture demand is greater than the expected supply and for how long these imbalances occur. An estimate of pasture utilisation could be gained from the magnitude of the differences.

5.4. Determination of residual milk response due to liveweight gain.

It could be assumed that condition gained while feeding concentrates will eventually be used for milk production, even if not until the following lactation. Each kg of liveweight mobilised for milk production supplies 16 MJ NE (AFRC 1993), enough for 0.38 kg MS/kg LW loss.

MS_{lw} = 0.47 x LWg (Equation 5.8)

where MS_{lw} is milksolids production due to mobilisation of extra liveweight and LWg is marginal liveweight gain from concentrate feeding which is later lost to produce milk:

LWg = (1- MP) x MEI/ 32 (Equation 5.9)

where MP is marginal partitioning to milk (Equation 5.3) and MEI is marginal energy intake.

It may be that not all of the extra liveweight gain will be used for milk production if it is carried over into the dry period. Thus, the proportion of the extra liveweight used for milk production must be specified. This may be difficult to determine, but an estimate could be made based on past experience and seasonal conditions.

5.5. Determination of reproductive response to concentrates.

It was established in Chapter 2 that feeding concentrates would probably increase fertility if cows were in negative energy balance and low condition score (< 4-4.3) before mating. Unfortunately, the expected response has not been quantified, however a reduction in mean calving date of 10 days if all cows were in poor condition and losing weight would not be unreasonable based on the findings of Wilson (1988). This would diminish to a 0 if all cows were in good condition or gaining weight prior to mating. To calculate the proportion of the herd likely to show improved reproductive performance from additional feed, an assessment of cow condition score and how it is likely to change is required. Thus, more than one assessment would be required. *Cows likely to benefit most would be less than condition score 4.3 and losing condition.* An estimate of liveweight change could be made from feed tables using milk production data and estimated intake. However, it is likely to be highly inaccurate since intake information is an average over the whole herd rather than individual animals. Thus, assessing condition loss by eye or using scales is preferred.

The extra milk production expected is 0.7 kg MF/c (1.2 kg MS) for each day by which calving date is advanced. Thus, a 10 days earlier mean calving date would result in the production of an extra 12 kg MS/cow (Figure 5.5).

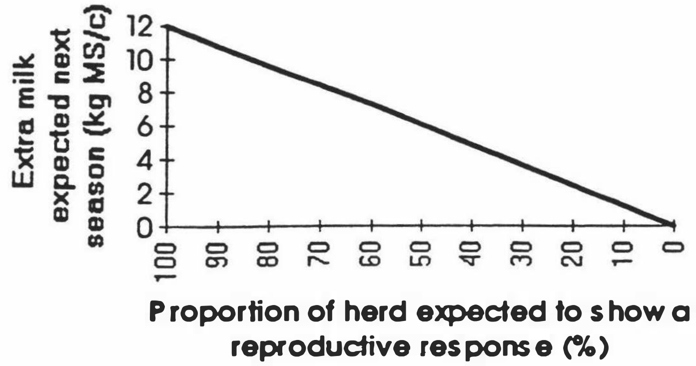


Figure 5.5: *An estimate of the milksolids (MS) response/cow (average for each cow in the herd) as a result of better reproductive performance for different proportions of a herd benefiting from feeding concentrates (i.e. below condition score 4.3 and losing condition).*

One problem with this approach is that it is likely to overstate the reproductive benefit since not all cows lower than condition score 4.3 and losing weight will actually benefit. The reproductive benefit per kg concentrate fed is even more difficult to calculate as it is not clear how much concentrate is required to elicit a response and this is likely to vary from cow to cow and from year to year. However, Wilson (1988) achieved a good response feeding 2 kg concentrate DM/c/d for four weeks prior to mating. Similarly, McCallum *et al.* (1994) brought the mean calving date forward 5 days by feeding 3 kg/c/d concentrate from calving and through mating when cows were underfed on pasture. It seems the response can be achieved at low levels of feeding so it is probably not unreasonable to assume that the response is relatively fixed. As an example, suppose 50% of the herd is in poor condition (below CS 4.3) and losing weight; from Figure 5.5, the expected benefit in the following lactation is about 6 kg MS for each cow in the herd. If 2 kg concentrate/cow/day was fed for four weeks (56 kg/c total), the benefit amounts to 0.11 kg MS/kg concentrate fed, in addition to immediate milk response (6/56).

5.6. Calculating profitability of feeding concentrates.

The calculation of profitability involves the summation of all the expected increases in milk production, valuing them and comparing the figure to the cost of providing the concentrate. This includes the price of the concentrate and the cost of a feeding system which may range from $500 to $25000 to install depending on the type and size of system (Neaves unpublished). The annual cost of a $25000 feeding system is shown below (Table 5.6). Cheaper bale feeding systems will normally require more labour input as the feed frequently must be carried to troughs.

Table 5.6: *Example calculation of the annual cost associated with a $25000 concentrate feeding system.*

Item	Cost ($)
Depreciation @ 5%	$1250
Opportunity cost of capital @ 8%	$2000
Operating cost (electricity)	$200
Total annual cost	$3450
Cost/kg concentrate if 100 tonne fed/yr	3.5 cents

Source: hypothetical figures.

5.7. A worked example of the model.

In this section the model is worked through for a case study farm.

5.7.1. Short term response.

Substitution rate.

Note: before proceeding an assessment of the current and expected feed supply and demand on the farm is required to determine if the feeding strategy employed is making best use of available resources (feed budget). This is most important. If this is not done, the following information is of academic interest only.

Number of cows = 150 .... (1)

Area grazed by herd/24 hrs (ha) = 3 .... (2)

Pre- grazing mass (kg DM/ha) = 1800 .... (3)

Post - grazing residual mass (kg DM/ha) = 1200 .... (4)

Pasture intake/cow/day (kg DM) = ((3)-(4)) x (2) / (1)= 12 .... (5)

Estimated average cow liveweight (if unknown, large Friesians 500 kg+, medium Friesians 450 kg, cross bred 400-450, Jersey 350 kg) = 450.................................... 6)

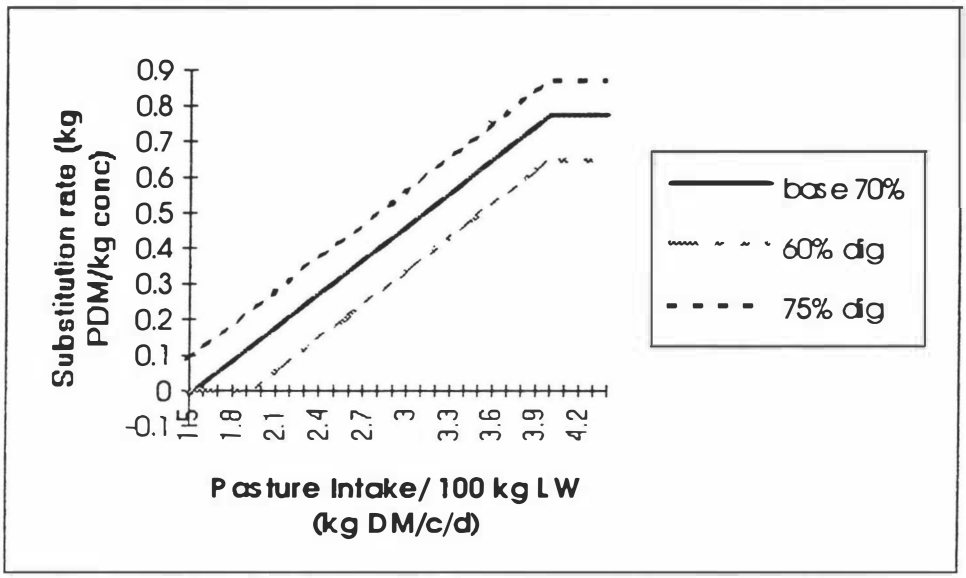
Pasture intake/100 kg LW = (5)/(6) x 100 = 2.7.. (7)

Pasture quality estimate: digestibility (60%, 70%, 75%) = 75% .... (8)

Calculate energy value of pasture from the table = 11.2 ....(8A)

DM digestibility (%)	Energy content (MJ ME/kg DM)
55	8.0
60	8.8
65	9.6
70	10.4
75	11.2
80	12.0

Read substitution rate off graph using the values of (7) and (8)



The substitution rate from the graph:= 0.45 .... (9)

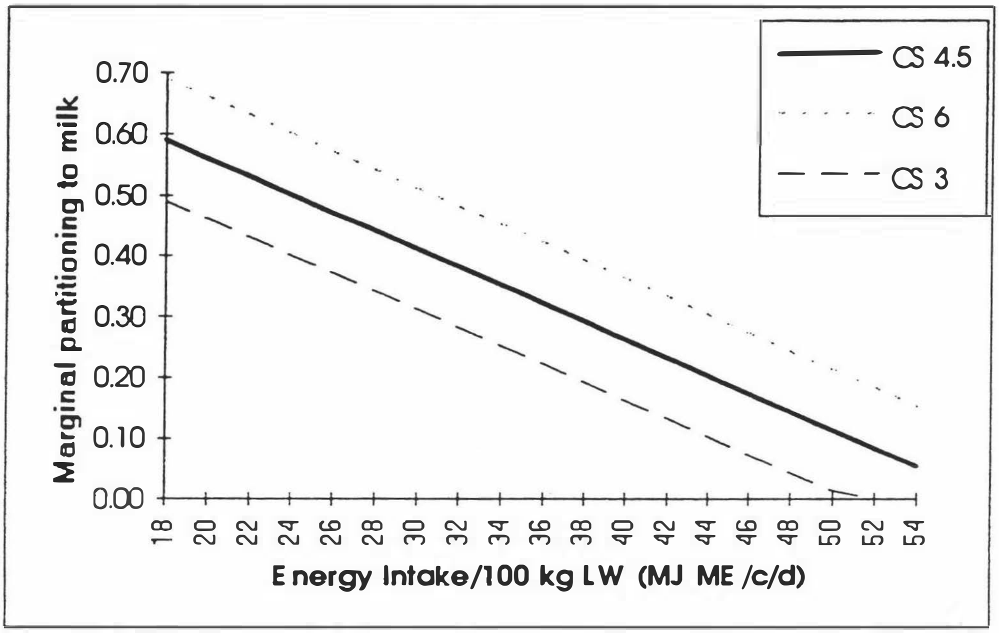
If high fibre supplements such as oats are used multiply (9) by 0.8:
SR = (9)x0.8 ....(9A)

Nutrient partitioning

Concentrate that will be fed (kg /c/d) = 3.5 kg .... (10)
Concentrate DM fed = (10) x DM% = 3 kg DM...(10A)
Expected reduction in pasture intake(kg DM/c/d) = (9) x (10A) = 1.4 .... (11)
Pasture intake (kg DM/c/d) = (5) - (11) = 12 - 1.4 = 10.6.................................. (12)
Energy intake as pasture (MJ ME/c/d) = (12) x (8A) = 11.2 x 10.6 = 119 MJ ME
.... (13)
Energy intake as concentrate (MJ ME/c/d) = (10A) x ME/kg DM = 12 x 3 = 36 (14)
Total energy intake (MJ ME/c/d)= (13) + (14) = 36 + 119 = 155....................... (15)
Marginal increase in energy intake (MJ ME/c/d) = (15) - ((5) x (8A)) = 155 - 134 = 21
.... (16)

Determine proportion marginal energy partitioned to milk production from graph using the value determined in (15)/(6)/100 kg = 155/450/100 = 25 MJ ME/100 kg LW = 0.50 .... (17)

If there is a high proportion of concentrate in the diet: (14)>(13) then proportion of marginal energy used for milk production is divided by 2 N/A........................(17A)



Adjust (17) or (17A) for BI and cow condition by adding or subtracting values in the following table: Adjusted marginal partitioning to milk = 0.50 -0.05 = 0.45 .... (18)

	BI 110	BI 125	BI 140
CS 6	0.05	+0.1	+ 0.15
CS 4.5	-0.05	0	+ 0.05
CS 3	-0.15	-0.1	-0.05

Extra energy partitioned to milk production (MJ ME/c/d) = (16) x (18)
= 21 x 0.45 = 9.5 MJ ME .... (19)

Extra energy partitioned to liveweight gain (MJ ME/c/d) = (16) x (1- (18)) = 21 x 0.55
= 11.6 MJ ME .... (20)

Extra milksolids production (kg MS/c/d) = (19)/68 = 9.5/68 = 0.14 kg MS........ (21)

Extra liveweight gain/ reduction in loss (kg/c/d) = (20)/32 = 0.36 kg .... (22)

Value of extra milksolids production ($/kg conc fed) = (21) x milk price/kg MS / (10)
= 0.14 x 3.15 / 3.5 = $0.12 .... (23)

Cost of concentrates fed ($/kg) = $0.45 .... (24)

Short term profitability ($/kg conc fed) = (23) - (24) = 0.12 - 0.45 =
-$0.32/kg concentrate fed .... (25)

If (25) < 0 then feeding concentrate at the prices used is not profitable in the short term.

5.7.2. Long term responses.

Pasture production

Extra pasture remaining/ha = (11) x (1) / (2) = 1.4 x 150/3 = 70 kg DM/ha........ (26)

Expected increase in pasture growth rate (kg DM/ha/d) = (26)/ 100 x 2.6 = 1.8 . (27)
(up to 1800 kg DM/ha)

Days until pasture grazed again (d) 17.. (28)

Extra pasture at time of next grazing (kg DM/ha) = (27) x (28) + (26)
= 1.8 x 17 + 70 = 100 kg DM/ha.. (29)

Expected utilisation of extra feed (%) = 80% .... (30)

Determine value of the extra pasture from the table using (30) ($/ha) = (29) x value in table = 0.16 x 100 = $16/ha .... (31)

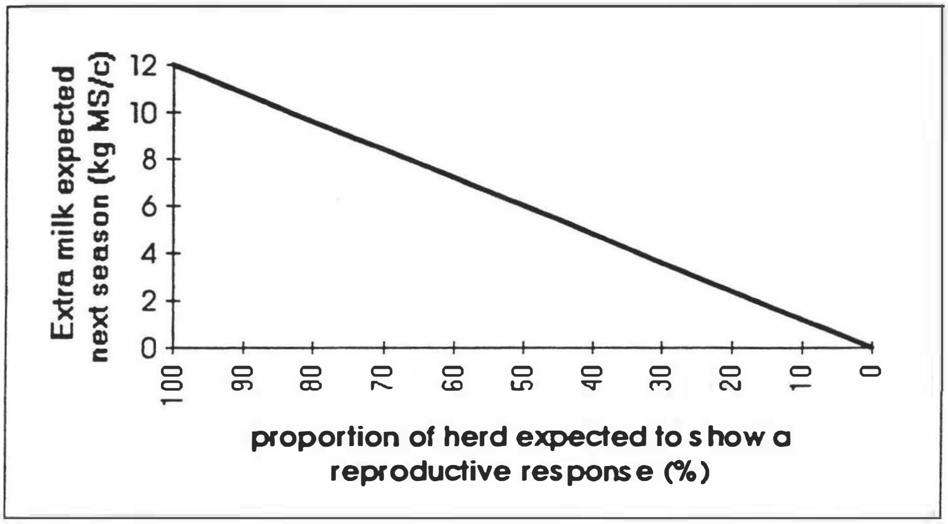
Cost of alternative feed ($/kgDM)	Utilisation of extra pasture grown (%)				
	0%	50%	60%	70%	80%
0.10	0	0.05	0.06	0.07	0.08
0.15	0	0.075	0.09	0.11	0.12
0.20	0	0.10	0.12	0.14	0.16
0.30	0	0.15	0.18	0.21	0.24
0.40	0	0.20	0.24	0.28	0.32
0.50	0	0.25	0.30	0.35	0.40

Value of extra pasture/cow/d ($) = (31) x (2) / (1) = 16 x 3 / 150 = $0.32/c/d.... (32)

Fertility (applies only if cows are to be fed concentrates for the month prior to mating).

Proportion of herd in condition score < 4.3 and losing weight prior to mating (%)
= 20%.. (33)

Read value from graph using (33) to obtain the expected average increase in per cow production in following year (kg MS) = 2.5 kg MS/c .... (34)



Total expected increase in milk production as a result of improved reproductive performance (kg MS)= (34) x (1) = 2.5 x 150 = 450... (35)
Value of improved fertility ($) = (35) x milk price/kg MS = $1420 .... (36)

Liveweight gain

Proportion of liveweight gain later used for milk production = 100% .... (37)
Expected increase in milk production due to liveweight gain when feeding concentrate (kg MS/cow/d) = (22) x ((37)/100)) x 0.38 = 0.36 x 1 x 0.38 = 0.14 kg MS ....(37A)
Value of extra milk from liveweight gain = (37A) x milk price ($/kg MS) = 0.14 x 3.15 = $ 0.44/c/d ....(37B)

5.7.3. Long term profitability (for one month of feeding concentrate).

Value of immediate milk response ($/herd/30 days) = (23) x (1) x (10A) x 30 days = 0.12 x 150 x 3 x 30 = $1620 .... (38)
Value of residual milk response from LW gain ($/herd/month) = (37B) x (1) x 30d = 0.44 x 150 x 30 = $1985 .... (39)
Value of extra pasture produced ($/30 days)= (32) x (1) x 30 days = 0.32 x 150 x 30 = $1440 .... (40)
Value of improvement in reproductive performance ($ Total/yr) = $1420 .... (36)
Cost of concentrate ($/30 d) = (10) x (24) x (1) x 30 days = 3.5 x $0.45 x 150 x 30 = $7100 .... (41)
Fixed cost of concentrate feeding ($/ month, as calculated) $100 .... (42)
Nett benefit from feeding concentrate for one month($)

= (36) + (38) + (39) + (40) - (41) - (42) = 1620 + 1985 + 1440 + 1420 - 7100 - 100
= $-735 ....

5.8. Development of a spreadsheet model.

Prelimiary testing of the model was carried out with two agricultural consultants. The process of working through the paper model took a long time (50 mins - one hour) and some of the calculations required looking back through the pages which caused some frustration. A spreadsheet model was considered more appropriate by the consultants. The model developed is shown below (Table 5.7). The spreadsheet model enabled different scenarios to be run quickly to test the model's predictions (Table 5.8). For example, when cows were consuming 12 kg pasture DM/day, it was profitable to feed concentrates at $300/tonne but not at $450/tonne.

Table 5.7: *Example of the results from the spreadsheet model.*

No. Cows	150	Extra pasture remaining (kg DM/ha/d)	84.58
Cow LW (kg)	450.0	Extra Pasture growth (kg DM/ha/d)	2.20
Area grazed in one day (ha)	3.0	Days until next grazing	16.67
Total farm area (ha)	50.0	Total extra pasture (kg/ha/d)	7.27
Intake before conc (kg DM/c/d)	15.0	Cost of alternative feed ($/kg DM)	0.25
Intake/100 kg LW (kg DM/c/d)	3.33	Expected utilisation of extra pasture (%)	70.00
DM% of concentrate (%)	85.0	Value of extra pasture($/ha/d)	1.27
Concentrate to be fed (kg/c/d)	3.0	Proportion LWg used for milk (%)	80.00
Digestibility concentrate (%)	85.0	Milksolids resulting from LWg (kg MS/c/d)	0.09
Ave Cow Breeding Index (units)	130	Value of milksolids from LWg ($/c/d)	0.29
Ave cow condition score (units)	5.0	Proportion of herd < CS 4.3 and losing wt (%)	
Digestibility of pasture (%)	75.0	prior to mating	20.00
Price of milk ($/kg MS)	3.15	Extra milk from repro improvement	2.40
Price of concentrate ($/tonne)	150.00	(kg MS/c for all cows in herd)	
Digestibility multiplier	0.10	Value of extra milksolids ($)	1134.00
Substitution rate (kg pasture DM/kg conc. DM)	0.66	Value of immediate milk response ($)	863.83
Energy in pasture (MJ ME/kg DM)	11.23	Value of milk from LW gain ($)	1289.67
Energy in conc (MJ ME/kg DM)	12.83	Value of reproductive response ($)	1134.00
Energy from pasture (MJ ME)	149.45	Value of extra pasture ($)	1909.28
Energy from concentrate (MJ ME)	32.72	Total benefits	5196.77
Energy Intake (MJ ME/c/d)	182.17	Cost of concentrate ($)	2025.00
Energy intake/100 kg LW (MJ ME/d)	40.48	Cost of feeding including fixed cost ($/mth)	100.00
Condition and BI multiplier	0.05	Total costs	2125.00
Marginal partitioning to milk	0.30	**Nett benefit ($)**	**3071.77**
Marginal increase in energy (MJ ME)	13.72		
Extra milk production (MS/c/d)	0.06		
Extra LW gain (kg/c/d)	0.30		
Value of extra milk ($/c/d)	0.19		
Cost of concentrate ($/c/d)	0.45		
Margin/ kg conc fed ($)	**-0.09**		

Table 5.8: *Predictions of net benefit ($) from concentrate feeding for different levels of pasture intake and concentrate prices for a herd of 150 cows (the base model is as shown in Table 5.7).*

	Pasture Intake (kg DM/c/d)		
Concentrate price ($)	9	12	15
150	$4093	$3542	$3072
300	$2069	$1517	$1047
450	$43	-$507	-$978

5.9. Summary and main points.

A decision support model to determine the likely profitability of feeding concentrates in the short-and long-term was developed. The model is based on a set of linear equations and is designed to be worked through using graphs and tables rather than mathematical equations, for ease of use. A major problem with this approach is that the time required to work through the steps is prohibitively long (50 minutes - one hour). Consequently, a spreadsheet version was developed (Table 5.7). This is much faster to operate (10-15 minutes) and enables different feeding scenarios to be analysed quickly. This is a big benefit of the spreadsheet. A problem is that it is more difficult for users to appreciate the relationships in the model. Thus, its value as an educational tool may be less than the paper model. Both the paper and spreadsheet models are therefore useful but for different purposes.

CHAPTER SIX

CONCLUSIONS

The aim of this study was to develop a simple decision support model to aid decisions regarding concentrate feeding of dairy cows on mainly pasture diets. The model differs from most others in that it attempts to assess both the short and long term implications of concentrate feeding. A comprehensive review of the available literature on factors affecting responses to concentrates was completed to obtain relationships between milk production, liveweight change, herd fertility responses and pasture production. The literature on agricultural modelling was also reviewed and from this it seemed that a step by step simulation model best met the criteria for a practical decision support model that would aid decisions in the field regarding concentrate feeding. A model comprising 43 distinct steps was constructed, that could be completed without the use of a computer. A spreadsheet model was developed after test runs of the paper model revealed it was slow and did not allow different scenarios to be analysed quickly as the spreadsheet model does.

In this Chapter, overall conclusions from the study are drawn. In particular, areas where further work (or improved trial design) is needed are discussed.

6.1. Main findings of the study.

The paper (i.e. manual) format for a model is likely to be a better educational tool than a computer model since the user must work through each calculation. However, there is a danger that user will become overwhelmed by the calculations and disgard it. In either format, however, the model allows a quick assessment of the likely profitability of concentrate feeding and encourages the users to think about the issues involved.

A relationship was established from the published results of experiments for substitution rate and pasture intake. Some relationship between substitution rate, pasture digestibility and concentrate fibre content was also evident in the data but were less clearly defined. The data examined did not show any consistent relationship between substitution rate, level of concentrate feeding and stage of lactation. Similarly, a significant relationship between marginal nutrient partitioning and level of energy intake was established. Concentrate intake and cow condition at calving were also related to marginal nutrient partitioning but no consistent effect of cow genetic merit, stage of lactation and type of concentrate was established from the data.

Reproductive response to concentrate appears to depend on cow condition and energy balance in the period between calving and mating. Some tentative relationships were established, however they are subject to debate. Similarly, the fate of saved pasture, extra pasture growth and liveweight gain resulting from concentrate feeding is difficult to predict, but in at least some situations they have an effect on subsequent production and therefore cannot be ignored. A lack of data on the long term responses to concentrate feeding has meant an estimate of the most likely response was required, in some instances, to complete the model.

The modeller's dilemma is whether to include or exclude aspects for which relationships are not well established. Ideally they would be excluded until further research was completed to establish the relationships. However, this research may either take a long time to yield results or never be completed. In this study, all relationships were included, irrespective of the amount of data available, if they had an important effect on the profitability of feeding concentrates.

6.2. Future work required on the model.

After a model is developed it should be validated and subjected to a sensitivity analysis conducted prior to its use for decision support (Figure 4.2). Unfortunately, it was not possible to complete these steps in the time available for the present study. The validation process requires comparison between the results predicted by the model and real situations. If the model does not provide reasonable predictions of what actually happens, then it can either be 'calibrated' to reflect the circumstances encountered in the field or alternatively, the relationships used to build the model reassessed. In addition, a sensitivity analysis would identify those parameters which are particularly important to the outputs from the model and therefore how accurate the estimates of each parameter must be. This would also help to identify priorities for further research. The model would then be updated and modified in response to the additional information obtained during these processes.

6.3. Deficiencies of the data and guidelines for further research.

Further work is required to establish meaningful relationships between some of the variables affecting the profitability of concentrate feeding (Section 6.1). If such relationships are to be established researchers must report the conditions under which experiments are performed. For example, it is not enough to say, that a residual milk response to concentrate feeding occurred and to nstate the response. Details about changes in cow condition, pasture and concentrate feeding level, cow genetic merit, stage of lactation, pasture growth rates, digestibility of pasture and concentrate and protein and fibre level of the concentrate fed are all required if accurate cause/effect relationships are ever to be established. This lack of descriptive detail is a major limitation of much of the present literature on concentrate feeding.

6.3.1. Marginal nutrient partitioning.

Research in this field should focus on marginal feeding responses rather than gross effects because the fate of additional feed inputs is of primary interest. Often, only one level of feeding has been included in genetic merit or condition score experiments whereas, at least two different feeding levels are required to establish a marginal effect.

Current literature suggests that, the effect of genetic merit on marginal nutrient partitioning is not significant although some trends are evident. More work is required to show if a consistent relationship exists. Similarly, the relationship between cow condition and marginal nutrient partitioning is not clear. Although several experiments report the effects of cow condition, very few have studied the marginal response to more than one level of feeding. More work is also required to establish this relationship. The research reviewed showed that cows of high genetic merit tended to move towards a lower condition score than cows of low genetic merit. However, it is not clear what happens to cows of very high genetic merit. Will they converge on even lower condition scores or has the minimum been reached?

6.3.2. Substitution rate.

The relationship between pasture digestibility and substitution rate needs to be clarified. It seems that when pasture digestibilty is low the substitution rate is lower than when the digestibility is high. Some evidence suggests that the relationship is due to the higher level of pasture intake associated with a given pasture digestibility rather than the effect of digestiblity *per se*.

6.3.3. Reproductive responses.

Further study is required to establish the conditions required to elicit a response to concentrates for pasture-fed cows. The *critical* cow condition/feeding level/ energy balance required to exist before a response will occur are not well established. Similarly, there is no information as to the *amount* of extra energy that must be fed before a response occurs or whether the response is continual (i.e. there are benefits of feeding beyond a certain level). The exact response in terms of extra milk in the next lactation is also poorly documented. Thus, trials need to be designed around these issues if the reproductive response to concentrate is to be fully established.

6.3.4. Pasture and liveweight responses.

The effect of feeding concentrates to dairy cattle at pasture on pasture growth rate has not been clearly established. The amount of extra pasture growth and conditions required to achieve full utilisation of the extra pasture grown need to be established more clearly. These conditions could have been obtained from past experiments if the appropriate measurements had been made. Thus, it should not be difficult to establish these relationships from future work.

The fate of extra liveweight gain also needs further exploration. For example, if is not clear whether the extra weight gained, while concentrates were fed, changes the nutrient partitioning later in lactation so cows produce more milk and partition less to weight gain is unclear.

6.4. Summary and final comments.

The nature of biological systems is likely to ensure that some questions are never satisfactorily answered. However, many of the questions could be answered if more detail was recorded in trials with a 'systems' orientation and if controlled experiments were more orientated towards obtaining a cause and effect relationship for the responses achieved. This provides a classic conflict: to establish 'cause and effect' relationships requires that as much variation as possible is controlled, but the performance of the whole system is what ultimately determines the value of feeding concentrates. To achieve both of these goals would require large scale systems research over several years. This is expensive and therefore unlikely to occur except via computer simulation. If there is only a small perceived benefit from this knowledge then research into other activities may be more appropriate. A cost benefit study to determine the value of being able to accurately predict the full response to concentrates under different conditions should be undertaken before further research is undertaken.

This research is part of the process of supplying useful information in a practical format for decision makers. The model provides a systematic framework to examine the factors affecting the response to concentrates. While it is not possible to guarantee that the predicted response from the model is completely accurate, this is less important than the need to ensure that farmers and their consultants systematically and rationally work through the decision problem.

In broad terms, if the model shows a large financial benefit from feeding concentrate, it is likely to be a good decision to commence feeding. On the other hand, if there is only a small predicted benefit, it is unlikely to be worthwhile feeding. One of the aims of this research was to provide an aid for decisions regarding concentrate feeding. This aim was achieved but further field testing and research is now required to validate the model.

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