EFFECTS OF UNDERFEEDING IN EARLY LACTATION

ON THE YIELD AND COMPOSITION OF MILK PRODUCED

BY HIGH AND LOW BREEDING INDEX COWS

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ABSTRACT

A grazing trial was carried out to examine the interactive effects of underfeeding in early lactation and cow breeding index on milk yield and composition.

From the fifth week of lactation, 16 high and 16 low breeding index cows were fed at a restricted or *ad libitum* feeding level. Digestible organic matter intakes were estimated directly using the herbage cutting technique and indirectly using the chromic oxide technique. Intake was reduced due to underfeeding by approximately 45 %. In comparison to cows on the *ad libitum* feeding level, underfed cows showed reductions in milk, milkfat and milk protein yields, milk protein concentration, long chain fatty acid concentration in the milkfat and liveweight gain. Milkfat concentration, short chain fatty acid concentration in the milkfat and loss in body condition were increased.

Following the return of all cows to a generous feeding level, previously underfed cows produced lower daily yields of milk, milkfat and milk protein for three to five weeks and gained more liveweight and condition over mid-lactation. The residual effect of underfeeding on milkfat production was 1.0 times the immediate effect. There appeared to be no effects of previous underfeeding on milk composition, concentrations of short chain or long chain fatty acids in the milkfat or digestible organic matter intake.

Cow breeding index interacted with the effects of underfeeding in that high versus low breeding index cows showed (a) a smaller residual effect of underfeeding on milkfat production (0.8 versus 2.0 times the immediate effects, respectively) and (b) a greater immediate reduction in milk protein concentration due to underfeeding.

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TABLE OF CONTENTS

CHAPTER TWO

METHODS AND MATERIALS

CHAPTER THREE

RESULTS

CHAPTER FOUR

DISCUSSION

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

CHAPTER ONE

REVIEW OF LITERATURE

1.1 THE RESPONSE OF DAIRY COWS TO THEIR LEVEL OF FEEDING

1.1.1 General Theory of Milk Yield Response to Level of Feeding

1) The Effects of Feeding on Immediate Milk Production

As an increasing amount of feed energy is made available to the cow in excess of her requirements for bodily maintenance, an increase in milk energy output can clearly be expected. However, the alternative use of nutrients for the deposition of liveweight (LW) means that in the short term there may be no simple relation between energy intake and milk production (Holmes *et al*, 1981). The response in milk yield to changing levels of feed intake has been found to be negatively curvilinear (Burt, 1957; Broster and Thomas, 1981) and the response in LW change positively curvilinear (Broster, 1976; see figure 1.1). This is because as feed intake is increased, the extra nutrients are partitioned more towards LW than milk production. The joint response of both output pathways to changing intake is linear in energy terms (Broster, 1976).

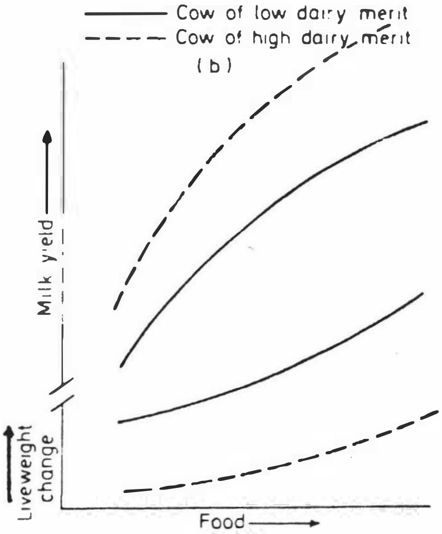
2) The Effects of Feeding on Subsequent Milk Production

At any given feeding level, a greater response in milk yield to extra nutrients can be expected in the long term due to the potential availability of those nutrients stored as body tissue for subsequent mobilization in support of milk production. Studies show that milk yield response to changing feed intake is still negatively curvilinear and generally the response at a given feeding level is greater than in the short term (Burt, 1957; Broster, 1972; Wiktorsson, 1979).

3) Efficiency of Milk Production

The partitioning of feed energy between milk production and LW deposition varies between cows. Hence not all cows operate on a single response curve. At a given level of feeding, milk yield response to extra feeding increases with genetic potential (see figure 1.1) and lactation number and decreases as lactation progresses, in direct relation to current yield (Burt, 1957; Broster, 1976; Broster and Thomas, 1981). Therefore cows of high current yield compared to cows of low current yield partition feed energy more towards milk yield and less towards body reserves. Hence, higher yielding cows have a higher

FIGURE 1.1 Simplified Model to Describe the Relationship of Food to Milk and Liveweight in Dairy Cows According to Response to Level of Intake (from Broster, 1976).



gross efficiency and marginal efficiency of milk production, defined as follows :

$$\text{gross efficiency} = \frac{\text{MJ energy output}}{\text{MJ feed energy input}} \times \frac{100}{1}$$

$$\text{marginal efficiency} = \frac{\text{MJ extra milk energy output}}{\text{MJ extra feed energy input}} \times \frac{100}{1}$$

4) Diet Type

Diet type can affect the partitioning of feed energy and hence the response of milk yield to changes in the level of feeding (Grainger and McGowan, 1982). In contrast to the curvilinear response obtained with cows fed on concentrate/roughage diets, most data that are available for pasture fed cows indicate a linear response in milk yield to increases in feeding level (Bryant, 1980; Stockdale et al, 1981; Grainger et al, 1982).

1.1.2 Immediate (Short Term) Effects of Feeding in Early Lactation on Milk Production

1) Early Lactation as a Feeding Period

Gross efficiency and marginal efficiency are highest in early lactation compared to subsequent stages (Hutton, 1963; Holmes et al, 1981). In early lactation peak intake lags behind peak milk yield and body reserves are mobilized to support milk output whereas later in lactation milk yield falls while intake remains high and body reserves are deposited (Bines, 1979; Bryant and Trigg, 1982). If allowance is made for such differences in changing levels of body reserves between stages of lactation, differences in efficiency may be expected to be much smaller in the long term (Holmes et al, 1981). However, feed energy is more efficiently converted to milk directly, rather than indirectly via the deposition and subsequent mobilization of body reserves (van Es, 1976; Holmes et al, 1981).

Therefore feeding during early lactation may be expected to have a maximal immediate effect on milk production, and it has been concluded that peak yield established in early lactation is dominant over persistency (the subsequent rate of decline in milk yield) in determining total lactation yield (Broster and Thomas, 1981).

Due to the common occurance of pasture shortages coinciding with early lactation in New Zealand, research has concentrated upon the effects of underfeeding during early lactation on milk production.

In a summary of early New Zealand work with grazing cows, Gerring and Young (1961) showed that underfeeding in early lactation depresses milk yield. However, no quantitative conclusions may be drawn from such work due to a lack of intake data.

Recent Australasian data, summarized in table 1.1, allows quantitative analysis and on average the results showed that :

i) a 38% restriction of DM intake resulted in a 24% reduction in milkfat yield, and

ii) a 1 kg increase in DM intake resulted in an increase of 0.039 kg milkfat and 0.174 kg LW. However, such changes expressed as percentages can be misleading since they may not apply to different absolute values of intake and milkfat yield. Furthermore, the milk yield response to changes in feed intake is variable, depending on the basal level of nutrition, as discussed previously.

2) The Timing, Duration and Severity of Underfeeding and Immediate Effects

Workers have found that severity of underfeeding in early lactation, (in terms of the degree of restriction of daily intake) appears to affect immediate production in a linear fashion (Bryant, 1980; Stockdale et al, 1981).

Grainger and Wilhelms (1979) compared two levels of intake (grazed pasture), ad libitum (H) versus 7.7 kgDM/cow/day (L) for weeks 1-5 and 6-10 of lactation, varying the timing and duration of underfeeding (L)

TABLE 1.1 Summary of Immediate Effects on Milkfat Yields and Liveweight (LW) Change from Australasian Experiments where Cows in Early Lactation were Grazed on Contrasting Amounts of Pasture (from Bryant and Trigg, 1982).

Source	Levels of Feeding	Days of Underfeeding	Control Milk Yield(kg/d)	Reduction(% Control)		Response (g/kg DM)	
				Fat Yield	DM Intake	Milkfat	LW Change
Stockdale *et al* (1981):year1	7	60	14.6	36	39	40	90
year2	3	60	18.9	33	48	40	90
Bryant (1980)	4	28	18.1	22	28	51	130
Bryant and Trigg (1979):exp1	2	21	18.8	12	20	46	570
exp1	2	42	18.5	19	22	49	220
exp2	2	42	21.2	26	49	40	230
Bryant (1978/79)	2	28	21.5	17	34	38	80
Glassey *et al* (1980)	3	22	16.7	21	41	32	150
Grainger and Wilhelms (1979)							
HvL	2	35	18.6	22	46	30	72
HHvLL	2	70	18.6	39	46	52	27
Hutton and Douglas (1975)	2	28	15.4	11	20	24	-
Moate *et al* (1980)	2	21	14.0	19	42	34	-
Santamaria *et al* (1979)							
fresh pasture	3	-	16.4	30	53	26	-
Mean		39	17.8	24	38	39	174

in 4 treatments : HH,HL,LH and LL. Immediate effects on milk production (weeks 1-10) were equal and additive, HL and LH groups producing 11 kg and the LL group 22 kg less milkfat than the HH group. Hence, while the timing was unimportant, the duration of underfeeding increased the effects of the same.

Bryant and Trigg (1979) offered an ad libitum pasture allowance of 50 kgDM/cow/day versus a restricted allowance of half the area given for the ad libitum allowance (at similar herbage mass). The treatments, beginning 4 weeks into lactation were as follows : E3, E6, L3, L6, restriction for weeks 1-3, 1-6, 7-9 and 7-12, respectively, with a control group well fed throughout lactation. In agreement with Grainger and Wilhelms (1979), the duration of underfeeding was found to increase immediate effects since restriction for 6 weeks resulted in reduced yields of milk constituents of about twice those for 3 weeks. However, in contrast to Grainger and Wilhelms (1979), the timing of underfeeding was also important. The effects of underfeeding increased with stage of lactation (reductions in milk yield were obtained for treatments E6 and L6 of 10% and 20%, respectively, relative to the control). Clearly, the effects of timing on immediate production need to be more precisely defined.

1.1.3 Residual (Long Term) Effects of Feeding in Early Lactation on Milk Production

The subsequent or residual effect of a period of differential feeding refers to the effect which is measured after the treatment has finished, expressed relative to the immediate effect measured during the treatment period. It may be calculated as follows :

RESIDUAL EFFECT = X TIMES IMMEDIATE EFFECT ON MILK PRODUCTION (Gordon, 1976)

The importance of early lactation as a feeding period depends upon the overall (total) effect on milk production which is most importantly determined by any residual effects in addition to the immediate effects on milk production.

1) Early New Zealand Research

Several New Zealand experiments in the 1950's examined the effects of underfeeding grazing cows in early lactation. These have been summarized by Gerring and Young (1961) and Broster (1972).

Flux and Patchell (1954) found that feeding 14 cows at 40% of the grazed pasture/roughage rations of their identical twins during weeks 3-8 of lactation resulted immediately in increased LW loss and reduced milk yields and that differences in milk yield had increased by the end of lactation (although this was not statistically significant).

Wallace (1957), using 22 sets of identical twins, examined the effects of feeding concentrates in addition to pasture during weeks 1-8 of lactation. In the first year, grazing was restricted while in the second year, grazing was on ample pasture. Production differences due to concentrate feeding were very much greater in the first year. For both years, concentrate feeding was associated with savings in LW and there was a marked residual effect of 3-4 times the immediate effect on milk production.

Patchell (1957), using 22 sets of identical twins in total over two years, looked at the effects of poor feeding for six-week periods immediately before and after calving on grazed pasture and roughages. The effects of underfeeding in early lactation on milk yield measured over the whole 36 week lactation were greater than when measured only during the period of treatment. However cows that were poorly fed in early lactation lost no more LW than their well fed counterparts during weeks 1-6 of lactation and subsequently made the greatest LW gains.

Comparing the results between years for Wallace's (1957) and Patchell's (1957) studies suggests that the greater the deficit in early lactation, the greater the residual effect.

Flux and Patchell (1957), using 15 sets of identical twins, studied the effects of very short periods of underfeeding (5 days and 10 days) immediately after calving. Although full lactation yields were not recorded, a residual effect from severe underfeeding was observed in the immediate post treatment period.

Gerring and Young (1961) concluded that losses incurred during actual periods of underfeeding in early lactation are only a fraction of the total losses resulting from such a practice.

2) European Research

European evidence has shown that underfeeding in early lactation not only reduces milk yield at that time but also later in lactation when underfeeding has ceased (Broster, 1972; Broster and Strickland, 1977). In a number of experiments by Broster and his colleagues (1958, 1964, 1969, 1975), these residual effects equalled on average some four times the immediate treatment effects. The actual absolute size of the response depended on the absolute levels of feeding imposed (Broster, 1974). However in the review by Broster and Strickland (1977) not all experiments were able to show a residual effect from feeding in early lactation.

Leading on from this, Broster and Thomas (1981) reviewed literature involving 46 world-wide experiments. The results were drawn together in a graph in which the immediate effects on milk yield of contrasting planes of nutrition in early lactation were plotted against the residual effects in later lactation when the plane of nutrition was equalized for all animals. Most experiments showed a positive residual effect but a few showed a negative effect. The length of period studied in mid-lactation and whether cows were stall fed or grazed did not appear to influence the outcome. Experiments were categorized according to the planes of nutrition imposed by the basal diet during the immediate treatment period in early lactation. By regressing the residual effects of contrasting planes of nutrition in early lactation on the immediate effects for each group it was shown that for low and medium planes of nutrition the residual effect was only 0.55 times the immediate effect, provided that the latter exceeded 1.5 kg milk/day. For the high plane of nutrition, no residual effect was found.

More recently, in Britain, Le Du and Newberry (1981) carried out a trial in which they examined the influence of short and medium-term grass shortage upon milk output when no alternative feeds were offered. Using a herd of spring-calving British, Friesian cows, five grazing severity treatments were imposed beginning approximately nine weeks into lactation (three weeks after turnout to pasture). In terms of daily herbage allowance offered in a strip grazing system, the treatments consisted of :

(a) control, C (55 gDM/kgLW),

(b) severe restriction, L (25 gDM/kgLW) for two or five weeks, and

(c) moderate restriction, M (40 gDM/kgLW) for five or eight weeks.

During the grazing season, before and after the treatments phase, all cows were offered pasture at the control allowance. Results are presented in table 1.2. It can be seen that cow LW was depressed during the restriction periods and that subsequently LW was regained. Milk yields were significantly depressed during the periods of restriction (except for treatment M8). However, upon return to adequate quantities of good quality herbage, recovery was rapid so that during the subsequent four weeks differences in milk yield were negligible.

In a second trial, Le Du and Newberry (1982) looked at the effects of feeding concentrate supplements during the severely

TABLE 1.2 The Effects upon Mean Daily Milk Yield and Cow Liveweight of Herbage Restriction and Supplementation Treatments Relative to a Control Treatment, both during the Treatment Periods and during the Period Following Return to Control Herbage Allowances (adapted from Le Du and Newberry, 1981;1982 - see text for explanation of treatments).

	TREATMENTS			
TRIAL 1 (Le Du and Newberry, 1981)	L2	L5	M5	M8
restriction phase :-				
mean cow Liveweight (kg)	-22	-21	-13	-14
mean daily milk yield (%)	-12(***)	-8(***)	-7(***)	-3(NS)
'recovery phase' (4 weeks) :-				
mean cow liveweight (kg)	-6	-15	+1	+28
mean daily milk yield (%)	0(NS)	+2(NS)	-4(NS)	+5(NS)
TRIAL 2 (Le Du and Newberry, 1982)	L2	L2S	L5	L5S
restriction phase :-				
mean cow liveweight (kg)	-18	-15	-16	-8
mean daily milk yield (%)	-19	-8	-20	-5
'recovery phase' (7 weeks):-				
mean cow liveweight (kg)	+3	+8	+12	-4
mean daily milk yield (%)	-11	-4	-14	-3

restricted pasture treatments as in the first trial (Le Du and Newberry, 1981). Half of the cows in the severely restricted groups were offered concentrates at a rate of three and two kg/cow/day for the two week (L2S) and five week (L5S) restriction periods, respectively. From table 1.2 it can be seen that cow LWs were depressed during the periods of restriction for all treatments and subsequently increased. In comparison to the L2 and L5 treatments of the first trial, the depressions in milk yield were considerably larger and the recovery from restricted feeding less marked. It was suggested that these differences may be the result of low pasture quality in the second trial.

Le Du and Newberry (1981) concluded that the scope for offering additional feeds profitably is quite small, due to the transient nature of even severe pasture restrictions. Conversely, it was concluded by Le Du and Newberry (1982) that in the circumstances of their trial (which are not fully understood), supplementation of severely restricted grazing dairy cows is financially viable. The magnitude of the response appeared to have been affected by the precise nature of the restriction, in terms of both the quantity and quality of herbage on offer, and by herbage quality during the recovery period.

3) Recent Australasian Research

Recent Australasian data and some of the early New Zealand data referred to in 1) in 1.1.3 are presented in table 1.3. The more recent data agree with the findings of Broster and Thomas (1981). In most cases the residual effects on milk and milkfat yield fall between one and zero (the exceptions being Bryant and Trigg (1979) who in one of their trials measured residual effects on milk yield and milkfat yield of 2.3 and 2.9, respectively, and Bluett (1977) who obtained a residual effect on milkfat yield of 1.5). Measured over the whole of lactation these effects were not significant except for two instances (Grainger and Wilhelms, 1979; Stockdale et al, 1981). Bluett (1977) obtained a significant residual effect on milkfat yield but this was partly due to measurements being made over only 90 days following under-feeding (Bryant and Trigg (1979).

Two Australasian experiments, carried out since the review by Bryant and Trigg (1982) and hence not included in table 1.3, are those by Grainger et al (1982) and Ngarmsak (1984). Data from Grainger et al (1982) are given in table 1.4. Cows were differentially fed on grazed pasture for the first 5 weeks of lactation. It can be seen that the better fed cows lost less condition (0.4 C.S) than the poorly fed cows. The effect of the different levels of feeding continued beyond the treatment period until the loss in condition by the previously underfed cows was regained during which time 7.8 kg less milkfat was produced in relation to the previously well fed cows. This residual effect was equal to 1.3 times the immediate effect on milkfat production.

In Ngarmsak's (1984) experiment, cows were offered pasture at a high or low allowance for weeks 8-10 of lactation. Data are presented in table 1.5. It can be seen that the restricted cows lost condition during the period of restriction. Subsequently, condition was regained although this was less than that gained by the previously generously fed cows. In total, the cows fed poorly in early lactation produced 3.6 kg less milkfat than their well fed counterparts. The residual effect of underfeeding was only 0.1 times the immediate effect on milkfat production.

TABLE 1.3 Effects on Underfeeding in Early Lactation on Immediate(I) and Subsequent(S) Yields of Milk and Milkfat (from Bryant and Trigg, 1982).

SOURCE	Restriction (days)	Lactation (days)	Effects on Milk on Milk Yield† (kg)			Effects on Fat Yield† (kg)			Significance of S††	
			I	S	S/I	I	S	S/I	MILK	FAT
Grainger & Wilhelms (1979) HL	35	229	261	88	0.3	11.1	9.2	0.8	NS	NS
LH	35	236	191	-177	-0.9	6.2	-0.3	-0.1	NS	NS
LL	70	206	492	365	0.7	21.9	21.4	1.0	*	*
Bryant & Trigg (1979) exp 1	21	132	50	113	2.2	2.3	6.6	2.9	NS	NS
	42	132	109	15	0.1	5.5	3.0	0.5	NS	NS
exp 2	42	168	310	-	-	10.7	7.8	0.7	-	NS
Flux & Patchell (1954)	42	270	93	195	2.1	3.7	10.6	2.9	NS	NS
Patchell (1957)										
year 1	42	252	59	-24	-0.4	-	-	-	NS	NS
year 2	42	252	83	143	1.7	-	-	-	NS	-
Stockdale _et al_ (1981)	60	210	68	39	0.6	2.4	1.5	0.6	*	*
Bluett (1977)	42	133	150	98	0.7	7.8	12.0	1.5	NS	NS
Wallace (1957)										
exp 1	56	260	182	490	2.7	8.2	27.7	3.4	-	-
exp 2	56	270	68	123	1.8	3.6	7.3	2.0	-	-
Glassey _et al_ (1980)	28	238	-	-	-	3.5	0.4	0.1	-	NS
Bryant (1978/79)	28	70	129	-6	-0.1	4.8	-1.1	-0.2	NS	NS
Hutton & Parker (1966) syst. 2	56	c.250	64	36	0.6	2.0	4.0	2.0	-	-
syst. 3	56	c.250	62	128	2.1	2.0	8.0	4.0	-	-

† Immediate (I) and subsequent (S) effects are differences between the control (c) that were well fed throughout expressed as C-I and C-S

†† NS = not significant * = statisically significant

TABLE 1.4 The Effect of Feeding Level during the First Five Weeks of Lactation on Milkfat Production and Body Condition Score for Cows Calving at Condition Score (CS) 5 (adapted from Grainger *et al*, 1982).

	Feeding Level (kg/cow/day)		Difference
	14	8	6
Immediate Effect (weeks 1-5)			
milkfat yield (kg/cow)	28.7	22.8	5.9*
CS	4.9	4.5	0.4
Total Effect (weeks 1-20)			
milkfat yield (kg/cow)	108.6	94.9	13.7
CS	4.9	4.9	0.0

* 21% reduction in milkfat yield due to underfeeding

TABLE 1.5 The Effect of Feeding Level during Three Weeks in Early Lactation (Weeks 8-10) on Milkfat Production and Body Condition Score (CS) (adapted from Ngarmsak, 1984).

	Generous Allowance	Restricted Allowance	Difference
Herbage Intake (weeks 8-10)			
kg DM/cow	373	233	140
kg DM/cow/day	18	11	7
Immediate Effect (weeks 8-10)			
milkfat yield (kg/cow)	21.0	17.9	+3.2*
change in CS	0.08	-0.20	+0.28
Total Effect (weeks 8-27)			
milkfat yield (kg/cow)	95.9	92.3	3.6
change in CS	0.58	0.38	0.20

* 15% reduction in milkfat yield due to underfeeding

4) The Plane of Nutrition Following Underfeeding in Early Lactation and Residual Effects

Clearly, the literature is in conflict regarding the residual effects of differential feeding levels imposed in early lactation.

Broster and Thomas (1981) have suggested that the relationship between immediate and total effects of contrasting levels of nutrition in early lactation may be influenced by the metabolizable energy (ME) intake in the residual (post treatment) period.

For cows underfed on concentrates in early lactation, there is evidence to suggest that residual effects are greatly reduced upon ample access to pasture in the post-treatment period (Gordon, 1976; 1977; Le Du et al, 1979). This would imply a compensatory response by cows poorly fed in early lactation and subsequently given a generous supply of good quality feed. There is some evidence from the work of Taylor (1959) and Bines et al (1969) that voluntary feed intake is greater in animals previously underfed and in thinner body condition. Although Le Du et al (1979) observed little effect of concentrate underfeeding upon the subsequent grazing behaviour and herbage intake of the cows in their experiment. Stockdale et al (1981), who obtained a significant residual effect of 0.6 times the immediate effect of underfeeding in early lactation (see 3) in 1.1.3), commented that this may have been due to the high stocking rate (6 cows/ha) used throughout the post-treatment period. The ability of cows to compensate for poor feeding in early lactation would appear to depend upon the availability of good quality feed later in lactation.

5) The Timing, Duration and Severity of Underfeeding in Early Lactation and Residual Effects

Variation in the timing, duration and severity of underfeeding in early lactation seems likely to be another factor accounting for the conflict between researchers in the extent of residual effects observed (Gordon, 1976). It has been shown that the first few weeks of lactation are the most critical in determining the extent of residual effects (Broster et al, 1975) and that the latter is greatest with gross underfeeding resulting in large LW losses which are to be made up in the post feeding period (Broster, 1974). In the review of literature by Broster and Strickland (1977) the more recent experiments generally involved more generous levels of feeding than earlier experiments and in contrast did not always show a residual effect of feeding in early lactation. It was suggested that this may have revealed an upper limit to feeding level in early lactation above which residual effects do not accrue from variation in intake .

In Ngarmasak's (1984) experiment, the very small residual effect (see 3) in 1.1.3) may have been because underfeeding was moderate (the resulting loss of condition was limited), of relatively short duration (three weeks) and did not begin until seven weeks after calving.The much larger residual effect found by Grainger et al (1982) (see 3) in 1.1.3) may be explained by the earlier timing (immediately after calving), the greater severity (evidenced by the greater loss of condition) and the longer duration (five weeks) of underfeeding.

It was found in Grainger and Wilhelms (1979) experiment (described in 2) in 1.1.2), that the residual effect of underfeeding (week 11 to the end of lactation) varied between treatments (HH = LH > HL > LL) but was significant only for the LL treatment (see table 1.3). The residual effect was 1.0 times the immediate effect for 10 weeks of underfeeding and 0.7 times the immediate effect for five weeks of underfeeding. Hence, the timing of underfeeding was not significant but the duration of underfeeding was important, in determining the extent of residual effects.

In contrast to Grainger and Wilhelm (1979), the residual effects of underfeeding were small and non-significant for all treatments in Bryant and Trigg's (1979) experiment, described in 2) in 1.1.2, (see table 1.3).

Furthermore, in a second experiment by Bryant and Trigg (1979), identical twins were used to study the effects of severe underfeeding for 6 weeks after calving. DM intake was reduced by 48% accompanied by a 40% reduction in milk yield and 70 kg loss of LW. Despite this severe underfeeding only small transient residual effects on milk production were observed (approximately 0.7 times the immediate effects on milkfat yield) (see table 1.3). Findings from complete energy balances (carried out indoors during weeks 8-18) supported this observation. Differences in energy partitioning between the previously underfed and well fed cows, although they accounted for about 70% of the milk production differences during weeks 8-18, were the equivalent of only 0.052 kg milkfat/day.

Hence, Bryant and Trigg (1979) showed underfeeding in early lactation has no significant effect on subseqent performance, regardless of the duration and severity of the underfeeding. In view of the conflicting evidence, an interaction between duration and severity could well be important. Such an interaction has not been studied.

1.1.4 Feeding in Early Lactation and Milk Compostion

Underfeeding has variously been reported by early workers to increase, decrease, or have a negligible effect on milkfat concentration (%), depending on the duration and severity of underfeeding (Blaxter, 1950; Burt, 1957). The solids-not-fat (SNF) concentration (%) of milk declines in response to underfeeding, protein concentration (%) more so than lactose concentration (%) (ibid; Broster et al, 1969, 1975; Wright et al, 1974). In agreement with the foregoing, Davey (1983) states that `increasing the level of feeding in early lactation increases the concentration of protein and SNF but has a variable effect on the concentration of milkfat.'

Bryant and Trigg (1982) present a summary of results of the immediate effects of underfeeding in early lactation on milk composition from the experiments presented in table 1.1 together with those of Flux and Patchell (1954), Patchell (1957), Hutton and Parker (1966) and Rogers et al (1979a) (see table 1.6). The effect on milkfat % was highly variable whereas protein % and SNF % tended to decline with underfeeding. In two reports the effects were assessed by multiple regression methods. Stockdale et al (1981) found that milkfat % was unaffected by underfeeding or hay supplementation whereas SNF % was increased by 0.076 units per 1.0 kg increase in DM intake. Rogers et al (1979a) found that milkfat % decreased and protein % increased, each by about 0.08 units per 1.0 kg increase in DM intake.

TABLE 1.6 Summary of Immediate Effects of Underfeeding in Early Lactation on Milk Compostion (from Bryant and Trigg, 1982).

Constituent	Number of Observations	Mean Content for Control	Difference(control-restricted)		
			mean	S.D.	range
fat	17	4.46	-0.09	0.32	-0.8 - + 0.70
protein	18	3.41	0.14	0.18	-0.38 - + 0.36
lactose	4	4.98	0.17	0.23	+0.51 - + 0.05
SNF	4	9.31	0.23	0.10	+0.30 - + 0.08

In a summary of stall feeding and field experiments involving 300-400 cows, Bryant (1979) found that a 50% reduction in intake increased milkfat % by 8% and decreased protein % and lactose % by 6% and 2%, respectively. It was noted that the effects of nutrition on milk composition were determined by stage of lactation and were small relative to the effects of breed and season.

It can be concluded that the immediate effects of underfeeding in early lactation on milk composition are small.

Data on the residual effects of feeding in early lactation on milk compostion are inconclusive (Bryant and Trigg, 1982). Many workers have found levels of milkfat % and/or milk protein % to return rapidly to normal after underfeeding (Glassey,1980; Grainger et al,1982; Flux and Patchell, 1954,1957; Patchell,1957; Wallace,1957). Others have observed significant residual effects on milkfat % and/or milk protein % (Broster et al,1969, 1975; Grainger and Wilhelms,1979; Bryant and Trigg,1979; Le Du and Newberry, 1982).

1.1.5 The Influence of Pre-Partum Nutrition on the Effects of Feeding in Early Lactation

1) European Resarch

The level of feeding before calving and after calving contribute jointly to the attainment of peak milk yield in early lactation. (Broster et al, 1970 cited by Wiktorsson, 1979). From experiments looking at pre-partum nutrition reviewed by Broster (1971), it seems that increasing pre-partum feeding levels to increase rates of LW gain up to 0.5 kg/day allows a greater potential LW loss in early lactation thus lessening the effects of underfeeding during that time on daily milk yield. However, many of the experiments involved roughage/concentrate diets and evidence obtained with grazing cows should therefore be considered.

2) Australasian Research

New Zealand experiments with grazing cows up until the early 1970's have been reveiwed by Grainger and McGowan (1982). The results suggest that cows should not lose body condition during the 8 weeks prior to calving otherwise milk production would suffer. However, in these earlier experiments the effects of LW change in late pregnancy could not be seperated from the effects of LW differences at calving on subsequent milk production.

Experiments carried out by Rogers et al (1979b) in Australia with grazing cows showed conclusively that it is absolute LW or condition at calving which most importantly influences milk yield rather than rates of change in LW or condition prior to calving. Grainger et al (1982), in Australia, carried out experiments which showed a positive, linear relationship between body condition at calving (over the range of condition scores 3-6) and subsequent milk production. This relationship was modified by the feeding level in early lactation such that higher feeding levels increased milkfat production but did not reduce the benefits of calving in a higher condition score (CS).

Residual effects of feeding during weeks 1-5 of lactation were found during weeks 6-20 which equalled 1.6 and 0.7 times the immediate effects on milkfat production for cows calving in CS6 and CS3, respectively.

1.2 GENETIC QUALITY OF THE DAIRY COW AND ITS INFLUENCE ON MILK PRODUCTION

1.2.1 Introduction

The level of milk production achieved by a cow is determined by the product of environmental effects (such as level of feeding, health and management) and effects of cow genotype (Holmes, 1984). Thus, a cow which is genetically superior for milk production will produce the most milk under a given set of environmental conditions. The reasons for increased production due to the genetic improvement of cows fed mainly on pasture are not clearly understood. In particular, there is a lack of experimental evidence on the relation between genetic merit and the efficiency of milk production.

Most experimental work regarding the effects of feeding during early lactation on milk yield and composition has involved cows yielding less than 15 kg milk daily (Bryant and Trigg, 1982). In view of the improvements which are occuring in the genetic quality of livestock and the likelihood of genotype/environmental interactions, e.g. the interaction of genotype with nutrition at different stages of the lactation cycle (Grainger, 1982), there is the need to use genetically superior cows in experiments designed to examine appropriate managment for efficient dairy production.

1.2.2 Genetic Quality in New Zealand

In New Zealand, the genetic merit of dairy cows for milk or milkfat production is indicated by their breeding index (BI) which shows the relative genetic merit of a cow to produce milk or milkfat in comparison to a baseline of 100, representing the average cow in the early 1960's (Holmes, 1984). The method of calculation has been outlined by Holmes (1984). For a cow, BI is a weighted combination of her own production records and the breeding indices of her sire and dam whereas for a bull, BI is a weighted combination of daughter productions and the breeding indices of his sire and dam (Wickham *et al*, 1978).

This system of genetic evaluation forms the basis of the New Zealand Dairy Board's (N.Z.D.B.) scheme of genetic progress. To this end the N.Z.D.B. operates an articial breeding service. Bulls used for semen collection are selected on their BI values which are calculated from herd testing records collected by New Zealand Livestock Improvement Associations.

Evidence for genetic improvement in the milk production of New Zealand dairy cattle due to artificial breeding is discussed by Wickham et al (1978) and Macmillan (1982). It can be seen in the 60th Annual Farm Production Report of the N.Z.D.B. (1983/84) that substantial changes have taken place in the BI values for New Zealand dairy cows and proven bulls used in artificial breeding. Over the years from 1954/55 to 1983/84, the BI of proven bulls has increased from 110 to 138.

Consequently, there has been a corresponding increase in the BI of cows sired by these bulls from 100 to 121. This compares with an increase in the BI of all other cows from 100 to only 113 (the size of the contribution of artificial breeding in the ancestry of these cows is unknown). Further evidence that estimated BI values are a good measure of genetic merit for milk production is provided by Wickham (1979).

Polish work begun in 1974 has compared the genetic merit of `black and white' cattle from different countries. This work is described by Grainger (1982) and MacMillan (1982). Most importantly it has shown that the genetic merit in terms of milkfat and milk yield of New Zealand Friesian dairy cattle, sired by N.Z.D.B. bulls, is among the highest in the world.

1.2.3 The Effect of Genetic Quality on Aspects of Productivity

1) Milkfat Production

Cows of differing BI are expected to differ in milkfat yield by the percentage of their average production which corresponds to their difference in BI units e.g. a cow of BI 120 is expected to outyield a cow of BI 100 by 20% of their average production.

Stall feeding and grazing trials carried out at Massey University and Ruakura Research Centre have shown high breeding index (HBI) cows to produce more milkfat than low breeding index (LBI) cows using Friesians (Grainger et al, 1985a and b, and Ngarmsak, 1984) and Jerseys (Bryant, 1981; Bryant and Trigg, 1981). In all the experiments there was close agreement between expected percentage differences based on BI and actual differences is milkfat yield. Data to illustrate milkfat production differences between HBI and LBI cows are presented in table 1.7.

Table 1.7 Production of High and Low BI Cows (from Bryant, 1981).

Experiment	BI	Number of Cows	Fat Yield (kg/cow)	Days in Milk
1	122	16	180	260
1	101	16	128	258
2	122	22	164	249
2	100	22	126	261

2) Cow Liveweight and Liveweight Change

The trials referred to in the previous section have shown HBI cows to gain less LW and condition over lactation than LBI cows.

experiments at Massey University (Grainger et al, 1985a and b), showed HBI cows were of similar LW and condition at calving but of lower LW and condition throughout lactation than LBI cows. At Ruakura Research Centre it was found that the HBI cows calved at a higher LW but similar condition and that they gained less LW and condition during lactation than the LBI cows (Bryant and Trigg, 1981). Increases in LW during lactation were 14 kg and 31 kg for the HBI and LBI cows, respectively, in one trial reported by Bryant and Trigg (1981).

Grainger (1982) noted that when expressed on a short-term (monthly) basis differences in LW change between HBI and LBI cows during lactation are very small and hence difficult to detect.

3) Level of Feed Intake

i) Lactating Cows. It has generally been shown that intake per unit of metabolic LW ($LW^{0.75}$) in HBI cows is higher than that of LBI cows by both stall feeding and grazing trials (Bryant, 1981; Grainger et al,1985a and b). However, grazing trials and some stall feeding trials have not found differences in intake per animal or per unit of metabolic LW due to BI (Grainger et al,1985a and b; Ngarmsak, 1984).

Bryant (1981) reports three stall feeding experiments in which HBI and LBI cows were fed fresh pasture ad libitum for 2-4 weeks in early to mid-lactation. An average difference in intake of 2.2 kgDM/cow/day was obtained. However, within each BI group daily intake increased by 1 kgDM for each 100 kg of LW and after adjusting for this effect between BI groups the intake difference became 1.1 kgDM/cow/day.

Grainger et al, (1985a and b) found no significant differences in the ad libitum pasture DM intake per cow between HBI and LBI cows in any of their four stall feeding experiments. However, in two of the four trials, metabolizable energy (ME) intakes were significantly higher by about 7% on average for the HBI cows when expressed per unit of metabolic LW, since the HBI cows were heavier than the LBI cows. There were no differences in ME intake per cow or per unit metabolic LW due to cow BI in the grazing trial of Grainger et al, (1985a).

Arave and Kilgour (1982) observed that that there were no differences in grazing, lying or standing times between HBI and LBI cows during early or mid-lactation but that HBI cows grazed significantly longer during late lactation when pasture was less readily available. This would suggest that the small difference in intake between lactating HBI and LBI cows at generous pasture allowances is due to differences in bite size and/or the rate of biting (see 1) in 1.3.6). Furthermore, as pasture availability declines it appears that HBI cows graze more efficiently than LBI cows since they increase their grazing time to a greater extent. However, a possible confounding factor in this study of grazing behaviour was that the HBI cows were on average 28 kg heavier than the LBI cows.

ii) Dry Cows. Work carried out indoors with HBI and LBI cows led Bryant (1981) to conclude that differences in ad libitum intake that occur during lactation are apparently not present during the dry period. Despite this, at a given pasture allowance groups of dry HBI cows have been shown to graze more severely than groups of LBI cows and consequently to achieve higher DM intakes and gains in condition (Bryant, 1983). Cows within groups were of similar condition but overall the HBI groups were of thinner condition than the LBI groups by about 0.5 CS. When grazed as mixed groups, HBI cows were found to outcompete LBI cows of similar condition at restricted pasture allowances and to achieve higher gains of LW and condition (ibid). Such findings support the suggestion made previously that HBI cows graze more efficiently than LBI cows when pasture availability is restricted (bearing in mind that LW and condition may have been confounding factors affecting grazing behaviour).

4) Efficiency of Feed Utilization

i) Digestion of Feed Energy. Energy metabolism studies reviewed by Grainger (1982) have shown that cows differing in productive ability do not differ in the efficiency with which they use ME for total energy balance (although none of the calorimetric balance studies reviewed actually set out to compare cows which differed in their genetic ability to produce milk). Furthermore, Grainger (1982) concluded from nutritional studies that 'high producing' cows do not differ in their ability to metabolize feed energy.

It has been shown that losses of energy in faeces, urine, methane and heat are similar for HBI and LBI cows, whether lactating or dry, thus confirming the above for cows of differing potential due to BI (Bryant, 1981; Grainger et al, 1985b).

ii) Feed Conversion Efficiency. Work at Massey University, in agreement with Ruakura Research Centre, has shown conclusively that HBI cows produce more milkfat in association with both a higher level of feed intake and a higher level of feed conversion efficiency (kg total dietary DM eaten/kg milkfat produced) due to the partitioning of a greater proportion of their ME intake to milk rather than to LW gain (Bryant, 1981; Grainger et al, 1985a and b). Therefore, HBI cows have a higher gross efficiency of milk production (kg milkfat produced/kg total dietary DM eaten) than LBI cows.

Data from three Ruakura trials showing the daily intake, fat yield and gross efficiency of HBI and LBI cows stall fed for 2-4 weeks in early lactation, are presented in table 1.8. Differences in gross efficiency over 105 days of indoor feeding throughout lactation (in another trial) were greater in that gross efficiencies of 52 and 44 gfat/kgDM were obtained for HBI and LBI cows, respectively (Bryant, 1981). This is in agreement with Grainger (1982) who concluded that differences in partitioning of energy between milk and body tissue by different genotypes could be clearly seen over the whole lactation. However in the short term differences in energy partitioning were much smaller and were more difficult to detect.

iii) Marginal efficiency of Milk Production. Experiments with cows of differing genetic potential have shown that at a given level of feed intake, cows of high potential for milk production respond to changes in the level of feeding to a greater extent in terms of milk yield and to a lesser extent in terms of LW gain compared to cows of lower potential (see 3) in 1.1.1; Broster, 1976; Broster and Thomas, 1981). This advantage of cow potential in terms of milk yield response to increases in feeding level has been shown to increase with the basal level of feeding (Broster and Thomas, 1981).

Some experiments however, have failed to observe greater responses from cows of high potential (Jeffrey et al, 1976; Johnson, 1979; Ostergaard, 1979; Steen and Gordon, 1980). Broster and Thomas (1981) have provided an explanation for this apparent conflict in the case of the latter two experiments in which cows were supplemented with concentrates at ad libitum levels of feeding with high quality

TABLE 1.8 Daily Intake, Fat Yield and Gross Efficiency of High (HBI) and Low (LBI) Breeding Index Cows in Early Lactation (n=16) (from Bryant, 1981).

Experiment	Liveweight (kg)		Intake (kgDM)		Fat Yield (kg)		Gross Efficency (g fat/kg DM)	
	HBI	LBI	HBI	LBI	HBI	LBI	HBI	LBI
1	366	320	13.4	11.5	0.83	0.66	62	57
2	373	325	12.3	10.7	0.96	0.73	78	68
3	385	359	16.3	14.3	0.83	0.71	51	50
mean	375	335	14.0	12.2	0.82	0.70	64	58

conserved forages. However the results of the former two conflicting experiments which involved low or fixed levels of feeding, are apparently not explained by Broster and Thomas' (1981) reasoning (see Grainger, 1982). Grainger (1982) concluded that the response to extra feed of 'high producing' cows compared to 'low producing' cows can be influenced by the particular system of feeding and absolute plane of nutrition.

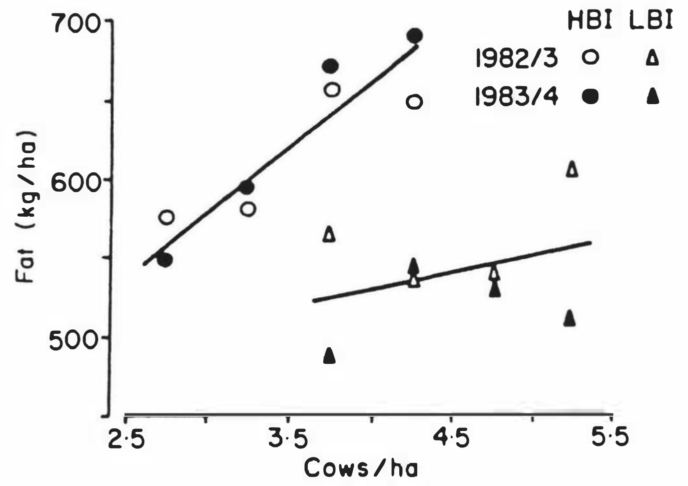
It has been found that the marginal efficiency (kg extra milkfat produced/kg extra feed DM eaten) of HBI cows is not significantly higher than that of LBI cows stall fed on fresh pasture (Bryant, 1981, Grainger et al, 1985a).

5) Farm Productivity

Evidence suggests the productive merit of cows has an effect on farm productivity measured as output/ha (Hutton ,1975 and Gleeson, 1978 - see Grainger, 1982 for a full discussion). It seems that higher output per ha can be achieved with 'high producing' cows but that their relative production advantage declines at high stocking rates.

These results have been confirmed for cows of HBI in work carried out at Ruakura Research Centre evaluating the effects of cow quality on farm production (Bryant, 1984). Data from two farmlet trials carried out over consecutive seasons are presented in figure 1.2. It can be seen that the increase in milkfat/ha as the stocking rate of HBI cows increased, was greater than that for the LBI cows. At 4.3 cows/ha the average production for the HBI and LBI farms was 680 and 535 kg fat/ha respectively, representing a 27% advantage to the HBI cows. Bryant (1984) attributed this superiority of the HBI cows to their higher daily production and food intake, longer lactations, higher feed conversion efficiency, more efficient grazing and possibly to a greater ability to recover from periods of underfeeding.

FIGURE 1.2 Effect of Cows of High (HBI) on Low (LBI) Breeding Index on Fat Production (from Bryant, 1984). Data for 1983/84 are up until April, 1984.



1.2.4 Metabolic and Physiological Differences between Cows of High or Low Genetic Potential

The metabolic and physiological mechanisms by which HBI cows produce more milk have not been clearly established. Lactating HBI cows produce more milk due to their ability to eat more and to partition a greater proportion of ingested nutrients to the mammary gland. Therefore it is to be expected that cows vary genetically in their 'homeorhetic ability' i.e. the ability to co-ordinate metabolism in various tissues to support a physiological state (Bauman and Currie, 1980). It has been pointed out that this variation could involve inherited differences in circulating hormones, in numbers of hormne receptors in a target tissue and in the synthesis/degradation of regulatory enzymes (ibid).

Due to the likely role of growth hormone as a homeorhetic regulator in association with its lipolytic (mobilization of bodyfat reserves) effect (Bauman and Elliot, 1983), differences in the levels of this hormone between cows of high and low genetic potential have been implicated as an explanation for the differences in milk production (Grainger, 1982). However, recent work with high and low yielding cows underfeeding in early lactation, have involved cows of higher productive potential than earlier experiments and have shown only small residual effects on milk production (Bryant and Trigg, 1982). Bryant and Trigg (1979) emphasized that the cows in their experiment were high producing by New Zealand standards and that this was probably a factor accounting for the conflict between their results and those reported earlier which had found large residual effects (see 1.1.3).

Ngarmsak (1984) used 24 HBI/ LBI cows in a grazing experiment for 3 weeks in early lactation. Results are presented in table 1.9. It was found that the immediate effects of a change in feeding level did not differ between HBI and LBI cows in agreement with Bryant (1981) and Grainger et al (1985a and b). However, in contrast to what might have been expected, no difference was found between the HBI and LBI cows in the residual effect of underfeeding which in both cases was small.

TABLE 1.9 The Effect of Three Weeks of Underfeeding in Early Lactation on the Milkfat Production (kg/cow) of High Versus Low Breeding Index (BI) Cows (adapted from Ngarmsak,1984).

	High BI Cows			Low BI Cows		
Stage of Lactation (weeks)	Gen.	Res.	Gen. - Res.	Gen.	Res.	Gen. - Res.
Experimental						
8-10	21.5	18.6	2.9	20.5	17.2	3.3
Post Experimental						
11-27	78.4	78.2	0.2	72.3	70.7	1.6
Residual Effect of Underfeeding		0.1			0.5	

Note: Gen. = Generous Pasture Allowance
Res. = Restricted Pasture Allowance

1.3 VOLUNTARY FOOD INTAKE BY GRAZING COWS

1.3.1 Introduction

The potential intake of a ruminant is determined by various physiological and anatomical factors together with characteristics of the diet. Achievement of the ruminant's potential intake depends on has shown no differences in circulating levels of growth hormone when feed intake was equalized relative to cow reqirements (Hart, 1983). Furthermore, work with HBI and LBI cows at Massey University has failed to show significant differences in mean blood concentrations of growth hormone, free fatty acids (break-down products of bodyfat) or β-hydroxy butyrate (a major precursor of bodyfat) for both ad libitum and restricted feeding levels (Davey et al, 1983; Flux et al, 1984).

Since glucose has a central role in milk synthesis it is likely that differences in levels of this metabolite and its major regulatory hormone, insulin, exist between cows of HBI and LBI. In work carried out at Massey University HBI cows on a restricted feeding level had plasma glucose concentrations similar to those of cows on an ad libitum feeding level ($P > 0.05$) and higher than LBI cows on the same restricted feeding level ($P < 0.05$) (Davey et al, 1983; Flux et al, 1984). Plasma concentrations of insulin were higher in restricted HBI cows than in ad libitum fed cows and restricted LBI cows ($P < 0.01$) (ibid). Furthermore, glucose infusions produced similar increases in glucose and insulin concentrations for both BI groups ($P > 0.05$) thus failing to indicate any marked differences in insulin secretion in response to increased concentrations of glucose (ibid). Therefore, it appears that HBI cows are less sensitive to the effects of insulin thus reducing glucose use by peripheral tissues and consequently increasing glucose availability to the lactating mammary gland (ibid). Flux et al (1984) tentatively attributed the exceptionally high insulin concentrations of the HBI restricted cows to higher rates of corticosteroid secretion by HBI cows especially during underfeeding.

1.2.5 The Interaction between the Effects of Genetic Quality and Level of Feeding on Milk Production

From the literature reviewed in 4) in 1.2.3, it appears that the marginal efficiency of cows of high genetic potential is no different to that of cows of low genetic potential, particularly when stall fed on fresh pasture (Bryant, 1981; Grainger, 1982). On this basis, it is to be expected that the immediate effects of underfeeding on milk production are similar for HBI and LBI cows.

However in view of the differences between HBI and LBI cows in the partitioning of feed energy towards milk production it is possible that there are differential effects during underfeeding on changes in LW and condition which give rise to differences in the extent of residual effects on milk production. Recent experiments on the effects of underfeeding in early lactation, have involved cows of higher productive potential than earlier experiments and have shown only small residual effects on milk production (Bryant and Trigg, 1982). Bryant and Trigg (1979) emphasized that the cows in their experiment were high producing by New Zealand standards and that this was probably a factor accounting for the conflict between their results and those reported earlier which had found large residual effects (see 1.1.3).

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Experimental						
8-10	21.5	18.6	2.9	20.5	17.2	3.3
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11-27	78.4	78.2	0.2	72.3	70.7	1.6
Residual Effect of Underfeeding		0.1			0.5	

Note: Gen. = Generous Pasture Allowance
Res. = Restricted Pasture Allowance

1.3 VOLUNTARY FOOD INTAKE BY GRAZING COWS

1.3.1 Introduction

The potential intake of a ruminant is determined by various physiological and anatomical factors together with characteristics of the diet. Achievement of the ruminant's potential intake depends on limitations imposed by food availability and environmental conditions.

In the grazing situation, herbage availability may be restricted by a variety of sward characteristics and factors of management origin. Furthermore, the following environmental factors can limit intake due to their effects on eating behaviour : ambient temperature (modified outdoors by air movement, humidity and solar radiation), water availability, rainfall, daylength and the season of growth of herbage. On this last point, lower voluntary feed intakes have been associated with ruminants fed autumn grown herbage as opposed to spring grown herbage which is thought to be due to an effect of the season on herbage chemical composition and differences between seasons in daylength (Reed, 1978).

1.3.2 Intake Regulation

The most important factor limiting voluntary intake in ruminants feeding on coarse forages is rumen fill. Experimental evidence has shown that the regulation of intake is biphasic (Conrad et al, 1964; Dinius and Baumgardt, 1970; ARC, 1980). During phase one intake is restricted physically (primarily due to rumen fill). In phase two intake is unrestricted but controlled at a level depending on the ruminant's metabolic requirements.

1) Phase 1 - The Restriction of Intake by Physical Factors

Intake is determined by the rate at which digesta are removed from the rumen by absorption of digestible components and the passage of indigestible components through the alimentary tract to be excreted as faeces. These processes are influenced by the same factors which determine the digestibility of a feed e.g. crude fibre %. With slower rates of digestion and passage (implied by decreasing digestibility), intake is more physically restrained by rumen fill. Hence digestibility and other factors which influence rumen fill (such as animal size and fatness) also limit intake.

2) Phase 2 - The Control of Intake According to Metabolic Demand

With feeds of high digestibility (such as concentrates), intake is unlimited by physical restrictions due to rumen fill. It is then controlled at a level determined by the ruminant's nutrient requirements for maintenance, support of a given physiological state (growth, pregnancy, lactation) and level of production.

Feed intake is usually described in terms of energy since it is assumed that energy intake is the major limiting factor to production and that provided energy requirements for production are met, protein, mineral and vitamin requirements will not usually be limiting.

3) Physiological Mechanisms

The initiation of feeding seems to occur in response to a relative deficit of energy to supply requirements (Forbes, 1980, 1983). During the physical phase of intake regulation, rumen fill is thought to restrict intake by physical stimulation of stretch receptors in the rumen wall. Such receptors have been identified electrophysiologically by Leek and Harding (1975).

When no restrictions are placed on intake, feeding is stopped in response to one or more satiety signals indicating that the animal's energy requirements have been met (Forbes, 1983). Such signals could be metabolic and/or hormonal; acetate, propionate and cholecystokinin all seen to be important as signal substances (Smith et al, 1974; Meijs, 1981). It seems likely that the liver plays an important role in receiving these humoral satiety signals and transmitting the information to the hypothalamus (Forbes, 1983).

In the long term, there are feedbacks from bodyfat reserves which modulate the short term control of feed intake to provide long term stability of body weight and compostion (Forbes, 1983). The mechanism of the negative feedback from fat on feeding is not yet clear and it may only be speculated that the effect of fat on feeding is similar for ruminants compared to rats but modified by the effects of artificial selection for rapid rates of fattening (ibid). The latter situation may be extended to selection for high yielding cows, a characteristic of which is the ability to produce more milk at the expense of bodyfat reserves.

1.3.3 The Restriction of Intake by Rumen Fill

Whether or not rumen fill limits intake depends on the equilibrium between degree of fill, stretch of the rumen and rates of digestion and passage (Van Soest, 1982). Certain other factors may also restrict intake independently of rumen fill e.g. nutrient deficiencies in the feed ingested, acidic conditions in the rumen, food palatability and toxic substances (ibid). Factors which affect intake through their influence on rumen fill will now be considered.

1.3.3.1 Animal Factors

The effect of gut capacity on intake has clearly been demonstrated by displacement of the gastrointestinal space with inert material such as balloons, sponges or plastic ribbons (Van Soest, 1982). Gut capacity is most importantly determined by size of the alimentary tract and abdominal cavity which is closely related to size of the ruminant. According to Bines (1979), it may be argued that an increase in LW without change in body composition will be accompanied by a similar increase in body volume and hence in gut capacity. Therefore, intake will be linearly related to LW (at comparable fatness). Thus, Conrad et al (1964) have shown intake to be proportional to $LW^{1.0}$ when rumen fill is limiting intake for feeds of low digestibility (52-66%). LW varies with breed, sex and age and hence these factors also influence intake through rumen fill.

Gut capacity may further be limited by displacement of the abdominal cavity into which the rumen expands during eating. This can be caused by fat deposits within and around the abdominal cavity or by foetal displacement during late pregnancy. Bines et al (1969) observed that thin cows ate more hay than fat cows with no difference in the mean retention time of digesta in the rumen. An effect of fatness on intake independent of rumen fill was also demonstrated.

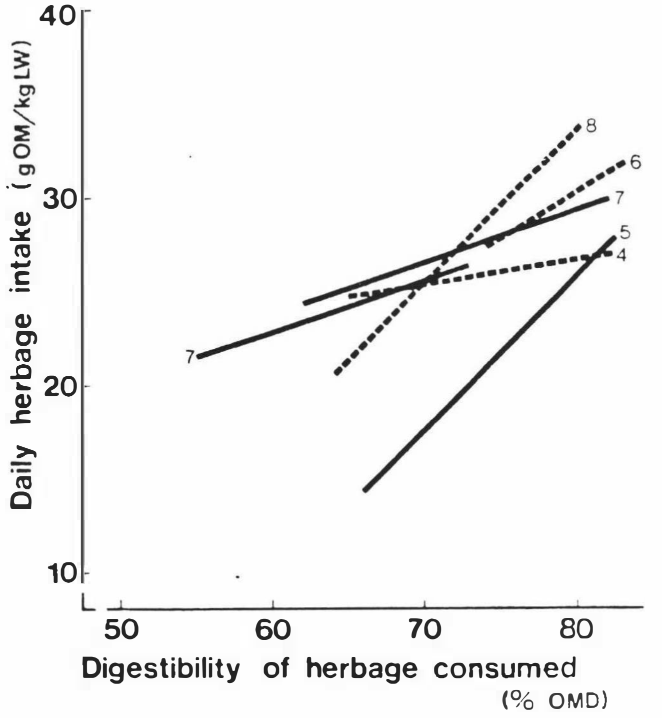
1.3.3.2 Food Characteristics

1) Digestibility

Digestibility has long been pointed to as a major factor influencing intake since digestibility is determined by the same factors which determine rumen fill i.e. indigestibility, rates of digestion and retention time. Hodgson et al (1977) found the organic matter digestibility of the herbage selected had a dominant influence on the intake of strip grazed calves. Experiments with cattle grazing temperate swards (reviewed by Hodgson, 1977) have shown a significant and constant rate of increase in herbage intake over the full range of digestibility values studied, i.e. 55-85%, as is illustrated in figure 1.3.

In contrast to Hodgson (1977), Balch and Campling (1969) reviewed early indoor trials and concluded that intake increases linearly with digestibility up to a value of only 65-70% above which intake changes little. However, Hodgson (1977) further reports that the results of

FIGURE 1.3 The Relationship between Digestibility of the Diet Selected (OMD%) and the Herbage Intake (g OM/kg liveweight) of Lactating Cows (----) and Growing Calves(____)(from Hodgson, 1977).
References as indicated on the figure are as follows:-
4 = Corbett (1963)
5 = Hodgson (1968)
6 = Holmes (1972)
7 = Rodriguez Capriles (1974)
8 = Stehr (1976)
For references 4,5,7 and 8, equations are quoted by authors(modified where necessary to a common LW base) For reference 6, equation calculated from authors' data. No equations differed significantly from linearity.

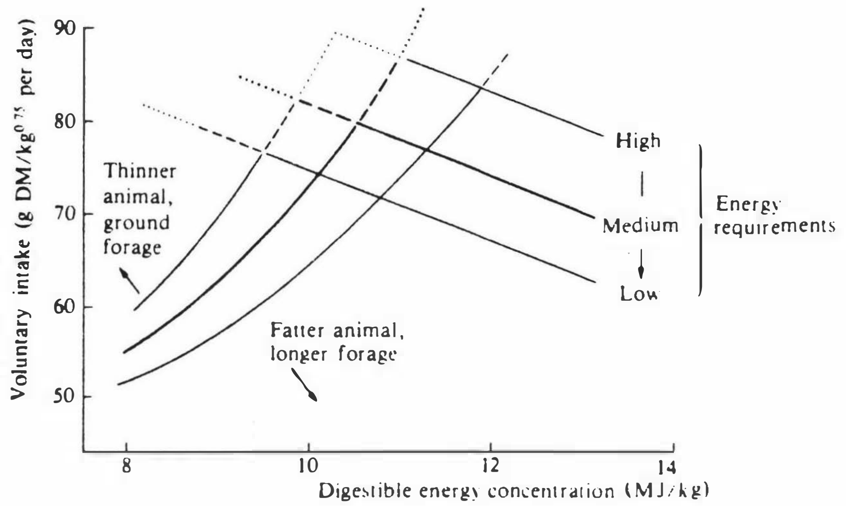


several more recent indoor trials with extensive series of fresh, frozen or dried forages support the results obtained with grazing cattle.

The different intake/digestibility relationships obtained may be partly explained by the fact that the early work was carried out with mature, non productive animals whereas the more recent work relates principally to lactating cows or animals with some capacity for growth (ibid).The higher the metabolic demand of a ruminant, the higher is the digestibility of it's diet to which rumen fill limits intake as is illustrated in figure 1.4. Furthermore, in the grazing situation sward characteristics (such as herbage mass and sward canopy structure) interact with each other and with digestibility to produce responses in herbage intake that may not be obtained in indoor feeding trials.

The digestibility of the plant components selected from a sward will therefore exert a dominant influence on ruminant intake and performance

FIGURE 1.4 Composite Diagram of Relationships between Voluntary Intake and Animal and Food Factors in Ruminants (from Forbes, 1983).



over a wide range of digestibilities for animals of high nutrient demand on a forage diet, particularly in the grazing situation.

2) Density

Dietary density (the volume occupied per unit weight of indigestible material) is another factor influencing rumen fill. Petersen and Baumgardt (1969) (cited by Baumgardt,1970) concluded from work with rats that energy density (MJ DE/unit volume) was a better predictor of intake than energy concentration (MJ DE/kgDM) alone. Therefore, at a given level of digestibility, feeds of higher density such as ground forages will be associated with higher intakes than feeds of lower density such as longer forages (see figure 1.4).

3) Cell Wall Content

The cell wall content (CWC) of a diet, i.e. the content of structural carbohydrates (cellulose, hemicellulose, lignin and silica), has recently been established as the primary feed characteristic responsible for the effect of rumen fill on intake (Van Soest, 1982). Intake is dependent upon the structural volume of a feed (as it affects rumen fill) and, therefore, CWC. Digestibility is dependent upon the CWC of a feed and its availability to digestion as determined by lignification and other factors. Thus, intake is only indirectly related to digestibility. Supporting evidence for the primary influence of CWC on intake is expounded upon by Van Soest (1982).

Differences in intake between species/varieties of pasture plants at the same level of digestibility have been shown which have been attributed to differences in crude fibre% related to CWC (Raymond, 1969). For example, indoor feeding trials have demonstrated higher intakes for legumes than for grasses at the same digestibility (ibid).

4) Mechanisms by which Feed Characteristics Influence Intake through Rumen Fill

Forages sometimes differ in the intakes they promote independently of differences in rumen fill and it appears that CWC affects intake through the alleviation of rumen fill (Van Soest, 1982). Rumen fill is alleviated by the rate of digestion (k_d) and the rate of passage (k_p) of which the latter is best related to intake (ibid). Since k_p is dependent upon the rate of breakdown of particles into sizes small enough to pass from the rumen, the importance of rumination and particle breakdown in the alleviation of rumen fill is emphasized. Evidence points to the association of CWC with this effect (Van Soest, 1982).

5) Factors Influencing the Characteristics of Herbage Ingested by Grazing Cows Affecting Intake

i) Sward Maturity. The ratio of plant leaf:sheath:stem, changes with stage of plant growth (depending on plant species or variety) and seasonal effects such that there is variation in plant digestibility and CWC. Hutton (1962) reports the results of 120 digestibility trials in which non-lactating identical twin cattle were fed fresh herbage indoors for six months. Seasonal changes in the apparent digestibility of energy were traced. Corbett et al (1963) found that as pasture digestibility declined during the spring from 80% to 68%, it was accompanied by a fall of about 20% in digestible organic matter intake (DOMI) by lactating cows. Seventy five % of this decline in intake was due to the decline in digestibility. The effect of sward maturity on sward characteristics (such as herbage mass and sward canopy structure) must also be borne in mind since these may influence intake by grazing cows independently of digestibility.

ii) Botanical Composition. At the same physiological stage of growth, pasture species/varieties have been shown to vary in digestibility thereby affecting intake as a result of differences in the ratio of leaf:sheath:stem (Raymond, 1969; Smetham, 1973). For example, ryegrass has been found to be more digestible than cocksfoot at similar stages of growth and in perennial ryegrass the tetraploid variety more digestible than the diploid variety S24 (Dent and Aldrich, 1968).

iii) Selective Grazing. As sward complexity (in terms of structure and composition) increases and the efficiency of grazing (in terms of the amount of herbage per grazing animal) declines, the impact of selective grazing increases (Hodgson, 1977). Cows select young, green, leafy material in preference to old, dead, stemmy material resulting in a diet of improved nutrient content compared to that of the sward as a whole and therefore intake is higher than expected (Hodgson, 1982).

1.3.4 The Control of Intake by Energy Demand

At any one time the total demand for energy by the grazing ruminant depends upon interactions among genotype, body size, fatness, the potential energy loss due to lactation, energy expenditure in exercise and grazing and expenditure in countering climatic effects.

1) Cow Liveweight

For feeds of high digestibility when rumen fill is no longer a limiting factor, intake is proportional to metabolic LW ($LW^{0.75}$) for an animal of given physiological state, as has been shown by Conrad *et al* (1964). Such a relationship arises from the reasoning that maximal feed capacity is related approximately to basal metabolism (Brody, 1945) and that there is a linear correlation between the logarithm of basal metabolism and the logarithm of LW showing that basal metabolism is proportional to a given power function of LW i.e. metabolic LW (Kleiber, 1961). The power of 0.75 is conventionally used to calculate cow metabolic LW and gives reasonable agreement in most cases. However, the power at which LW is best related to intake can vary with such factors as breed, sex and age of the animal and of course whether or not rumen fill is a limiting factor as discussed previously (Meijs, 1981).

2) Cow Condition(fatness)

Bines *et al* (1969) found thin cows ate more of a high concentrate diet than fat cows thus demonstrating an effect of fatness which was independent of rumen fill. There is little information available about this effect for grazing animals (Meijs, 1981).

Hodgson (1977) has presented data for grazing cattle which illustrate the change in energy demand and hence herbage intake per unit LW due to age, pregnancy and lactation. Intake was found to vary significantly between pregnant heifers, calves and lactating cows within each of three periods.

3) Pregnancy

The demands of pregnancy are small in relation to the demands imposed by the lactating mammary gland and it is not until late pregnancy that foetal requirements become important when paradoxically, there is a decline in intake. This decline has been ascribed to a decreased effective rumen volume and a change in endocrine balance (Bines, 1976b; Forbes, 1970).

4) Lactation

An increase in energy demand and hence intake occurs with lactation. Lactating cows eat 35-50% more than non-lactating cows of the same weight and on the same diet (ARC, 1980). A 50% difference in the herbage intake of stall fed lactating and non-lactating twin cows by the fifth month of lactation has been demonstated by Hutton (1963).

5) Stage of Lactation

The rise and fall of intake with stage of lactation following the rise and fall of milk yield has been clearly documented (Bines, 1979). However there is a problem in relating intake to the level of milk yield in lactating cows due to the mobilization and storage of body reserves. In early lactation peak intake is reached sometime after peak milk yield and LW is lost in compensation (ibid). Reasons for this lag of intake behind milk yield are unclear. Various suggestions include : gradual hypertrophy of the alimentary tract (Tulloh, 1966); time taken for the rate of metabolism in the rumen and tissues to adapt to the increased nutrient demand after calving (Bines, 1976a); time taken for the mobilization of abdominal fat deposited before calving to allow maximum rumen fill (ibid); an influence of endocrinal factors on intake in early lactation (Forbes, 1970) and the release of free fatty acids from adipose tissue after calving corresponding to a low intake (Journet and Remond, 1976).

A physical limitation on intake with long roughages seems likely, especially in early lactation when energy demands of lactation are relatively high (Forbes, 1970). Peak intake is reached earlier after calving with diets of higher metabolizability (Journet and Remond, 1976). However, physiological limiting factors are also implied since complete equilibration of intake with energy output has not been achieved in experiments in which high levels of concentrates were fed ad libitum in early lactation (Bines, 1979). Possibly this is due to accumulation in the rumen during eating of the end products of fermentation but attempts to rectify this situation through neutralization by buffers have not been completely successful (ibid). Clearly more work is required.

Problems associated with the measurement of intake for grazing cows further increase the difficulty of relating intake to level of milk yield (see 4.1.1).

6) Cow Genetic Potential

Increased intake per unit of LW and metabolic LW by cows of superior genotype has been demonstrated (Bryant and Trigg, 1981; Grainger et al, 1985a and b). t'Hart (1979) (cited by Meijs, 1981) found a significant, positive relationship between the intake of grazing cows and the level of daily milk yield at comparable stages of lactation. ARC (1980) quote a value of 0.2 kgDM increased intake per kg increase in fat corrected milk per day for diets of 55-65% metabolizability (as representative of short term trials).

However these increases in intake account for only a portion of the increase in milk yield since cows of high potential partition food energy more efficiently towards milk production, storing less energy as bodyfat (Grainger et al, 1985a).

1.3.5 Herbage Allowance and its Relationship with Herbage Intake

1) Herbage Allowance and Herbage Intake

Herbage allowance or its reciprocal, grazing pressure, (see table 1.10 for definitions) is usually the single most important factor influencing herbage intake in the grazing situation. Rattray and Jagusch (1978) suggest that the allowance of pasture (see table 1.10) is probably the single factor that is responsible for differences in production per animal between farms, between years and between stocking rates under New Zealand pastoral conditions.

Leaver (1976) has described the theoretical relationship between the amount of herbage offered and intake. Animal intakes are maximal at low grazing pressure where large quantities of herbage are available. As grazing pressure is increased, animal intakes decline initially very slowly and eventually more rapidly. Finally a point is reached where the herbage is inaccessible in the base of the sward and intakes reach zero.

Gordon et al (1966), Greenhalgh et al (1966; 1967) Combellas and Hodgson (1979) and Le Du et al (1979) have all demonstrated that the actual relationship between daily herbage allowance and herbage intake of grazing dairy cows is asymptotic such that intake declines at a progressively faster rate when the daily allowance is reduced below a critical level. Essentially similar relationships have been demonstrated for lambs and calves under strip grazing management by

Gibb and Treacher (1976), and Jamieson (1975) cited by Combellas and Hodgson (1979).

2) New Zealand Experiments with Grazing Dairy Cows

Data from New Zealand experiments on the relationship between herbage intake and herbage allowance involving rotationally grazed (as

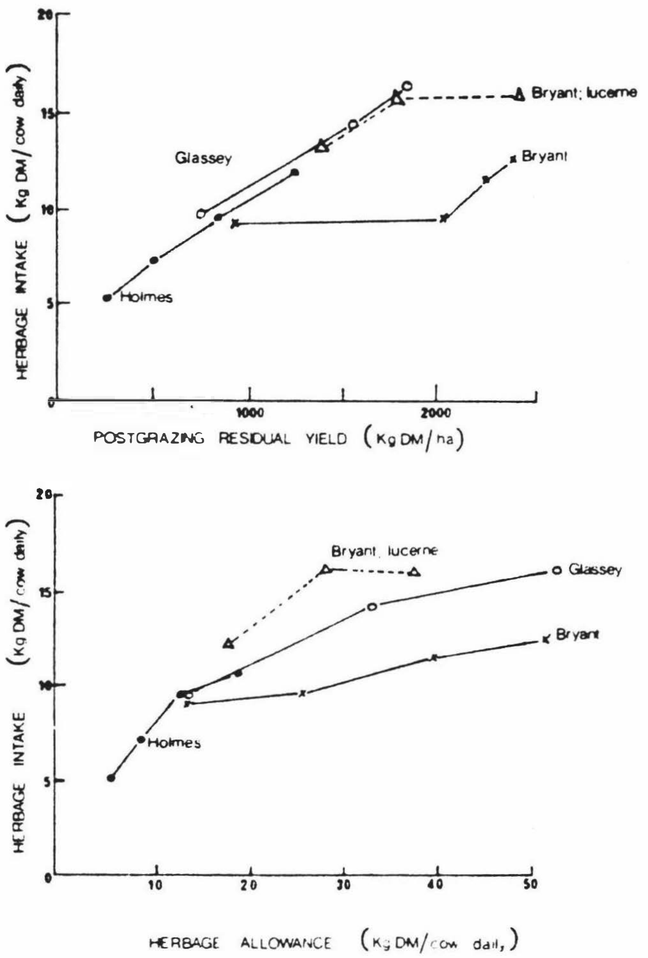
TABLE 1.10 Definitions of Terms Used in Relation to Grazing Animals (based on Hodgson, 1979).

TERM	DEFINITION
SWARD	The above- and below-ground parts of a population of herbaceous plants, characterized by a relatively short habit of growth and relatively continuous ground cover.
SWARD CANOPY	The above-ground parts of a sward (as defined above). This term carries with it connotations of the distribution and arrangement of the constituent plant parts to distinguish it from 'herbage'.
HERBAGE	The above-ground parts of a population of herbaceous plants, viewed as an accumulation of plant material with characteristics of mass and nutritive value, but no connotations of organization or structure.
PASTURE	An area of sward, usually bounded by a fence, considered as a functional unit for grazing.
HERBAGE MASS	The instantaneous measure of the total weight of herbage per unit area of ground, preferably measured to ground level.
HERBAGE ALLOWANCE	The weight of herbage available per unit of animal liveweight or, more commonly, per animal at a point in time.
GRAZING PRESSURE	The number of animals of a specified class per unit weight of herbage at a point in time.
RESIDUAL HERBAGE MASS	The mass of herbage remaining after grazing.
GRAZING EFFICIENCY	Herbage intake expressed as a proportion of the herbage accumulated.
NUTRITIVE VALUE	The concentration of nutrients (usually digestible energy) per unit weight of herbage.

Note:- Weight of herbage is best expessed in terms of dry or organic (ash-free) matter.

opposed to set-stocked) dairy cows, are presented in figure 1.5. and table 1.11. All the experiments show similar trends of increasing

FIGURE 1.5 Data from New Zealand Experiments in which Cows Grazed on Pasture or Lucerne (from Holmes and Macmillan, 1982).



herbage intake (kgDM/cow/day) with increasing herbage allowance (kgDM/cow/day). Associated with increasing herbage allowance are increasing residual herbage mass after grazing (kgDM/ha) and decreasing grazing efficiency for a single grazing (see table 1.10 for definitions). Thus, it is not possible to achieve maximum herbage intake per cow and a high grazing efficiency simultaneously.

It can be seen from figure 1.5 that the relationship between herbage allowance and herbage intake is curvilinear which is in agreement with the literature reviewed in 1) in 1.3.5. The rate of increase in intake with allowance falls as allowance increases until an allowance is reached beyond which intake is no longer limited by herbage availability and remains at a constant, maximal level which is

TABLE 1.11 Values for Herbage Allowance, Intake and Residual Yields from Experiments with Dairy Cows (from Holmes and Macmillan,1982).

	Herbage Allowance (kgDM/cow)	Herbage Intake (kgDM/cow)	Post-Grazing Residual Yield(kgDM/ha)
LACTATING COWS			
Bryant (1980)			
Paspalum, ryegrass,	52	12.5	2,390
clover. 3,100kgDM/ha	40	11.6	2,250
before grazing.	26	9.4	2,010
	13	9.1	920
Glassey et al (1980)			
Ryegrass,clover.	53	16.3	1,850
2,700kgDM/ha before	33	14.3	1,550
grazing.	14	9.6	750
Bryant (1978)			
Lucerne.	38	16.0	2,420
4,200kgDM/ha	23	16.0	1,790
before grazing.	18	12.1	1,380
DRY COWS			
Holmes and McClenaghan (1980)	19	11.9	1,220
2,850 to 4,020 kgDM/ha	13	9.6	815
before grazing.	9	7.3	500
	6	5.1	260

determined by physical and metabolic factors of the animal and its diet (see 1.3.3 and 1.3.4).

It is also apparent from figure 1.5 that the actual quantitative relationship between intake, allowance and residual mass varied quite markedly between experiments. Reasons for such variation most importantly include :

(a) differences in the base level to which intake, allowance and residual mass were measured,

(b) animal factors e.g. breed (Jersey versus Friesian) and physiological state (dry cows versus lactating cows),

(c) differences in herbage quality e.g. DM digestibility (due to differences in stage of maturity, botanical composition and selective grazing) and

(d) variation in sward characteristics e.g. herbage mass on offer (kgDM/ha) and sward canopy structure (see definitions in table 1.10).

Sward characteristics are commonly a confounding influence in herbage allowance/herbage intake experiments. Thus, any relationship between intake, allowance and residual mass will apply only to the particular set of sward characteristics under which it is determined (Holmes, 1984). With regard to points (c) and (d) above, allowance and residual mass should probably be expressed as kg digestible DM/ha or kg leaf/ha in order to give greater precision to the relationships (Holmes and Macmillan, 1982).

1.3.6 The Influence of Sward Characteristics on Herbage Intake

1) Ingestive Behaviour of the Grazing Animal

Non-nutritional characteristics of the sward, associated primarily with variations in the mass of herbage and its distribution within the foliage canopy, may restrict the intake of grazing animals (Hodgson, 1977). It was first shown conclusively that such restrictions are due to behavioural limitations (as well the intake regulatory mechanisms discussed in previous sections of this review) by Chacon and Stobbs (1976) for cows grazing sub-tropical swards. Jamieson and Hodgson (1979a and b) have confirmed this for animals grazing temperate swards.

Allden and Whittaker (1970) have defined the herbage intake (I) of an animal as the product of the rate at which it eats (RI) and the time spent grazing (GT). The rate of herbage consumption (RI) is itself the product of the amount of food ingested per bite (IB) and the rate of biting (RB), so that :

$$I = IB \times RB \times GT \quad \text{(Hodgson, 1982)}$$

Such a view, although mechanistic, provides a convenient basis for considering the influence of sward characteristics on intake. Bite size (IB) is usually subject to substantially more variation than either RB or GT (Hodgson, 1982). When IB is depressed, RB and/or GT are increased in compensation but this is seldom sufficient to avoid some reduction in intake (ibid).

2) Gross Sward Characteristics and Herbage Intake

According to Hodgson (1977), herbage intake usually increases at a progressively decreasing rate with increase in either herbage mass or sward height. However, there is marked variation in the pattern of response observed in individual studies (Hodgson 1977). This variation may be partly accounted for by differences in techniques of measuring sward characteristics and intake (ibid) and also the confounding influence of concomitant changes in the nutritive value (defined in table 1.10) of the herbage ingested (Hodgson, 1982). Furthermore, it has been suggested that other sward characteristics, namely bulk density of herbage within the sward (weight per unit volume) and the extended height of leaves or tillers (as opposed to surface height of the sward), may provide a more adequate description of sward availability (ibid).

i) Herbage Mass. The effects of herbage mass and herbage allowance on intake have often been confused in grazing studies. For instance, Le Du et al (1981) varied the herbage allowance of continuously stocked dairy cows by varying herbage mass and obtained a positive relationship with intake whereas Combellas and Hodgson (1979) found a negative relationship between herbage mass and intake at equal levels of herbage allowance for strip grazed dairy cows. Meijs (1982) carried out two trials with stall fed and grazing cows in which herbage mass was varied by varying sward maturity with daily herbage allowance kept equal. There were no significant effects of mass on daily organic matter intake from herbage for both stall fed and grazing cows. A probable explanation for this lack of effect was suggested as being the high level of herbage digestibility which for all treatments exceeded 70%.

Herbage mass appears to have little use as a non-nutritional sward characteristic in accounting for variation in herbage intake.

ii) Bulk Density. The effect of bulk density on intake has seldom been examined in grazing studies (Hodgson, 1982). Significant relationships between leaf bulk density and bite size have been demonstrated by Stobbs (1975) for cattle grazing tropical swards but the effects of leaf density and leaf:stem ratio could not be separated.

iii) Sward Height. According to Hodgson (1982), variations in herbage mass and in surface height are often closely correlated and tend to influence intake in the same way. Measurements of sward height in terms of the extended height of leaves or tillers may however give a quadratic relationship with intake declining on either side of an optimum extended height (Hodgson, 1982). The usual interpretation of such an observation is usually in terms of the increasing difficulty of prehending and ingesting both excessively long and very short leaves from the sward (ibid). Furthermore, Hodgson (1982) suggests that the phase of increasing intake or rate of intake with increasing height is usually apparent in temperate swards whereas in tall-growing tropical swards the phase of declining intake with increasing height is more common.

4) Sward Structure and Herbage Intake

It seems that measurements of gross sward characteristics are likely to be inadequate in themselves to explain variations in grazing behaviour and hence herbage intake (Hodgson, 1977). Instead, a more detailed description of sward structure is required which would seem to incorporate descriptions of the distribution of plant components within the vegetation canopy, and particularly their association with short-term measurements of ingestive behaviour within specified sward strata (Hodgson, 1982). The results of studies involving this approach have indicated differences between temperate and tropical swards in the sward descriptions which best explain variations in intake such that for temperate swards intake appears to be most sensitive to height of the grazed surface while for tropical swards herbage bulk density has a greater influence on intake than sward surface height (*ibid*).

CHAPTER TWO

METHODS AND MATERIALS

2.1 AIMS OF THE EXPERIMENT

(1) To evaluate the effects of underfeeding for four weeks in early lactation on immediate and subsequent milk yields per cow and on milk composition.
(2) To examine the influence of cow genetic merit on the results obtained.
(3) To measure post treatment effects on herbage intake.

2.2 EXPERIMENTAL ENVIRONMENT

The experiment was carried out during the 1983-1984 dairy season at the Dairy Cattle Research Unit, Massey University (Palmerston North, New Zealand). Approximately 100 cows plus their replacements are milked on an area of 45 ha. The herd consists of about 25 pairs of monozygotic twins and about 50 Friesian cows of high (H) or low (L) breeding index (BI). The latter have been identified by the Farm Production Division of the N.Z. Dairy Board and purchased from N.Z. dairy farmers (Davey et al, 1983).

Pastures are mainly a mixture of perennial rye grasses (Lolium spp.) and white clover (Trifoliun repens) with small amounts of cocksfoot (Dactylis glomerata), prairie grass (Bromus uniloides) and red clover (Trifolium pratense). The soil type is Tokomaru silt loam which has been tile and mole drained. Topdressing with superphosphate is carried out annually.

2.3 OUTLINE OF THE EXPERIMENT

2.3.1 Statistical Design

Thirty two HBI/LBI cows in their second or subsequent lactation (three-year-olds versus mature cows) were used in a 2X2 factorial, repeated measurement experiment of randomized block design. The treatments imposed were cow BI and feeding level, each at two levels.

Thus there were four treatment combinations or groups defined as follows :

Treatment Group	Cow BI	Feeding Level
(1)	high	restricted
(2)	high	ad libitum
(3)	low	restricted
(4)	low	ad libitum

Within each group, cows were blocked on age so that during analysis of the results the effect of age could be removed before examining treatment effects.

2.3.2 Cow Selection and Relevant Data

Thirty two cows were available from the HBI/LBI herd at the beginning of the 1983-1984 season for the present experiment. Cows were grouped according to their age and BI. Average BI values were 127 and 103 for the HBI and LBI cows, respectively. Using a random numbers table, cows from each age and BI group were randomly allocated to a feeding level treatment. This resulted in four treatment groups (as defined above) each containing six mature and two three-year-old cows (eight in total).

The experimental cows calved over eight weeks with the mean calving date 17th August. At the beginning of the experiment (12th September) the cows were on average 26 $\pm$ 11 days into lactation.

2.3.3 Feeding Levels

In mid August 10 paddocks were set aside from the normal grazing rotation of the herd for use in the present experiment. Grazing management was such that by the beginning of the experiment the paddocks ranged between an estimated 1,600 to 3,300 kgDM/ha herbage mass before grazing.

The two experimental feeding levels were achieved by setting target values to herbage allowance (using the data summarized in figure 1.5). Thus allowances of 40-50 and 13-15 kgDM/cow/day were used to aim for intakes of 16-17 and 9-11 kgDM/cow/day for the ad libitum and restricted feeding levels, respectively. Herbage masses before and after grazing at each feeding level are shown in plates A and B at the end of this chapter.

2.3.4 Experimental Periods

Period A (experimental,12/9/83 - 9/10/83). The experimental cows were grazed seperately from the main herd in their four treatment groups for four weeks to determine immediate treatment effects on milk production and herbage intake.

Period B (post-experimental,10/10/83 - 23/10/83). For a further two weeks the experimental cows continued to be grazed seperately from the main herd but at a generous herbage allowance for all four treatment groups. The previously ad libitum fed cows (groups (1) and (3)) were grazed seperately from the previously restricted cows (groups (2) and (4)) in order to determine any differences in herbage intake.

Period C (post-experimental,24/10/83 - 1/5/84). The experimental cows were managed as part of the main herd for the remainder of the dairy season. No further differential treatment was imposed except that some of the experimental animals were involved in two further grazing experiments. The first used eight of the HBI cows over six weeks in November/December and involved high versus low herbage masses before grazing but at a common herbage allowance. The second experiment was for four weeks in March/April using 10 each of the HBI and LBI cows used in the present experiment and involving feeding treatments of supplementation (five kg concentrates/cow/day) versus no supplementation.

2.4 MANAGEMENT OF THE EXPERIMENTAL COWS AND PADDOCKS

1) Daily Milking

The dairy herd was milked twice daily at about 0530 and 1530 hours throughout lactation in a walk-through dairy shed. The routine consisted of a brief, warm-water udder wash; hand stripping; cups on; cups off (automatic removal) and application of a teat spray. During spring, cows were drenched as a protection against bloat after the p.m. milking before being let onto a fresh pasture break.

During periods A and B, the experimental cows were milked after the main herd each day at about 0630 and 1630 hours. They were subsequently returned to their paddock plots in their treatment groups. For ease of management cows in each group were identified by necklaces of a particular colour.

2) Grazing

The herd was rotationally grazed throughout lactation and given a fresh pasture break each 24 hours. Supplements of hay and silage were fed as necessary in late lactation.

During periods A and B the experimental cows were grazed seperately from the main herd in their treatment groups. Temporary electric fences were used to divide the experimental paddocks :

i) For period A, cows on restricted feeding were grazed in a seperate paddock from those on ad libitum feeding. Ten paddocks were grazed in total. Each was divided longitudinally for the seperation of BI groups and transversely for daily pasture breaks (back fences were used to prevent cows from eating the regrowth of previously grazed breaks).

ii) Six of the 10 experimental paddocks were regrazed in period B in the same way as in period A except that cows were all grazed in one paddock (the longitudinal fence seperating cows according to their feeding level during period A).

Fresh pasture breaks were given following each afternoon milking except for restricted cows in period A where breaks were given after each milking to minimize fouling of the pasture on offer.

Pre-determination of daily pasture allowances : Herbage mass (kgDM/ha) of the particular paddock area about to be grazed was initially estimated using an electronic probe (Clark, 1980). The probe had been calibrated with cutting measurements just prior to the beginning of the experiment. However use of the probe was discontinued after only a few days in favour of an Ellinbank rising plate meter (Earle and McGowan, 1979; Michell, 1982). The rising plate meter had been calibrated with previous cutting measurements at the Dairy Cattle Research Unit and the regression equation (relating meter readings to herbage mass) was modified as actual herbage mass data became available from sward quadrat cuts (see 2.6.1). Daily estimates of herbage mass were used to calculate the areas of pasture necessary to offer the required herbage allowances at each feeding level. An example is given in appendix 1.

3) Drinking Water

During the experimental periods when cows did not always have access to paddock troughs, ample water was made available in large troughs at the milking shed.

4) Animal Health

The cows received veterinary attention as necessary. Throughout the experimental periods there were five cases of lameness due to foot infections, one case of grass staggers and one case of clinical mastitis.

2.5 MEASUREMENTS OF ANIMAL PRODUCTION RESPONSES

2.5.1 Milk Production,Composition and Fatty Acid Composition of the Milkfat

Milk yield was measured by the use of milk sampling meters (Tru-test Distributors Ltd), which sampled a proportion of the milk flow of each cow. Daily yields were obtained by adding together the recordings made at consecutive afternoon and morning milkings. Measurements of daily yield were carried out at the following frequencies :

Periods A and B : three days per week
Period C (until 31/12/83) : two days per week
Period C (1/1/85 to 2/5/84) : one day per week

Mean daily yields were calculated for each week. Milk yield was also measured for three days and a mean obtained for the week immediately prior to period A (pre-experimental).

Milk samples were taken from consecutive afternoon and morning milkings. They were combined and tested for milkfat and milk protein concentration (%). The equipment used consisted of a milko-tester, Mark III F 3140 (A/s N Foss Electric, Denmark) for measuring fat %, and a Pro-milk tester, Mark II 12500 (A/s N Foss Electric, Denmark) for measuring protein %. Yields of milkfat and milk protein were calculated for each cow from the daily measurements of milk yield, milkfat % and milk protein %. Thus weekly averages were determined.

Fatty Acid Composition of the Milk Fat : Using a random numbers table, 16 of the experimental cows were selected for analysis of the fatty acid composition of their milkfat (four cows from each treatment group, including one three-year-old and three mature cows). Samples were collected in the last week of period A (4-5 and 6-7/10/83) and the first week of period C (25-26 and 27-28/10/83). Two composite (afternoon plus morning) samples were taken per week.

The methods and equipment used for the extraction of milkfat from each sample and analysis of the fatty acids by gas liquid chromatography have been described in detail by Grainger (1982). A Varian Aerograph 1200 Gas Chromatograph was used to analyse the fatty acids as their methylesters and a Varian Aerograph Digital Integrator 480 was used to obtain proportions (%) of the individual fatty acids. These were then grouped into short chain fatty acids (SCFA) (C_6,C_8,$C_{10:0}$,$C_{10:1}$,C_{12},$C_{14:0}$ and $C_{14:1}$) versus long chain fatty acids (LCFA) ($C_{18:0}$ and $C_{18:1}$).

2.5.2 Cow liveweight and Condition Score

The experimental cows were each weighed and condition scored (single observations) on the day that they calved. Average liveweights (LW) and condition scores (CS) at calving were as follows :

	LW(kg)		CS	
	$\bar{x}$	σ_{n-1}	$\bar{x}$	σ_{n-1}
HBI cows	444	50	4.7	0.8
LBI cows	477	60	4.7	0.4

Thereafter, recordings of cow LW and CS were made at the beginning and end of period A, at the end of period B and at intervals throughout period C. The recording at the end of period A was made two days after removal of the cows from their feeding treatments to allow for equalization of gut fill.

At each recording, measurements were made at about 0800 hours for two or three consecutive days. Cows were weighed (unfasted) and assigned a CS (Earle, 1976) by two independent scorers. The scores were averaged for each day. Liveweights and CS were then averaged over the two or three days on which they were taken.

2.6 ESTIMATION OF HERBAGE DIGESTIBLE ORGANIC MATTER (DOM) INTAKE

2.6.1 The Herbage Cutting Technique (HCT)

1) Herbage Mass Before and After Grazing (kgDM/ha)

Daily measurements of herbage mass (kgDM/ha) were made before and after grazing for all treatments during periods A and B. This was done using the herbage cutting technique (HCT).

Five quadrats were cut on every paddock plot before and after grazing. Thus each day a total of 20 quadrats during period A and 10 quadrats during period B were cut from the plots to be grazed that afternoon. Similarly each day a total of 20 quadrats during period A and 10 quadrats during period B were cut from the plots which had been grazed the day before.

The quadrats were taken randomly on a diagonal line across each plot. Herbage within each quadrat was cut to ground level using a portable shearing handpiece. The quadrat was an open-ended rectangle (25cmx75cm). Herbage cut from each plot was bulked, washed to remove soil contamination, oven-dried at 85°C for about 48 hours and then weighed.

Samples were kept of the oven-dried herbage from the daily sward quadrat cuts before and after grazing for the purposes of laboratory analysis (see 1) in 2.7). These were bulked for each `ad libitum paddock' and for the corresponding days grazed in the `restricted paddocks'.

2) DOM Allowance and Intake (kgDOM/cow/day)

For each day and group of cows (four groups in period A and two groups in period B), the area grazed (ha) and herbage mass before and after grazing (kgDM/ha) were used to calculate average herbage allowance (kgDM) and average herbage remaining (kgDM) per cow. These DM values were converted to digestible organic matter (DOM) values using estimated OM concentrations and predicted *in vivo* OM digestibilities (see 2) in 2.7). Average daily DOM intake per cow was then calculated as the difference between herbage allowance (kgDOM) and herbage remaining (kgDOM). It was assumed that the herbage which disappeared during grazing had been eaten by the cows and no correction was made for herbage growth during the grazing period since this was unlikely to have been significant (Meijs *et al*, 1982).

2.6.2 The Chromic Oxide Technique (COT)

During periods A and B the individual intakes of 16 cows randomly selected from the experimental group (one three-year-old and three mature cows from each treatment) were estimated as follows :

(a) faecal outputs were indirectly estimated using an indigestible faecal marker, namely chromium sesquioxide (Cr_2O_3),

(b) samples of the herbage on offer were fed to sheep to measure *in vivo* organic matter digestibility (OMD) and

(c) intakes were calculated using the equation :

$$\text{intake (kgDOM/cow/day)} = \frac{\text{faecal output (gOM/day)}}{(1 - \textit{in vivo}\text{ OM digestibility (\%)})}$$

1) Faecal Output

Cows were dosed twice daily, after milking, with a gelatine capsule containing 10g Cr_2O_3 in oil (R.P. Scherer Pty Ltd, Australia). Dosing was begun on day 12 of period A. A preliminary dosing period of seven days allowed sufficient time for stable conditions to be reached prior to sampling the faeces to determine Cr_2O_3 concentration.

Faeces samples from each cow were taken from the sward twice daily. Most samples were obtained between 0530 and 0830 hours, and again between 1300 and 1600 hours. The collection of faeces was carried out over days 19-28 of period A and days 5-14 of period B. Over the two 10-day collection periods, samples were bulked for consecutive periods of five days and stored in a freezer.

Subsequently the bulked faeces collections for each cow were thawed, mixed thoroughly and a sample taken. After oven-drying at 85°C for seven days, these samples were ground using a 1mm sieve and analysed for chromium concentration by spectrophotometry. Control samples had been collected once daily for any two of the undosed cows (one from each feeding level treatment) in order to determine any natural levels of chromium in the faeces. The method of determination used was that described by Fenton and Fenton (1979) as 'method A'.

Faecal output was then calculated as follows :

$$\text{faecal output (gDM/day)} = \frac{\text{weight of marker given (g/day) X RR}}{\text{chromium concentration in faeces (g/g)}}$$

(Le Du and Penning, 1982)

RR (recovery rate) was assumed to be 100% and each gelatine capsule contained 10g Cr_2O_3 so that :

$$\text{faecal output (gDM/day)} = \frac{20 \times 1}{\text{g } Cr_2O_3 \text{ /g faeces}}$$

Oven-dried, ground samples of each cow's faeces were ashed in duplicate to determine organic matter concentration (OM%). The average was used to convert DM faecal output to OM faecal output.

2) In Vivo Measurement of Herbage OM Digestibility

At the same time as the two periods of faeces collection, mature sheep (rams) were fed indoors on freshly cut samples of the herbage on offer. An initial period of two days was allowed to accustom the sheep to their indoor environment and diet before carrying out collection of each sheep's faeces. Measured sheep intakes and faecal outputs were used to calculate herbage digestibility.

i) Collection of herbage. Strips of the pasture on offer to the experimental cows were mown daily prior to grazing. A reciprocating mower and lawnmower were used during periods A and B, respectively.

ii) Feeding of the sheep. Six sheep during period A (three per feeding level) and three sheep during period B were fed generously. The herbage fed to each sheep was first weighed (around 3-4 kg fresh herbage/sheep/day). There were no refusals. Daily samples of the herbage from each paddock were taken in triplicate to determine DM concentration (%). The average DM% was used to determine DM intake per day for each sheep. Further herbage samples were collected daily for each paddock which were bulked and freeze-dried for the purposes of laboratory analysis (see 1) and 3) in 2.7). Samples of these samples were ashed in duplicate to determine OM % and the average used to calculate OM intake.

iii) Sheep faeces collection. Each sheep's faeces were collected daily and bulked for each period of 10 days. Samples were taken in duplicate for the determination of DM %. Oven-dried samples were ashed to determine OM % and the average used to calculate OM output.

iv) Calculation of herbage digestibility. OM digestibility of the OM was calculated as follows :

$$\text{OMD}\ (\%) = \frac{\text{OM intake} - \text{OM output}}{\text{OM intake}} \times \frac{100}{1}$$

Averages were calculated for each paddock.

2.7 DETERMINATION OF HERBAGE OM CONCENTRATION, OM DIGESTIBILITY, NITROGEN CONCENTRATION AND NITROGEN DIGESTIBILITY

1) OM Concentration and In Vitro OM Digestibility

Oven-dried samples from the herbage quadrat cuts (see 1) in 2.6.1) were ashed to determine OM concentration (%) and subjected to laboratory analysis to determine *in vitro* OM digestibility (OMD). The method used was that described by Roughan and Holland (1977) to obtain OM digestibility of the DM (DOMD). Additionally, the indigestible residue of each sample was ashed, which together with the known OM % of each sample, enabled OM digestibility of the OM (OMD) to be obtained.

For each run of *in vitro* analysis i.e. periods A and B, standard herbage samples of known *in vivo* OMD were analysed together with the quadrat samples. These standards consisted of freeze-dried samples of the herbage fed to each group of sheep in the present experiment (see

2) in 2.6.2) and dry herbage samples kept from various recent sheep indoor feeding trials carried out at Massey University. The standards were chosen for a range of in vivo / in vitro OMD values to give a good regression (in vivo OMD was regressed on in vitro OMD).

2) Predicted In Vivo OM Digestibility

For period B, in vivo OMD of the herbage quadrat samples was predicted from in vitro OMD using the regression obtained from the standard in vivo/in vitro OMD values.

However for period A, in vivo OMD could not accurately be predicted. This was because the standards used provided an insufficient range of in vivo/in vitro OMD values to obtain a good regression. However the standards did range sufficiently in terms of dry OM digestibility (DOMD, as defined below) so that a good in vivo/in vitro DOMD regression was obtained. Therefore, in the case of period A predicted in vivo OMD was derived from predicted in vivo DOMD as follows :

$$\text{predicted in vivo OMD (\%)} = \frac{\text{predicted in vivo DOMD (\%)}}{\text{OM concentration (\%)}}$$

$$\text{where DOMD (\%)} = \frac{\text{OM intake - OM output}}{\text{DM intake}} \times \frac{100}{1}$$

OMD (as defined in 2) in 2.6.2) was used in the determination of digestible OM allowances and intakes (see 2) in 2.6.1) rather than DOMD (as defined above). This was because herbage quadrat cuts (especially after grazing for the restricted cows) inevitably contained soil (inorganic matter) which was not entirely removed by washing.

3) Nitrogen Concentration and In Vivo Digestibility

The following samples were subjected to laboratory analysis to determine nitrogen concentration using the Kjedahl method :

(a) oven-dried herbage quadrat samples,

(b) freeze-dried herbage samples of the herbage fed to each group of sheep and

(c) oven-dried samples of each sheep's faeces.

The results of analysing (b) and (c) were used together with the known sheep DM intakes and outputs to estimate in vivo nitrogen digestibility as follows :

$$\text{N digestibility (\%)} = \frac{\text{N intake (g) - N output (g)}}{\text{N intake (g)}} \times \frac{100}{1}$$

2.8 STATISTICAL ANALYSIS

All data were analysed using the computer package REG which is based on generalized linear models (Gilmour, 1981).

1) Pre-experimental measurements of milk production were not used in a covariate analysis because this would have removed the effect of cow BI which was an experimental treatment. Cows entered the experiment (12/9/83) at different stages of lactation (see 2.3.2) but this effect was ignored since it was found to be randomly distributed over the treatment groups i.e. days in lactation on 12/9/83 did not differ between groups (P > 0.05) (see 1) in appendix 2). Futhermore, it was found that when each milk production characteristic for the week prior to 12/9/83 was regressed on days in lactation on 12/9/83 within BI groupings, the regression coefficients were small and not significant except in the case of milk protein % where the coefficients were 16.65 (P < 0.01) and 9.30 (P < 0.01) for the LBI and HBI groups respectively (see 2) in appendix 2). However, as shown in table 3.10 there were no differences between the treatment groups in milk protein % (P < 0.05).

2) Changes in LW and CS were analysed rather than the actual measurements. This was because at the beginning of the experiment (12/9/83) there were differences between some of the treatment groups in LW and CS (see appendix 3 and 3) in appendix 2). Cows of LBI were heavier than HBI cows (for treatment groups (1) versus (3) (P < 0.05) and treatment groups (1) versus (4) (P < 0.02)). Similarly, LBI cows were higher in CS than HBI cows (for treatment groups (1) versus (4) (P < 0.05)). Also the restricted LBI cows were of higher CS than the *ad libitum* fed LBI cows (P < 0.02).

Changes in LW and CS were calculated over the following periods :

Period	Weeks of Lactation
A (experimental)	5-8
B (post-experimental)	8-10 (adjustment to generous feeding levels)
C (post-experimental)	10-27 (November - January, mid lactation)
	27-34 (February - March, late lactation)

Unless otherwise stated all data presented in the results and discussion, are least square means (L.S.M.).

2.8.1 Multivariate Analysis of Variance

Milk production data (yields of milk, milkfat and milk protein;

milkfat % and protein %), milkfat composition data and DOM intake (COT) data were subjected to repeated measurement analyses of variance.

The <u>repeated measurement analysis</u> takes into account the error structure that exists between any two times of measurement for each animal. The null hypotheses that the treatment effects are similar are tested within each time of measurement.

The analyses were based on the following model :

$$y_{ijkl} = \mu + a_{il} + b_{jl} + c_{kl} + (b.c)_{jkl} + t_l + e_{ijklm}$$

where y_{ijkl} is milk yield, milkfat yield, milk protein yield, milkfat %, protein %, weight % of SCFA, weight % of LCFA or DOM intake for a cow of ith age and jth BI on kth feeding level for lth time

μ is the general mean

a_{il} is the effect of cow age for time l

b_{jl} is the effect of cow BI for time l

c_{kl} is the effect of feeding level for time l

$(b.c)_{jkl}$ is the interactive effect of cow BI and feeding level for time l

t_l is the effect of time where measurements are carried out on the same animal (t_l is in weeks for the milk production data, days for the milkfat composition data and 5-day sub-periods for the DOM intake (COT) data)

e_{ijklm} is the random residual unique to y_{ijkl} which is assumed to be normally distributed with mean 0 and variance σ^2

Milk production data were analysed within the following six periods :

Period	Weeks of Lactation	Number of Measurements (Milkings) per Weekly Mean
(1)	5-8	6
(2)	9-10	6
(3)	11-13	4
(4)	14-16	4
(5)	17-19	4
(6)	21*-38	2

* no data were available for week 20

The post-experimental phase was divided into periods firstly on the basis of number of measurements (milkings) involved in each weekly mean (see 2.5.1) so that each period was of the same error structure. Secondly, short (three weekly) periods were chosen to identify the stage of lactation at which any residual effect of the experimental treatments disappeared. The last 17 weeks of lactation were combined in period six since it was clear from the raw data that there were no longer any effects of feeding level.

Milkfat composition data were analysed within two periods, each of two sampling days (see 2.5.1).

DOM intake (COT) data were analysed within two periods, each of two sampling (five-day) subperiods (see 2) in 2.6.2).

2.8.2 Univariate Analysis of Variance

Changes in LW and CS data and pre-experimental milk production data (the latter collected in the week immediately prior to period A) were subjected to analyses of variance based on the following model :

$$y_{ijk} = \mu + a_i + b_j + c_k + (b.c)_{jk} + e_{ijkl}$$

where y_{ijk} is change in LW, change in CS, pre-experimental milk yield, milkfat yield, milk protein yield, milkfat % or protein % for a cow of ith age and jth BI on kth feeding level.

μ is the general mean

a_i is the effect of cow age

b_j is the effect of cow BI

c_k is the effect of feeding level

$(b.c)_{jk}$ is the interactive effect of cow BI and feeding level

e_{ijkl} is the random residual unique to y_{ijk} which is assumed to be normally distributed with mean 0 and variance σ^2

DOM allowance and intake (HCT) data were subjected to analyses of variance based on the following models :

Period A $$y_{jkl} = \mu + b_j + c_k + (b.c)_{jk} + d_l + (c.d)_{kl} + e_{jklm}$$

where y_{jkl} is DOM allowance or DOM intake for a cow of jth BI, on kth feeding level for day l

μ is the general mean

b_j is the effect of cow BI

c_k is the effect of feeding level

$(b.c)_{jk}$ is the interactive effect of cow BI and feeding level

d_l is the effect of day of measurement

$(c.d)_{kl}$ is the interactive effect of day of measurement and feeding level

e_{jklm} is the random residual unique to y_{jkl} which is assumed to be normally distributed with mean 0 and variance σ^2

Period B $\quad y_k = \mu + c_k + e_{kl}$

where y_k is DOM allowance or DOM intake for a cow on kth previous feeding level

μ is the general mean

c_k is the effect of previous feeding level

e_{kl} is the random residual unique to y_k which is assumed to be normally distributed with mean 0 and variance σ^2

PLATE A : HERBAGE MASS BEFORE AND AFTER GRAZING
AT THE AD LIBITUM FEEDING LEVEL

PLATE B : HERBAGE MASS BEFORE AND AFTER GRAZING
AT THE RESTRICTED FEEDING LEVEL

CHAPTER 3

RESULTS

3.1 ANIMAL PRODUCTION RESPONSES

3.1.1 Milk Production

3.1.1.1 Pre-Experimental Milk Production

The milk yields, milkfat yields, milk protein yields, milkfat concentrations and milk protein concentrations of each treatment group for the week immediately prior to the experimental period are shown in tables 3.1, 3.3, 3.5, 3.7 and 3.9, respectively. Significance levels of pre-experimental differences between the treatment groups are shown in tables 3.2, 3.4, 3.6, 3.8, and 3.10. High breeding index (HBI) cows produced more than low breeding index (LBI) cows in terms of milk yield ($P < 0.05$), milkfat yield ($P < 0.01$) and milk protein yield ($P < 0.001$) but there were no differences in terms of milkfat or milk protein concentrations ($P > 0.05$). Apart from the effect of cow BI there were no differences between treatment groups for any of the milk production characteristics ($P > 0.05$).

3.1.1.2 Experimental and Post-Experimental Milk Yield

The milk yields of each treatment group during and after the experimental period are shown in figure 3.1 and table 3.1. Table 3.2 shows the significance levels of treatment effects on milk yield for each period of analysis. Restricted feeding (underfeeding) in early lactation reduced milk yield during the period of restriction ($P < 0.001$) and during the two week period following the return to generous feeding levels ($P < 0.001$) but not during any subsequent periods of analysis. There was no effect of cow BI during any of the periods ($P > 0.05$). Furthermore, there were no interactive effects of cow BI and feeding level (FL) during early lactation (cow BI X FL) at any stage ($P > 0.05$).

3.1.1.3 Experimental and Post-Experimental Milkfat Yield

The milkfat yields of each treatment group during and after the experimental period are shown in figure 3.2 and table 3.3. Table 3.4 shows the significance levels of treatment effects on milkfat yield for each period of analysis. There were reductions in milkfat yield due to underfeeding in early lactation during the period of restriction ($P < 0.001$) and during the two periods of analysis following the return to generous feeding levels i.e. weeks 9-10 and 11-13 of lactation ($P < 0.001$ and $P < 0.05$, respectively) but not during any subsequent periods ($P > 0.05$). HBI cows had higher milkfat yields than LBI cows for all periods of analysis i.e. for weeks 5-8, 9-10, 14-16, 17-19, 21-38 ($P < 0.05$) and 11-13 ($P < 0.01$) of lactation. There were no interactive effects of cow BI X FL except for the period: weeks 14-16 of lactation when milkfat yields of LBI cows were reduced by previous underfeeding in early lactation to a greater extent than HBI cows ($P < 0.05$).

3.1.1.4 Experimental and Post-Experimental Milk Protein Yield

The milk protein yields of each treatment group during and after the experimental period are shown in figure 3.3 and table 3.5. Table 3.6 shows the significance levels of treatment effects on milk protein yield for each period of analysis. Milk protein yields were depressed due to underfeeding in early lactation during the period of restriction ($P < 0.001$) and during the two periods of analysis following the return to generous feeding levels i.e. weeks 9-10 and 11-13 of lactation ($P < 0.01$ and $P < 0.05$, respectively) but not during any subsequent periods. Compared to LBI cows, HBI cows had higher milk protein yields during the experimental ($P < 0.01$) and post-experimental ($P < 0.05$) periods except for the periods: weeks 14-16 and 17-19 of lactation, when there was no effect of cow BI ($P > 0.05$). There was no interactive effect of cow BI X FL on protein yield for any of the periods ($P > 0.05$).

3.1.1.5 Experimental and Post-Experimental Milkfat Concentration

The milkfat concentrations of each treatment group during and after the experimental period are shown in figure 3.4 and table 3.7. Table 3.8 shows the significance levels of treatment effects on milkfat concentration for each period of analysis. Underfeeding in early lactation increased milkfat concentration during the period of restriction ($P < 0.001$) but not during any subsequent periods of analysis ($P > 0.05$). Cow BI and cow BI X FL had no effects on milkfat concentration at any stage ($P > 0.05$).

3.1.1.6 <u>Experimental and Post-Experimental Milk Protein Concentration</u>

The milk protein concentrations of each treatment group during and after the experimental period are shown in figure 3.5 and table 3.9. Table 3.10 shows the significance levels of treatment effects on protein concentration for each period of analysis. Protein concentrations were reduced due to underfeeding in early lactation during the period of restriction ($P < 0.001$) and during the two week period following the return to generous feeding levels ($P < 0.05$) but not during any subsequent periods ($P > 0.05$). The protein concentrations of HBI cows were reduced by underfeeding in early lactation to a greater extent than LBI cows during the period of restriction ($P < 0.05$). Otherwise, there were no effects of cow BI or cow BI X FL on protein concentration ($P > 0.05$).

TABLE 3.1 The Milk Yields (kg/cow/day) of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels during Early Lactation (least square means and their standard errors).

Stage of Lactation (weeks)		Treatment Group							
		(1) HBI Restricted		(2) HBI *Ad libitum*		(3) LBI Restricted		(4) LBI *Ad libitum*	
		$\bar{x}$	$S.E._{\bar{x}}$	$\bar{x}$	$S.E._{\bar{x}}$	$\bar{x}$	$S.E._{\bar{x}}$	$\bar{x}$	$S.E._{\bar{x}}$
Pre-exp	4	22.6	1.3	23.8	1.3	18.3	1.3	21.3	1.3
Exp	5	18.5	1.4	23.5	1.4	14.5	1.4	20.9	1.4
	6	16.5	1.4	23.9	1.4	15.0	1.4	21.5	1.4
	7	12.5	1.5	22.4	1.5	10.7	1.5	19.6	1.5
	8	11.6	1.3	21.5	1.3	10.0	1.3	19.1	1.3
Post-exp	9	14.5	1.3	20.0	1.3	12.0	1.3	18.6	1.3
	10	15.7	1.3	19.3	1.3	12.9	1.3	17.5	1.3
	13	15.9	1.8	18.0	1.8	14.5	1.8	17.6	1.8
	16	17.8	1.6	17.1	1.6	13.2	1.6	16.4	1.6
	19	16.7	1.3	16.1	1.3	14.6	1.5	16.2	1.3
	38	9.7	0.7	8.3	0.7	8.6	0.9	8.6	0.8

TABLE 3.2 Levels of Significance of Treatment Effects (Cow BI, Feeding Level during Early Lactation and their Interaction) on Milk Yield.

Period of Analysis (weeks of lactation)		Cow BI	Feeding Level	Cow BI X Feeding Level
Pre-exp	4	*	NS	NS
Exp	5-8	NS	***	NS
Post-exp	9-10	NS	***	NS
	11-13	NS	NS	NS
	14-16	NS	NS	NS
	17-19	NS	NS	NS
	21-38	NS	NS	NS

NS = Not Significant(P > 0.05) * = P < 0.05 ** = P < 0.01
*** = P < 0.001 Exp = experimental

FIGURE 3.1 The Milk Yields of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels in Early Lactation (least square means).

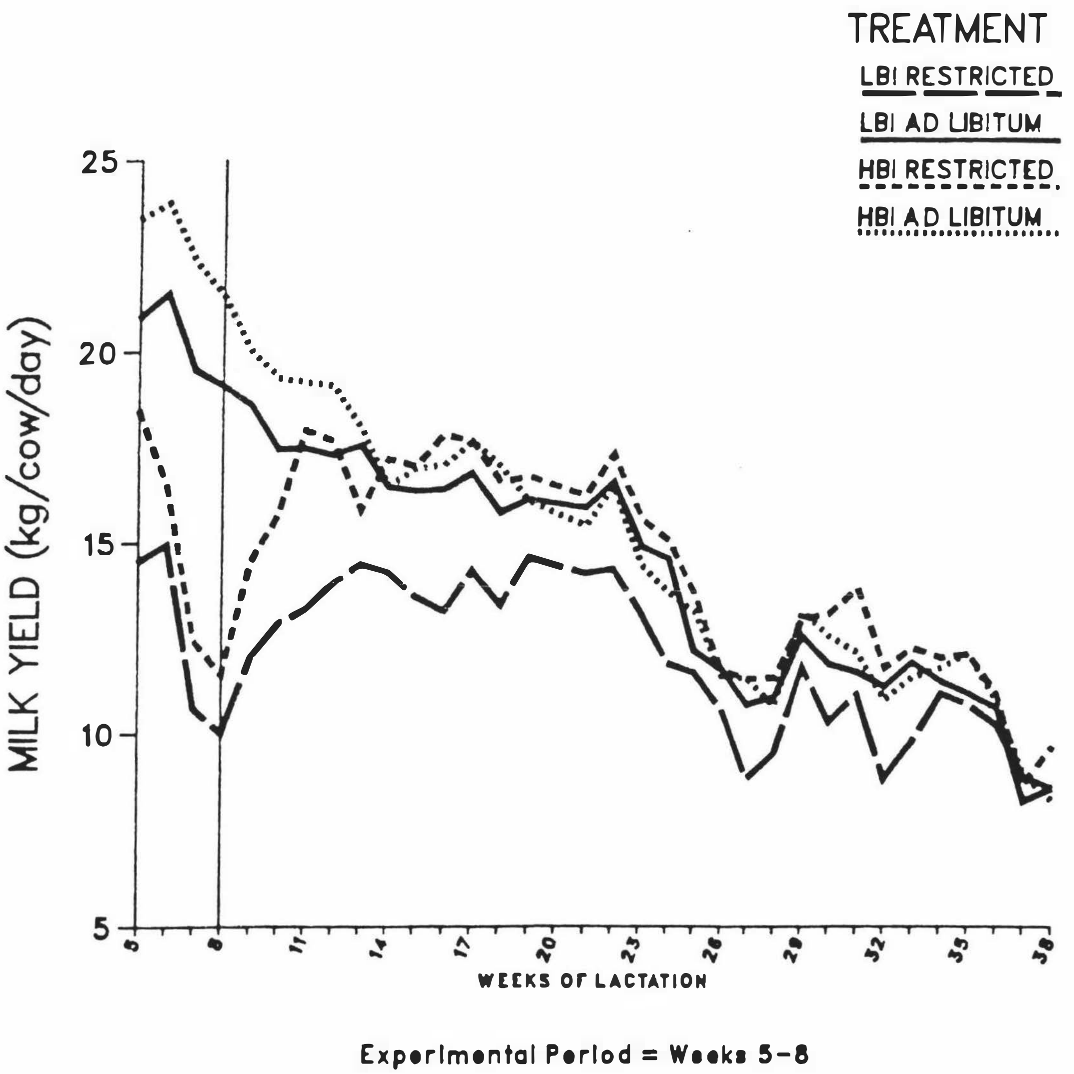


TABLE 3.3 The Milkfat Yields (kg/cow/day) of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels during Early Lactation (least square means and their standard errors).

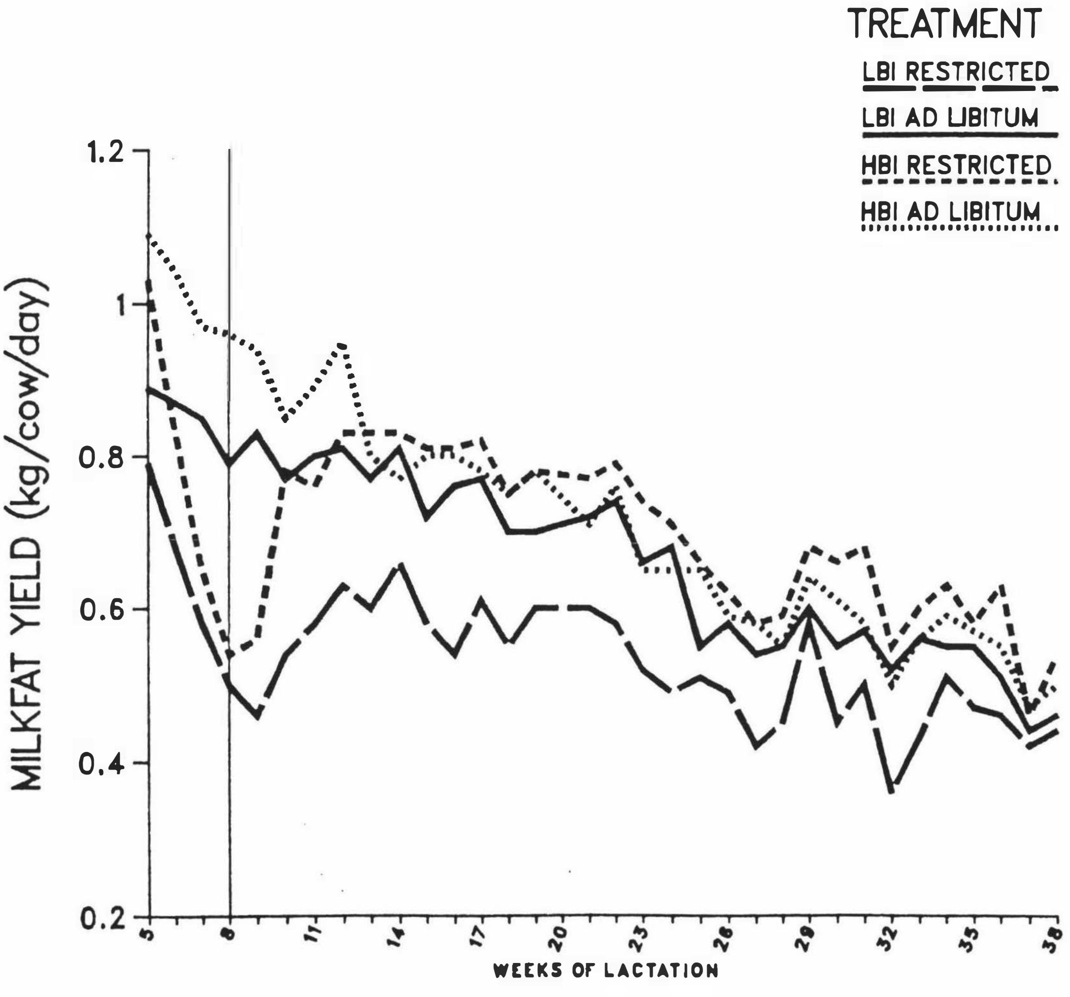
Stage of Lactation (weeks)		Treatment Group (1) HBI Restricted		(2) HBI *Ad libitum*		(3) LBI Restricted		(4) LBI *Ad libitum*	
		$\bar{x}$	S.E.$_{\bar{x}}$	$\bar{x}$	S.E.$_{\bar{x}}$	$\bar{x}$	S.E.$_{\bar{x}}$	$\bar{x}$	S.E.$_{\bar{x}}$
Pre-exp	4	1.04	0.07	1.02	0.07	0.80	0.07	0.85	0.07
Exp	5	1.03	0.07	1.09	0.07	0.79	0.07	0.89	0.07
	6	0.83	0.07	1.04	0.07	0.68	0.07	0.87	0.07
	7	0.65	0.07	0.97	0.07	0.58	0.07	0.85	0.07
	8	0.54	0.06	0.96	0.06	0.50	0.06	0.79	0.06
Post-exp	9	0.56	0.06	0.94	0.06	0.46	0.06	0.83	0.06
	10	0.78	0.07	0.85	0.07	0.54	0.07	0.77	0.07
	13	0.83	0.06	0.80	0.06	0.60	0.06	0.77	0.06
	16	0.81	0.06	0.80	0.06	0.54	0.06	0.76	0.06
	19	0.78	0.06	0.78	0.06	0.60	0.06	0.70	0.06
	38	0.54	0.04	0.50	0.04	0.44	0.04	0.46	0.04

TABLE 3.4 Levels of Significance of Treatment Effects (Cow BI, Feeding Level during Early Lactation and their Interaction) on Milkfat Yield.

Period of Analysis (weeks of Lactation)		Cow BI	Feeding Level	Cow BI X Feeding Level
Pre-exp	4	**	NS	NS
Exp	5-8	*	***	NS
Post-exp	9-10	*	***	NS
	11-13	**	*	NS
	14-16	*	NS	*
	17-19	*	NS	NS
	21-38	*	NS	NS

NS = Not Significant(P > 0.05) * = P < 0.05 ** = P < 0.01 *** = P 0.001
Exp = experimental

FIGURE 3.2 The Milkfat Yields of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels in Early Lactation (least square means).



Experimental Period = Weeks 5–8

TABLE 3.5 The Milk Protein Yields (kg/cow/day) of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels during Early Lactation (least square means and their standard errors).

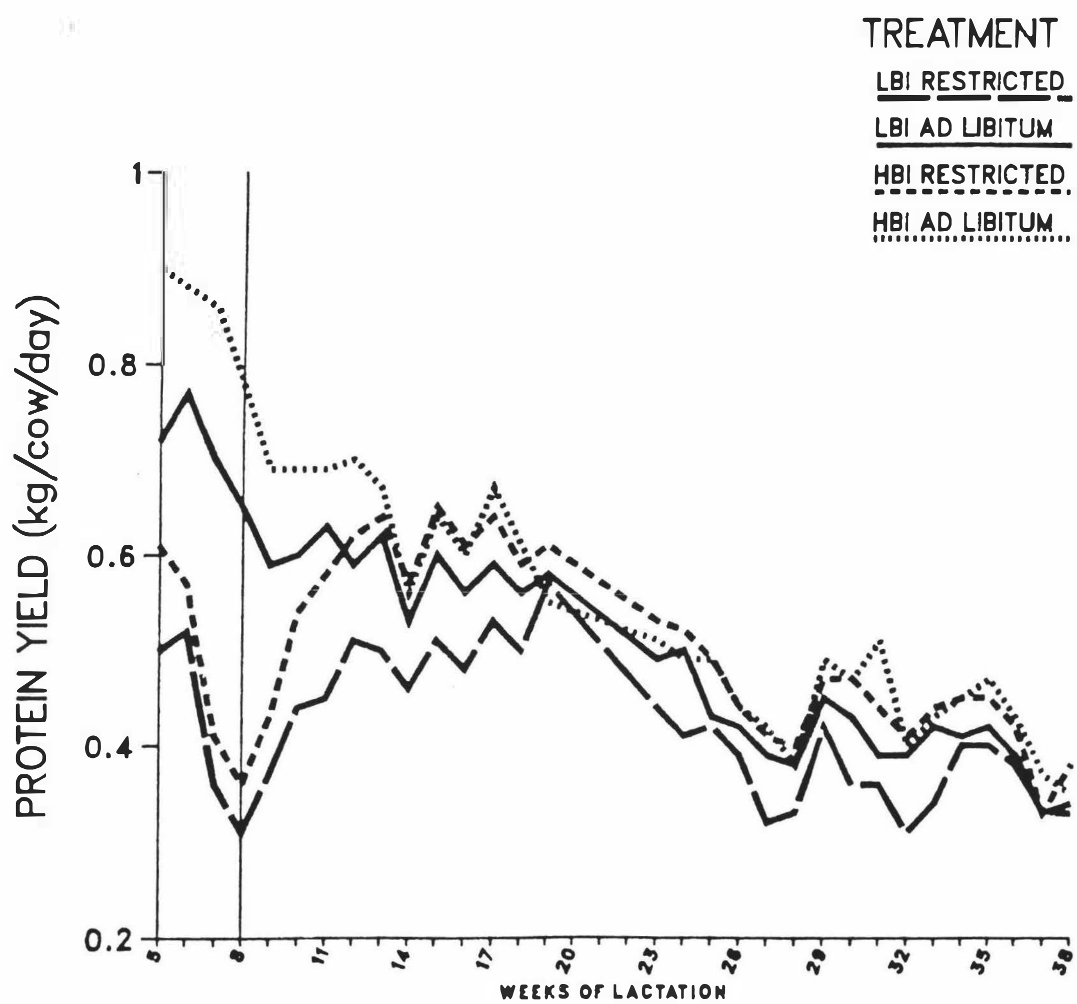
Stage of Lactation (weeks)		Treatment Group (1) HBI Restricted $\bar{x}$	S.E.$_{\bar{x}}$	(2) HBI *Ad libitum* $\bar{x}$	S.E.$_{\bar{x}}$	(3) LBI Restricted $\bar{x}$	S.E.$_{\bar{x}}$	(4) LBI *Ad libitum* $\bar{x}$	S.E.$_{\bar{x}}$
Pre-exp	4	0.92	0.04	1.00	0.04	0.73	0.04	0.78	0.04
Exp	5	0.61	0.04	0.90	0.04	0.50	0.04	0.72	0.04
	6	0.57	0.05	0.88	0.05	0.52	0.05	0.77	0.05
	7	0.41	0.05	0.86	0.05	0.36	0.05	0.70	0.05
	8	0.36	0.05	0.78	0.05	0.31	0.05	0.65	0.05
Post-exp	9	0.43	0.03	0.69	0.03	0.37	0.03	0.59	0.03
	10	0.54	0.04	0.69	0.04	0.44	0.04	0.60	0.04
	13	0.64	0.04	0.67	0.04	0.50	0.04	0.62	0.04
	16	0.61	0.05	0.60	0.05	0.48	0.05	0.56	0.05
	19	0.61	0.04	0.56	0.04	0.57	0.04	0.58	0.04
	38	0.38	0.03	0.35	0.03	0.33	0.03	0.34	0.03

TABLE 3.6 Levels of Significance of Treatment Effects (Cow BI, Feeding Level during Early Lactation and their Interaction) on Milk Protein Yield.

Period of Analysis (Weeks of Lactation)		Cow BI	Feeding Level	Cow BI X Feeding Level
Pre-exp	4	***	NS	NS
Exp	5-8	**	***	NS
Post-exp	9-10	*	***	NS
	11-13	*	*	NS
	14-16	NS	NS	NS
	17-19	NS	NS	NS
	23†-38	*	NS	NS

NS = Not Significant($P > 0.05$) * = $P < 0.05$ ** = $P < 0.01$
*** = $P < 0.001$ † no data were available for weeks 21-22
Exp = experimental

FIGURE 3.3 The Milk Protein Yields of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels in Early Lactation (least square means).



Experimental Period = Weeks 5-8

TABLE 3.7 The Milkfat Concentrations (%) of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels during Early Lactation (least square means and their standard errors).

Stage of Lactation (weeks)		Treatment Group (1) HBI Restricted $\bar{x}$	S.E.$_{\bar{x}}$	(2) HBI *Ad libitum* $\bar{x}$	S.E.$_{\bar{x}}$	(3) LBI Restricted $\bar{x}$	S.E.$_{\bar{x}}$	(4) LBI *Ad libitum* $\bar{x}$	S.E.$_{\bar{x}}$
Pre-exp	4	4.62	0.27	4.31	0.27	4.37	0.27	4.11	0.27
Exp	5	5.53	0.18	4.62	0.18	5.36	0.18	4.32	0.18
	6	5.00	0.24	4.37	0.24	4.49	0.24	4.02	0.24
	7	5.19	0.26	4.28	0.26	5.33	0.26	4.39	0.26
	8	4.65	0.20	4.48	0.20	4.88	0.20	4.17	0.20
Post-exp	9	3.85	0.21	4.70	0.21	3.94	0.21	4.51	0.21
	10	4.93	0.25	4.43	0.25	4.12	0.25	4.36	0.25
	13	4.58	0.21	4.41	0.21	4.23	0.21	4.37	0.21
	16	4.54	0.22	4.69	0.22	4.11	0.22	4.73	0.22
	19	4.71	0.19	4.91	0.19	4.18	0.21	4.35	0.19
	38	5.62	0.27	6.06	0.27	5.27	0.31	5.38	0.28

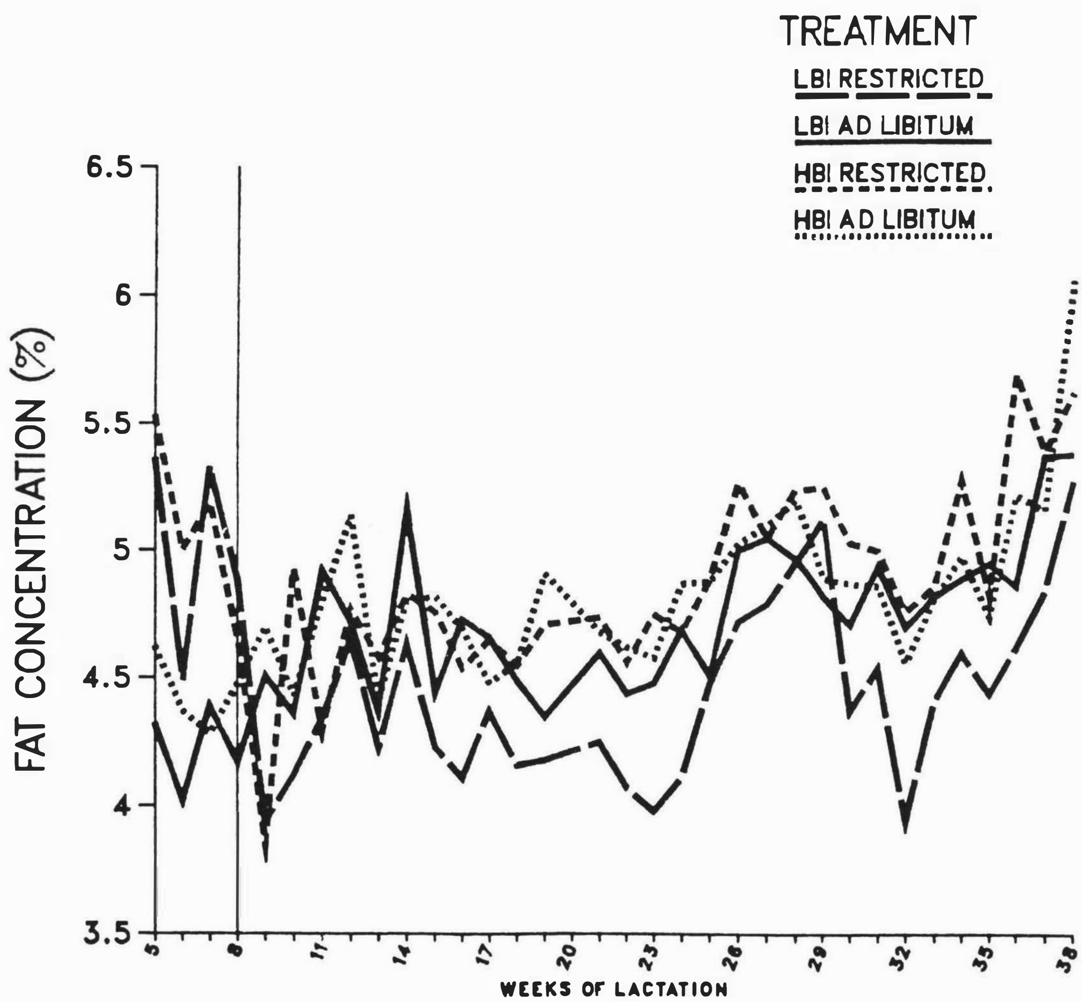
TABLE 3.8 Levels of Significance of Treatment Effects (Cow BI, Feeding Level during Early Lactation and their Interaction) on Milkfat Concentration.

Period of Analysis (weeks of lactation)		Cow BI	Feeding Level	Cow BI X Feeding Level
Pre-exp	4	NS	NS	NS
Exp	5-8	NS	***	NS
Post-exp	9-10	NS	NS	NS
	11-13	NS	NS	NS
	14-16	NS	NS	NS
	17-19	NS	NS	NS
	21-38	NS	NS	NS

NS = Not Significant($P < 0.05$) ** = $P < 0.01$ *** = $P < 0.001$

Exp = experimental

FIGURE 3.4 The Milkfat Concentrations of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels in Early Lactation (least square means).



Experimental Period = Weeks 5-8

TABLE 3.9 The Milk Protein Concentrations (%) of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels during Early Lactation (least square means and their standard errors).

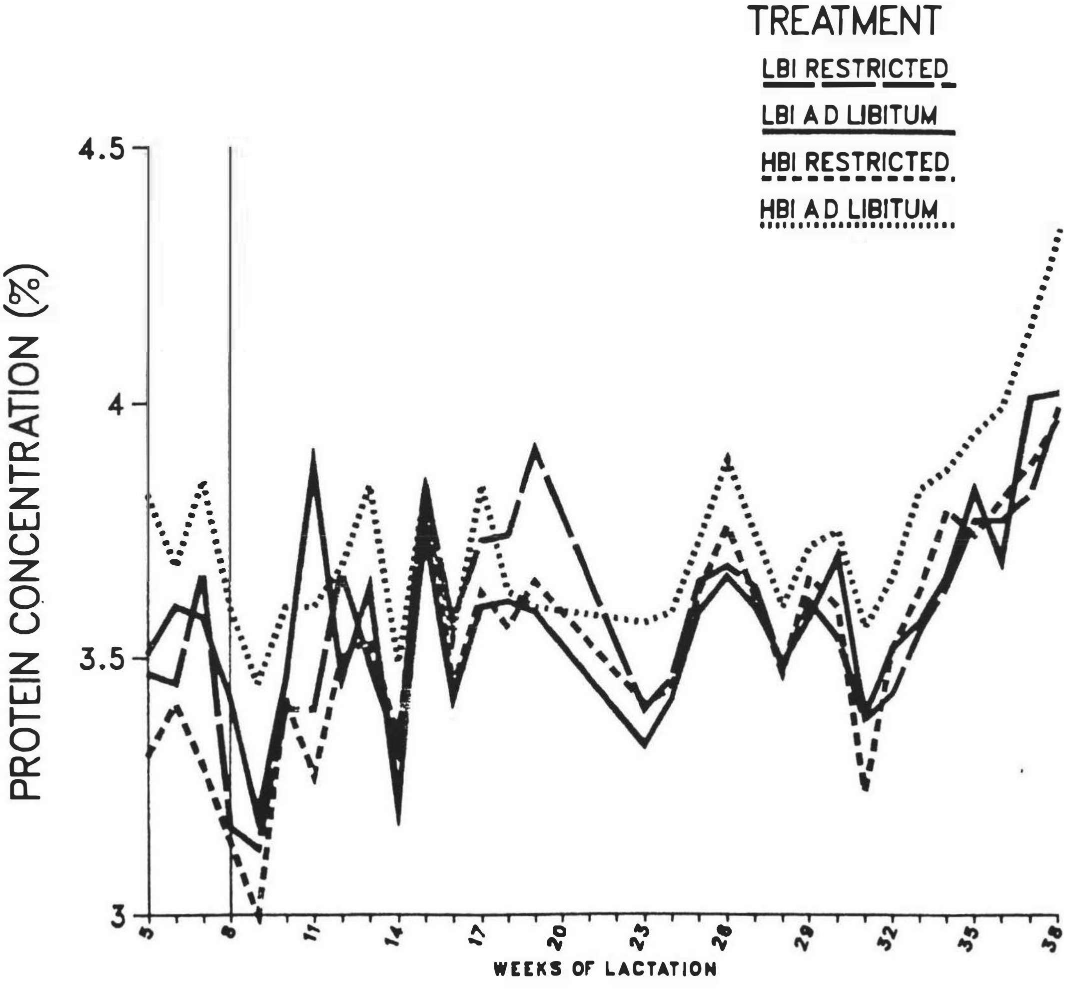
Stage of Lactation (weeks)		Treatment Group: (1) HBI Restricted		(2) HBI *Ad libitum*		(3) LBI Restricted		(4) LBI *Ad libitum*	
		$\bar{x}$	S.E.$_{\bar{x}}$	$\bar{x}$	S.E.$_{\bar{x}}$	$\bar{x}$	S.E.$_{\bar{x}}$	$\bar{x}$	S.E.$_{\bar{x}}$
Pre-exp	4	4.07	0.13	4.06	0.13	4.03	0.13	3.74	0.13
Exp	5	3.31	0.09	3.82	0.09	3.47	0.09	3.51	0.09
	6	3.41	0.08	3.68	0.08	3.45	0.08	3.60	0.08
	7	3.29	0.07	3.85	0.07	3.67	0.07	3.58	0.07
	8	3.14	0.08	3.60	0.08	3.17	0.08	3.42	0.08
Post-exp	9	3.00	0.10	3.45	0.10	3.13	0.10	3.19	0.10
	10	3.42	0.10	3.60	0.10	3.40	0.10	3.46	0.10
	13	3.54	0.14	3.84	0.14	3.49	0.14	3.64	0.14
	16	3.44	0.12	3.54	0.12	3.57	0.12	3.42	0.12
	19	3.65	0.16	3.60	0.16	3.91	0.18	3.59	0.16
	38	3.97	0.14	4.33	0.14	3.99	0.16	4.02	0.15

TABLE 3.10 Levels of Significance of Treatment Effects (Cow BI, Feeding Level during Early Lactation and their Interaction) on Milk Protein Concentration.

Period of Analysis (weeks of lactation)		Cow BI	Feeding Level	Cow BI X Feeding Level
Pre-exp	4	NS	NS	NS
Exp	5-8	NS	***	*
Post-exp	9-10	NS	*	NS
	11-13	NS	NS	NS
	14-16	NS	NS	NS
	17-19	NS	NS	NS
	23†-38	NS	NS	NS

NS = Not Significant(P > 0.05) * = P < 0.05 ** = P < 0.01
*** = P < 0.001 † no data were available for weeks 21-22
Exp = experimental

FIGURE 3.5 The Milk Protein Concentrations of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or Ad libitum Feeding Levels in Early Lactation (least square means).



Experimental Period = Weeks 5-8

3.1.2 Fatty Acid Composition of the Milkfat

The concentrations of SCFA and LCFA in the milkfat of each treatment group are shown in table 3.11. Table 3.11(A) gives data for the last week of the experiment (period one) and table 3.11(B) for the third week following the return to generous feeding levels (period two).

In period one, underfeeding reduced the concentration of SCFA ($P < 0.05$) but had no effect on concentration of LCFA in the milkfat ($P > 0.05$). There were no effects of cow BI, cow BI X FL or sampling day for either SCFA or LCFA ($P > 0.05$).

In period two, there were no effects of previous feeding level (FL), cow BI, cow BI X FL or sampling day on either SCFA or LCFA concentrations in the milkfat ($P > 0.05$).

3.1.3 Cow Liveweight and Condition Score

Measurements of cow liveweight (LW) and condition score (CS) (raw data means) for each treatment group taken throughout lactation are presented in appendix 3. Changes in LW and CS of each treatment group over the experimental period and subsequently, are shown in table 3.12.

During the experimental period restricted cows gained less LW (P < 001) and condition ($P < 0.001$) than cows fed *ad libitum* (restricted cows actually lost condition). Following the return to generous feeding levels, in comparison to their previously *ad libitum* fed counterparts previously restricted cows gained more LW over weeks 8-10 and 10-27 of lactation ($P < 0.001$). They also gained more condition over weeks 8-10 ($P < 0.01$) and 10-27 ($P < 0.05$) of lactation (previously *ad libitum* fed cows actually lost condition over weeks 8-10 of lactation). There was no effect of feeding level in early lactation on changes in LW and condition over weeks 27-34 of lactation ($P > 0.05$).

Over weeks 10-27 of lactation HBI cows gained less LW ($P < 0.001$) and condition ($P < 0.05$) than LBI cows. During weeks 8-10 of lactation previously restricted LBI cows gained more condition than their HBI counterparts ($P < 0.05$). There were no effects of cow BI or cow BI X FL on changes in LW or condition for any other period ($P < 0.05$).

TABLE 3.11 The Concentrations (% by Weight) of Short Chain Fatty Acids (SCFA) and Long Chain Fatty Acids (LCFA) in the Milkfat of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels during Early Lactation (least square means and their standard errors).

(A) Experimental Period A (4-7/10/83)

Cow BI	Previous Feeding Level	Sampling Day†	SCFA $\bar{x}$	SCFA S.E.$_{\bar{x}}$	LCFA $\bar{x}$	LCFA S.E.$_{\bar{x}}$
HBI	Restricted	1	20.18	2.43	41.43	3.36
		2	25.55	3.58	33.61	4.10
HBI	*Ad libitum*	1	25.83	1.92	36.32	2.65
		2	29.14	2.82	31.57	3.23
LBI	Restricted	1	19.45	2.14	44.17	2.95
		2	24.73	3.14	36.02	3.60
LBI	*Ad libitum*	1	30.20	1.92	32.04	2.65
		2	26.49	2.82	35.08	3.23

Significance Levels of Treatment Effects and Time of Sampling	SCFA	LCFA
Cow BI	NS	NS
Feeding Level (FL)	*	NS
Cow BI X FL	NS	NS
Sampling Day	NS	NS

NS = Not Significant ($P > 0.05$) * = $P < 0.05$ ** = $P < 0.01$

† Sampling Day 1 = 4-5/10/83 Sampling Day 2 = 6-7/10/83

(B) Post-Experimental Period C (25-28/10/83)

Cow BI	Previous Feeding Level	Sampling Day†	SCFA $\bar{x}$	SCFA S.E.$_{\bar{x}}$	LCFA $\bar{x}$	LCFA S.E.$_{\bar{x}}$
HBI	Restricted	1	28.33	1.30	30.07	1.13
		2	28.28	1.66	29.81	2.09
HBI	*Ad libitum*	1	27.62	1.16	32.53	1.00
		2	28.73	1.48	30.34	1.86
LBI	Restricted	1	29.01	1.16	33.13	1.00
		2	29.12	1.48	31.09	1.86
LBI	*Ad libitum*	1	30.72	1.16	29.34	1.00
		2	29.99	1.48	28.86	1.86

Significance Levels of Treatment Effects and Time of Sampling	SCFA	LCFA
Cow BI	NS	NS
Feeding Level (FL)	NS	NS
Cow BI X FL	NS	NS
Sampling Day	NS	NS

NS = Not significant

†Sampling Day 1 = 25-26/10/83 Sampling Day 2 = 27-28/10/83

TABLE 3.12 The Changes in Liveweight (ΔLW) and Condition Score (ΔCS) of High (H) Versus Low (L) Breeding Index (BI) Cows Grazed at Restricted or *Ad libitum* Feeding Levels during Early Lactation (least square means and their standard errors).

Cow BI	Feeding Level	5-8 $\bar{x}$	5-8 $S.E._{\bar{x}}$	8-10 $\bar{x}$	8-10 $S.E._{\bar{x}}$	10-27 $\bar{x}$	10-27 $S.E._{\bar{x}}$	27-34 $\bar{x}$	27-34 $S.E._{\bar{x}}$
ΔLW(kg/cow)									
HBI	Restricted	3	6	12	3	21	6	-13	8
HBI	*Ad libitum*	42	6	1	3	6	6	-12	8
LBI	Restricted	3	6	18	3	43	6	-14	8
LBI	*Ad libitum*	46	6	-1	3	23	6	-26	8
ΔCS(per cow)									
HBI	Restricted	-0.2	0.2	0.0	0.1	0.4	0.1	0.0	0.1
HBI	*Ad libitum*	0.4	0.2	0.0	0.1	0.1	0.1	0.1	0.1
LBI	Restricted	-0.3	0.2	0.1	0.1	0.6	0.1	0.0	0.1
LBI	*Ad libitum*	0.4	0.2	-0.2	0.1	0.4	0.1	0.0	0.1

Period of Change (weeks of lactation)

Significance Levels of Treatment Effects		5-8	8-10	10-27	27-34
ΔLW	Cow BI	NS	NS	***	NS
	Feeding Level(FL)	***	***	***	NS
	Cow BI X FL	NS	NS	NS	NS
ΔCS	Cow BI	NS	NS	*	NS
	Feeding Level(FL)	***	**	*	NS
	Cow BI X FL	NS	*	NS	NS

NS = Not Significant($P > 0.05$) * = $P < 0.05$ ** = $P < 0.01$
*** = $P < 0.001$

3.2 HERBAGE DIGESTIBLE ORGANIC MATTER (DOM) INTAKE (KG/COW/DAY)

3.2.1 Experimental

Herbage DOM allowances and intakes of each treatment group during the experimental period estimated using the herbage cutting technique (HCT) and chromic oxide technique (COT) are shown in table 3.13 .

3.2.1.1 DOM Allowance (HCT)

As expected, DOM allowance of the restricted cows was less than that of the cows fed *ad libutum* (8.6 versus 30.5kg DOM/cow/day, respectively, $P < 0.001$). Allowance did not differ between BI groups at each feeding level ($P > 0.05$).

3.2.1.2 DOM Intake (HCT and COT)

DOM intakes of the restricted cows were less than those of the *ad libitum* fed cows ($P < 0.001$): 7.7 versus 17.9 , 9.5 versus 12.8 and 5.9 versus 10.1 kgDOM/cow/day for the HCT, COT sampling periods (1) and (2), respectively. Cow BI and cow BI X FL had no effects on intake for either technique ($P > 0.05$). Intakes estimated using the COT were lower for sampling period (2) than sampling period (1) ($P < 0.001$).

In estimating herbage DOM intake, the HCT and COT showed reasonable agreement for cows on the restricted feeding level. Means and their standard errors (S.E.) were 7.7 ± 0.5, 9.5 ± 1.3 and 5.9 ± 0.7 kg DOM/cow/day for the HCT, COT sampling period (1) and sampling period (2), respectively. However, for cows on the *ad libitum* feeding level, agreement between the HCT and COT was poor. Means and their S.E. were 17.9 ± 0.5, 12.8 ± 1.3 and 10.1 ± 0.7 kg DOM/cow/day for the HCT, COT sampling period (1) and sampling period (2), respectively.

3.2.2 Post-Experimental

Herbage DOM allowances and intakes of cows fed at a generous feeding level for the two weeks immediately following the experimental period estimated using the herbage cutting technique (HCT) or chromic oxide technique (COT) are shown in table 3.14.

3.2.2.1 DOM Allowance (HCT)

DOM allowance was the same for the previously restricted versus the previously ad libutum fed cows ($P > 0.05$) : 25.3 kgDOM/cow/day.

3.2.2.2 DOM Intake (HCT and COT)

There was no effect of previous feeding level on DOM intake for either the HCT or COT ($P > 0.05$). For intakes estimated using the COT there were no effects of cow BI, cow BI X FL or sampling period ($P > 0.05$).

The HCT and COT showed reasonable agreement in estimating intake. Means and their S.E. were 11.9 ± 0.5, 9.7 ± 0.4 and 10.6 ± 0.4 kg DOM/cow/day for the HCT, COT sampling period (1) and sampling period (2), respectively.

TABLE 3.13 The Digestible Organic Matter (DOM) Allowances and Intakes (kg/cow/day) of High (H) Versus Low (L) Breeding Index (BI) Cows when Grazed at Restricted or *Ad libitum* Feeding Levels for Weeks 5-8 of Lactation (least square means and their standard errors).

Cow BI	Feeding Level	HERBAGE CUTTING TECHNIQUE		CHROMIC OXIDE TECHNIQUE			
				(1)†		(2)†	
		$\bar{x}$	$S.E._{\bar{x}}$	$\bar{x}$	$S.E._{\bar{x}}$	$\bar{x}$	$S.E._{\bar{x}}$
Allowance							
HBI	Restricted	8.4	0.7	-	-	-	-
HBI	*Ad libitum*	30.6	0.7	-	-	-	-
LBI	Restricted	8.8	0.7	-	-	-	-
LBI	*Ad libitum*	30.4	0.7	-	-	-	-
Intake							
HBI	Restricted	7.4	0.6	8.4	1.7	6.3	0.9
HBI	*Ad libitum*	18.1	0.6	13.8	1.7	9.8	0.9
LBI	Restricted	7.9	0.6	10.6	1.7	5.6	0.9
LBI	*Ad libitum*	17.6	0.6	11.8	1.7	10.3	0.9

Significance Levels of Treatment Effects	Herbage Cutting Technique	Chromic Oxide Technique
Allowance		
Cow BI	NS	-
Feeding Level (FL)	***	-
Cow BI X FL	NS	-
Intake		
Cow BI	NS	NS
Feeding Level (FL)	***	***
Cow BI X FL	NS	NS
Sampling Day	-	***

NS = Not Significant (P > 0.05) *** = P < 0.001

† = Sampling Period

TABLE 3.14 The Digestible Organic Matter (DOM) Allowances and Intakes (kg/cow/day) of High (H) Versus Low (L) Breeding Index (BI) Cows when Grazed at Generous Feeding Levels for Weeks 9-10 of Lactation (least square means and their standard errors).

Previous Feeding Level (weeks 5-8 of lactation)	HERBAGE CUTTING TECHNIQUE			CHROMIC OXIDE TECHNIQUE (1)†		(2)†	
	$\bar{x}$	$S.E._{\bar{x}}$		$\bar{x}$	$S.E._{\bar{x}}$	$\bar{x}$	$S.E._{\bar{x}}$
Allowance							
Restricted	25.3	1.4		-	-	-	-
Ad libitum	25.3	1.4		-	-	-	-
Intake							
Restricted	11.4	0.7	HBI	9.4	1.0	10.2	0.8
			LBI	9.0	1.0	11.1	0.8
Ad libitum	12.5	0.7	HBI	9.8	1.0	11.1	0.8
			LBI	10.5	1.0	10.2	0.8

Significance Levels of Treatment Effects	Herbage Cutting Technique	Chromic Oxide Technique
Allowance		
Previous FL	NS	-
Intake		
Cow BI	-	NS
Previous FL	NS	NS
Cow BI X FL	-	NS
Sampling Period	-	NS

NS = Not Significant ($P > 0.05$) † = Sampling Period

3.3 HERBAGE DIGESTIBILITY, NITROGEN CONCENTRATION AND NITROGEN DIGESTIBILITY

The nitrogen concentrations, predicted in vivo OMD and organic matter (OM) concentrations of the herbage quadrat samples before and after grazing are presented in appendix 4 (raw data means) for the paddocks used at each feeding level in period A (experimental) and over all the paddocks used in period B (post-experimental).

For the herbage on offer, mean nitrogen concentration ranged from 2.8 - 3.1% DM and mean OMD ranged from 75.3 - 75.9%.

Digestibility of the nitrogen as measured in vivo (see 3) in 2.7) was 77.1% for the 'ad libutum paddocks' in period A, 75.9% for the 'restricted paddocks' in period A and 74.3% in period B.

CHAPTER FOUR

DISCUSSION

4.1 RELIABILITY OF METHODS USED

4.1.1 The Measurement of DOM Intake

1) Feeding Levels

Measured herbage allowances of 47 and 12-13 kgDM/cow/day (calculated from table 3.13 using the before grazing OMD and OM concentration given in appendix 4) were in good agreement with target herbage allowances of 40-50 and 11-15 kgDM/cow/day for the *ad libitum* and restricted feeding levels, respectively. Allowance (DOM) varied from day to day ($P < 0.001$) and between day variation was greater at the *ad libitum* compared to the restricted feeding level ($P < 0.001$, $\sigma_{n-1} = 5.2$ and 1.2 kg DOM/cow/day, respectively). However, more importantly, intake (DOM) did not vary from day to day ($P > 0.05$). Therefore it appears that use of the rising-plate meter was adequate in pre-determining herbage allowances. Rising-plate meter readings and herbage DM mass (as measured by cutting 0.2 m^2 quadrats to ground level) have been found to correlate well (r was at least 0.8) for rotationally grazed dairy pastures (Michell, 1982).

2) The Herbage Cutting Technique

Walter and Evans (1979) state:- `Of the sward sampling techniques available the `Difference' method, based on pre- and post-grazing sampling, is considered to have the greatest potential for providing valid estimates of intake, especially when grazing periods are relatively short and stocking densities are high'. However, values of C.V. ranging from 7% to 250% have been reported for intake estimation using this method depending on the level and variability of pasture yield and number and size of sample units in addition to length and intensity of the grazing period (Walters and Evans, 1979).

Indirect intake estimates using animal measurements are generally considered to be more accurate and precise (*ibid*) and Walters and Evans (1979) suggest they should be used wherever possible as confirmation.

Studies by Clark and Brougham (1979) and Walters and Evans (1979) showed little difference between chromic oxide dilution and difference techniques in the estimation of DOM intake by grazing ruminants. In comparison, the results of the present experiment showed poor agreement between the COT (chromic oxide dilution technique) and the HCT (difference technique) especially at the ad libitum feeding level.

Inaccuracy of the HCT or 'Difference' method can be put down to :

i) Sward 'Clumpiness' and Representative Sampling. The difference method becomes increasingly inaccurate as grazing pressure decreases i.e. herbage allowance increases (Clark and Brougham, 1979). This is due to increased variability in herbage mass within the grazed area or 'clumpiness' particularly after grazing. More samples are required to accurately estimate herbage mass but this conflicts firstly with the physical limitation and time restraints of cutting large numbers of samples and secondly the need to ensure that the area harvested does not interfere with the experimental treatment (Michell, 1982).

ii) Wet Conditions and Pugging of the Soil. High soil moisture is associated with increased inaccuracy of the difference method since there is a greater likelihood of herbage being trampled below ground level (Clark and Brougham, 1979). Throughout the present experiment the soil was very wet and pugging was a problem particularly at the restricted feeding level. Not only was there very little material to collect when sampling after grazing in the 'restricted' paddocks but also a considerable amount of root material tended to get included in the samples due to soft soil and the inevitability of cutting below ground level. Inclusion of root material may have contributed to the considerable reduction in the estimate of OMD compared to the samples taken after grazing in the 'ad libitum paddocks' (see appendix 4).

iii) Losses Incurred in Cutting and Collecting Herbage Samples. Incomplete recovery of sampled herbage from quadrat areas was a problem due to wind and the action of the shearing handpiece which tended to flick short, stemmy material outside the quadrat (particularly white clover stolens).

3) The Chromic Oxide Technique

Carruthers and Bryant (1983) found that the COT overestimated intake by 14% on average compared to direct measurements on cows fed indoors on fresh herbage. Also the variation in intake between cows of similar BI was greater for the COT versus direct measurement so that the COT was less sensitive to the small but real differences in intake between BI groups which existed when measured directly. However, Carruthers and Bryant (1983) used rectal grab sampling of the faeces which has been found to give a higher C.V. and to overestimate faecal output compared to sward sampling (Wanyoike and Holmes, 1981). Furthermore COT estimates may also have been more reliable if Cr_2O_3 impregnated paper had been used instead of capsules since the former gives less diurnal variation and a higher recovery rate of chromium faecal content (Meijs, 1981).

In the present experiment faeces were sward sampled. However gelatine capsules were used and the recovery rate was assumed to be 100% (Krohn and Konggaard (1976) found a recovery rate of only 94% with gelatine capsules). Furthermore herbage samples for the determination of in vivo OMD were cut with a reciprocating mower which cut to a level more representative of the 'ad libitum paddocks' after grazing than the 'restricted paddocks'. During the post-experimental period of intake measurement a lawnmower was used to collect herbage samples which cut to a level more representative of the experimental 'restricted paddocks' after grazing. Thus, in vivo OMD was probably overestimated for the restricted cows during the experiment and underestimated during the post-experimental period when all cows were fed generously.

4) Reliability of DOM Intake Measurements

Clark and Brougham (1979) calculated the relationship between DOM intake measured by the chromic oxide dilution technique and the difference technique. Despite the close agreement of the two techniques variation around the intake estimates was high. This emphasized the lack of precision of current methods in measuring grazing intake. Results from the present experiment support this statement and give little more than a broad indication of levels of DOM intake. Variation was high around each intake estimate. There was a lack of agreement between the techniques both in absolute levels of intake and differences in intake between feeding levels.

4.1.2 The Determination of Fatty Acid Composition of the Milkfat

Fatty acids in the milkfat which are synthesized in the mammary gland range from C_4 to C_{16} with possibly small amounts of $C_{18:0}$ (Rook and Thomas, 1983). Typically, all of C_6 - C_{12}, most of C_{14} and at least half of C_{16} fatty acids are synthesized de novo in the gland from acetate and β hydroxy-butyrate supplied by the diet (ibid). Lipids carried in the blood plasma, derived from the bodyfat, represent the other source of fatty acids accounting for the remaining C_{14}, C_{16} and long chain fatty acids (primarily $C_{18:0}$ and $C_{18:1}$) (ibid).

It has been found that the fatty acid composition of milkfat is highly correlated to the digestible energy intake of lactating dairy and beef cattle grazing on tropical (Stobbs and Brett, 1974; 1976) and temperate (Payne et al, 1981) swards. Stobbs and Brett (1974-1976) found that within approximately six days following a restriction of energy intake the proportion of C_4-C_{16} fatty acids in milkfat decreased while the proportion of $C_{18:1}$ increased. In Payne et al's (1981) trials the ratio of $C_{18:1}$ to C_{10} was observed to increase within a week in response to inadequate energy intake. Bartsch et al (1981) compared cows fed every three hours with cows not fed for 24 hours and found that after 12-18 hours milkfat samples of the cows not fed contained less C_6,C_8,C_{10},C_{12},C_{14} and C_{16} fatty acids and more $C_{18:1}$ and $C_{18:2}$ fatty acids.

On the basis of the above, the collective proportions of C_6-C_{14} (short chain) and $C_{18:0}$ - $C_{18:1}$ (long chain) fatty acids were determined in the present experiment as representative of energy for the production of milkfat derived from the diet and mobilization of body fat, respectively. This was done in order to compare information provided by the measurement of intake and changes in LW/CS with regard to the immediate and subsequent effects of underfeeding on milk production and the effects of cow BI on the same. Yields of fatty acids (the proportion of each acid times mean daily milkfat yield) were not determined since this would have introduced a further source of error thus reducing sensitivity of the statistical analysis.

4.2 THE EFFECTS OF UNDERFEEDING IN EARLY LACTATION

4.2.1 Immediate Effects on Milk Production

4.2.1.1 Milk, Milkfat and Milk Protein Yields

During the experiment, underfeeding reduced milk yield in agreement with early reviews of literature (Blaxter, 1950; Burt, 1957), more recent European work (Broster, 1972; Broster and Strickland, 1977; Le Du and Newberry, 1981; 1982), early N.Z. research (Gerring and Young, 1961) and recent Australasian data (Bryant, 1980; Bryant and Trigg, 1979; Glassey et al, 1980; Grainger and Wilhelms, 1979; Grainger et al,1982; Hutton and Douglas, 1975; Moate et al,1980; Ngarmsak, 1984 and Stockdale et al, 1981). Yields of milkfat and milk protein were also reduced by underfeeding as found by the above Australasian authors. Other experiments reporting reduced milkfat yeilds due to underfeeding in early lactation are shown in table 1.1.

Yields of milk and milkfat of restricted versus ad libitum fed cows and their percentage reductions due to underfeeding during the experimental period are shown in table 4.1. Over the four weeks there was a 6.6 kg/cow or 25% reduction in milkfat due to underfeeding (see appendix 7). This compares with a 24% reduction in milkfat yield reported by Bryant and Trigg (1982) (see 1.1.2). However, variation between experiments must be borne in mind when making such comparisons e.g. expression of intake, nature of the diet, control levels of feeding and milk production, and timing, duration and severity of underfeeding.

Table 4.1 The Yields of Milk and Milkfat (kg/cow/day) for Cows Grazed at Restricted (R) or *Ad Libitum* (AL) Feeding Levels during Early Lactation (least square means and their standard errors).

Week of Lactation		Milk Yield					Milkfat Yield				
		R $\bar{x}$	AL $\bar{x}$	S.E.$_{\bar{x}}$	R-AL (%)	L.O.S.	R $\bar{x}$	AL $\bar{x}$	S.E.$_{\bar{x}}$	R-AL (%)	L.O.S.
Experimental	5	16.5	22.2	1.0	26		0.91	0.99	0.05	8	
	6	15.7	22.7	0.9	31	***	0.75	0.96	0.05	22	***
	7	11.6	21.0	1.1	45		0.61	0.91	0.05	33	
	8	10.8	20.3	0.9	47		0.52	0.88	0.04	41	
Post-Experimental	9	13.3	19.3	1.0	31	***	0.51	0.89	0.04	43	***
	10	14.3	18.4	1.0	22		0.66	0.81	0.05	19	
	11	15.6	18.3	1.2	15		0.67	0.84	0.04	20	
	12	15.8	18.2	1.1	13	NS	0.73	0.88	0.05	17	*
	13	15.2	17.8	1.3	15		0.72	0.78	0.05	8	

Note: $\text{R-AL} = \frac{\text{R-AL}}{\text{AL}} \times \frac{100}{1}$

NS = Not Significant($P > 0.05$) * = $P < 0.05$ *** = $P < 0.001$
L.O.S. = Level of Significance (of each period of analysis)

The Timing, Duration and Severity of Underfeeding. The immediate effects of underfeeding on milk and milkfat production as found by the present experiment are greater than those reported by other recent work (Grainger *et al*, 1982; Le Du and Newberry, 1981; 1982; Ngarmsak, 1984; see tables 1.4, 1.2 and 1.5, respectively). Primarily this can be explained by the greater severity of underfeeding since the duration of underfeeding did not vary markedly and the effects of timing are unclear (see 1.1.2). Grainger et al (1982) and Ngarmsak (1984) measured smaller intake differences between feeding levels (see 1) in 4.2.1.2; bearing in mind that intake was expressed as DM and not DOM). The difference in herbage allowance between the control and severly restricted feeding levels in Le Du and Newberry's (1981, 1982) experiments was on average only 16 kgDM/cow/day compared to 22 kgDOM/cow/day in the present experiment. Furthermore, there were smaller effects of underfeeding on cow LW and CS in the above compared to the present experiments (see tables 1.4, 1.2 and 1.5).

4.2.1.2 The Availability of Energy for Milk Production

The immediate effects of underfeeding on milk production were due to a decreased amount of dietary energy intake in association with a reduction in the partitioning of dietary energy towards LW gain. Support for this statement is discussed as follows :

1) DOM Intake

The greater amount of dietary energy received by the *ad libitum* fed compared to restricted cows is evidenced by their greater DOM intake. Herbage DOM intake (kg/cow/day) was reduced due to underfeeding by 10.2 (57%), 3.3 (26%) and 4.2 (41%) as estimated by the HCT and COT sampling periods (1) and (2), respectively. However, the lack of precision of current methods for measuring intake of grazing animals must be borne in mind (see 4.1.1).

Other researchers have measured herbage intake and in the trials reviewed by Bryant and Trigg (1982) (summarized in table 1.1) DM intake was depressed due to underfeeding by 38% on average. In Grainger et al's (1982) and Ngarmsak's (1984) trials DM intake was depressed by 43% and 37%, respectively.

2) Change in Cow Liveweight and Condition

i) Liveweight. During underfeeding, restricted cows gained 41 kg/cow less LW than *ad libitum* fed cows. This indicates that less dietary energy was partitioned towards LW gain in the underfed cows.

Experiments reviewed by Broster (1972) ,including early New Zealand research, have shown that underfeeding results in decreased LW gains or increased loss of LW. Similarly, recent Australasian work (reviewed by Bryant and Trigg, 1982) has shown restrictions in herbage intake to be associated with reductions in LW relative to control animals (see table 1.1). Le Du and Newberry (1981, 1982) found that restrictions in herbage allowance resulted in depressed cow LW's relative to well fed animals (see table 1.2). In Ngarmsak's (1984) experiment restricted cows gained 15 kg less LW than cows which were generously fed ($P < 0.001$).

ii) Condition. The mobilization of bodyfat to support milk production in the underfed cows is shown by the loss of 0.3 CS/cow while *ad libitum* feeding resulted in a gain of 0.4 CS/cow; a difference of 0.7 CS by the end of the experimental period (associated with the difference of 41 kg LW).

Three of the experiments in table 1.1 measured changes in body condition : Bryant and Trigg (1979), Glassey *et al* (1980) and Stockdale *et al* (1981) all found that underfeeding caused losses in condition (as assessed by CS) in line with LW loss. Similarly losses in CS due to underfeeding occured in Grainger *et al*'s (1982) and Ngarmsak's (1984) experiments which can be seen in tables 1.4 and 1.5, respectively.

iii) Liveweight Versus Condition. It is at first surprising that the underfed cows did not lose LW in keeping with the loss in CS (this was also found by Ngarmsak, 1984). However, LW is composed of protein and water in addition to fat whereas CS is a measure of bodyfat cover. Hence while bodyfat was mobilized to support milkfat production it seems that dietary nutrients were still partitioned towards tissue protein and water. Gray *et al* (1981) (cited by Grainger and McGowan, 1982) have shown that as cow CS decreases, composition of the bone-free carcass and guts changes such that fat % decreases, protein % increases slightly and water % increases.

3) SCFA % and LCFA % in the Milkfat

In the last week of underfeeding the proportions of short chain fatty acid (SCFA%) in the milkfat of restricted cows were found to be reduced by 8% and 6% (for sampling days one and two respectively) relative to cows fed *ad libitum*. This confirms the DOM intake data in showing that restricted cows were consuming less dietary energy (see 4.1.2). Ngarmsak (1984) found underfeeding to reduce SCFA% in the milkfat by 17% ($P < 0.001$) relative to generous feeding. The greater effect of underfeeding on SCFA% in Ngarmsak's experiment is perplexing. It is unlikely to be due to more severe restriction since reductions in intake and effects on cow LW and CS were smaller than in the present experiment.

During the last week of underfeeding there were differences in the proportions of long chain fatty acids (LCFA%) in the milkfat between restricted and *ad libitum* fed cows (significant at $P < 0.10$ but not at $P < 0.05$). LCFA% in the milkfat of restricted cows were found to be increased by 25% and 4% (for sampling days one and two, respectively). This indicates that the restricted cows were mobilizing bodyfat to a greater extent (see 4.1.2) thus confirming the change in CS data discussed previously. Ngarmsak (1984) obtained a 22% increase of LCFA% in the milkfat due to underfeeding ($P < 0.001$). The higher level of significance attached to Ngarmsak's result indicates a more substantial effect of underfeeding on bodyfat mobilization. Indeed, Ngarmsak's milkfat samples were collected in the second and third weeks of underfeeding and the mean LCFA% calculated. It is suggested for the present experiment that by the fourth and last week of underfeeding the bodyfat reserves of restricted cows were largely depleted.

4) Milk and Milkfat Responses Per Kg Change in DOMI

Table 4.2 shows the differences in DOM intake, milk yield and milkfat yield between the restricted and *ad libitum* fed cows and hence milk and milkfat responses per kg change in DOM intake for each experimental week. The effects of underfeeding on milk and milkfat yields (shown in table 4.1) increased with the duration of the experiment ($P < 0.001$) and hence responses per kg increase in DOM intake increased from the first to the last week.

Table 4.2 Milk and Milkfat Responses (kg/cow/day) to Changing DOM Intake (I) (kg/cow/day) during the Experimental Period (intake, milk yield and milkfat yield, data are derived from least square means).

Week of Experiment	DOMI (R-AL)	Milk Yield (MY)(R-AL)	$\frac{\Delta MY}{\Delta 1kgDOMI}$	Milkfat Yield (MFY)(R-AL)	$\frac{\Delta MFY}{\Delta 1kgDOMI}$
1	10.1	5.7	0.6	0.08	0.01
2	9.5	7.0	0.7	0.21	0.02
3	10.2	9.4	0.9	0.30	0.03
4	10.2	9.5	0.9	0.36	0.04

Note: R-AL = difference between restricted and *ad libitum* fed cows

It appears probable that early on in underfeeding bodyfat was mobilized to support milkfat production. Hence the negligible effect on milkfat yield (8%) and the low response of only 0.01 kg milkfat/kg increase DOM intake. Furthermore, milk yield was initially affected to a greater extent than milkfat yield. Late in underfeeding fewer bodyfat reserves were available to support milkfat production hence there was a substantial reduction in milkfat yield (41%) and a much higher response of 0.04 kg milkfat/kg increase DOM intake. This is in keeping with the suggestion made previously that bodyfat reserves of the underfed cows were largely depleted by the last week of the experiment.

The milk and milkfat responses in table 4.2 are only meaningful in relation to one another rather than as absolute values due to the lack of precision associated with the measurement of DOM intake discussed in 4.1.1. For this reason the responses obtained in the present experiment have been used for illustrative purposes only and are not compared with responses calculated by other researchers. Also, other researchers have often expressed intake as DM and not DOM.

4.2.2 Residual Effects on Milk Production

1) Recovery from Underfeeding

i) Changes in LW and CS. Considering the effects of underfeeding in early lactation on cow LW and CS, a residual effect on milk production was to have been expected while LW and CS were being regained. Indeed there were differences in LW gain and CS gain immediately following the experiment (weeks 8-10 of lactation) and over mid-lactation (weeks 10-27). Cows which were underfed in early lactation gained more LW over both periods, they lost less condition over weeks 9-10 of lactation and gained more condition over mid-lactation.

However, these differences were small in energy terms (MJ net energy retained). During the third week after the experiment (week 11 of lactation) no differences were detected in the LCFA% in the milkfat between previously restricted and ad libitum fed cows thus indicating no differences in the mobilization of bodyfat. Any differences in bodyfat mobilization must have been very small, confirming CS measurements of only 0.1 CS loss and a negligible gain in CS for the previously ad libitum fed and restricted cows, respectively, over the first post-experimental period. By the end of mid lactation, differences in LW and CS due to previous underfeeding were 33 kg and 0.4 CS, respectively. Assuming that 1 kg LW contains 20 MJ net energy and 1 kg Freisian milkfat contains 78 MJ net energy (Moe et al, 1971), the LW difference of 33 kg was calculated to be 8.5 kg milkfat which agrees closely with the 6.4 kg milkfat reduction due to underfeeding, following the experiment (see following section).

ii) Milk,Milkfat,and Milk Protein Yields. In keeping with the above, previously underfed cows had reduced yields of milk, milkfat and milk protein immediately following the experiment (weeks 9-10 of lactation) and reduced yields of milkfat and milk protein for a further three weeks. Table 4.1 shows milk and milkfat yields for previously restricted versus ad libitum fed cows following the experiment until there were no longer any differences ($P > 0.05$) due to previous underfeeding. In the five weeks following the experiment previously restricted cows produced 6.4 kg less milkfat so that there was a total residual effect of 1.0 times the immediate effect of underfeeding on milkfat production (see appendix 7).

The small and transient nature of this residual effect contrasts with early New Zealand research (Gerring and Young, 1961) and European work reviewed by Broster (1972) and Broster and Strickland (1977). However it is in agreement with more recent experiments in Europe reviewed by Broster and Strickland (1977), recent Australasian data reviewed by Bryant and Trigg (1981) (see table 1.3) and world-wide research reviewed by Broster and Thomas (1981). The fact that many of the experiments summarized in table 1.3 found residual effects to be non significant would have been largely because total milkfat production following underfeeding to the end of lactation was compared. In Bluett's (1977) work there was a significant residual effect which was partly because it was measured for only 90 days following underfeeding (Bryant and Trigg, 1982).

2) Compensatory Response from Previously Underfed Cows

It has been suggested by Broster and Thomas (1981) that cows show a compensatory response in terms of voluntary intake when offered generous quantities of good quality food following a period of underfeeding thus reducing any residual effects on milk production (see 4) in 1.1.3). However in the present experiment there was no increase in DOM intake of previously restricted versus ad libitum fed cows following underfeeding. Furthermore during the third week subsequent to the experiment there was no effect of previous underfeeding on SCFA% in the milkfat suggesting no effect on the level of dietary energy consumed for the production of milkfat (see 4.1.2). Therefore it appears that rapid recovery of the previously restricted cows in milk production was not due to any compensatory increase in voluntary intake.

3) The Timing, Duration and Severity of Underfeeding

There is evidence to suggest that the timing, duration and severity of underfeeding are important in determining the extent of residual effects on milk production (see 5) in 1.1.3). The residual effect of 1.0 times the immediate effect on milkfat yield obtained in the present experiment agrees more closely with Grainger et al's (1982) measurement of 1.3 than the residual effect of 0.1 found by Ngarmsak (1984). This was expected since in Ngarmsak's experiment underfeeding was shorter, less severe (as evidenced by the smaller percentage reduction in intake and loss in CS discussed in 4.2.1) and occured later in lactation than the former two experiments (see tables 1.4 and 1.5).

4.2.3 Immediate and Residual Effects on Milk Composition

1) Immediate Effects

Underfeeding increased milkfat concentration(%) during the experiment (see tables 3.7 and 3.8) in agreement with Bryant (1978/79), Bryant and Trigg (1979), Flux and Patchell (1957), Grainger and Wilhelms (1979), Hutton and Parker (1966), Patchell (1957) and Rogers et al (1979a). Other workers found underfeeding in early lactation decreased milkfat % (Bryant, 1979; 1980) or had a negligible effect (Glassey, 1980; Grainger et al, 1982; Le Du et al, 1982; Moate et al, 1980; Ngarmsak, 1984; Stockdale et al, 1981). The increases in milkfat % in the present experiment were 0.97, 0.55, 0.92 and 0.44 percentage units for weeks 5-8 of lactation, respectively. These were in the upper range of those values reported by Bryant and Trigg (1982) (see table 1.6). The reason for the increase in milkfat % is probably that underfeeding depressed milkfat yield to a lesser extent than the yield of water and solids-not-fat due to the increased mobilization of bodyfat (see table 4.2). There was a greater effect on condition in the present experiment than in Grainger et al's (1982) and Ngarmsak's (1984) experiments (see 4.2.1.2) which at least partly explains the positive effect on milkfat %. It would appear that the effects of underfeeding on milkfat % depend on changes in body condition and the reduction in energy intake.

Milk protein concentration (%) was reduced by underfeeding during the experiment (see tables 3.9 and 3.10) in agreement with many other workers (Broster and Strickland, 1977; Bryant, 1978/79; 1979; 1980; Bryant and Trigg, 1979; Flux and Patchell, 1954; 1957; Glassey, 1980; Grainger and Wilhelms, 1979; Hutton and Douglas, 1975; Hutton and Parker, 1966; Ngarmsak, 1984; Patchell, 1957; Rogers et al, 1979; Stockdale et al, 1981). However Grainger et al (1982) and Moate et al (1980) found that underfeeding in early lactation had no effect on protein %. In the present experiment the reductions in protein % were 0.28, 0.21, 0.39 and 0.36 percentage units for weeks 5-8 of lactation respectively, which again were in the upper range of those values reported by Bryant and Trigg (1982) (see table 1.6). In Ngarmsak's (1984) experiment protein % was reduced on average by only

0.24 percentage units.

2) Residual Effects

Following the experiment there was no effect of previous feeding level on milkfat % (see tables 3.7 and 3.8) in agreement with Flux and Patchell (1954, 1957), Glassey (1980), Grainger and Wilhelms (1979), Grainger et al (1982), and Patchell (1957). Bryant and Trigg (1979), however, found some indication of residual effects of underfeeding on milkfat percentage in their second experiment. When energy balances were being carried out in the 10 weeks following their experiment, milkfat percentage was lower ($P < 0.05$) for cows previously severely restricted versus those fed ad libitum. Le Du et al (1982) also noted that in the recovery phase of their experiment milkfat % was significantly depressed after severe restriction for five weeks in early lactation.

Protein % was depressed in previously restricted cows for a further two weeks following the experiment. Grainger and Wilhelms (1979) found that protein % remained depressed for the whole of lactation ($P < 0.05$). Other workers have found protein % to return rapidly to normal following underfeeding (Bryant and Trigg, 1979; Flux and Patchell, 1954; 1957; Grainger et al, 1982; Le Du and Newberry, 1982; Patchell, 1957).

4.3 THE EFFECTS OF COW BI ON ASPECTS OF PRODUCTIVITY

4.3.1 Milkfat Yield, Change in Liveweight and Condition Score

High BI cows had higher yields of milkfat (kg/cow/day) than LBI cows (see table 4.3) and gained less LW and condition during mid-lactation (weeks 10-27) in agreement with previous trials carried out at Massey University (Grainger et al, 1985a and b; Ngarmsak, 1984) and Ruakura Agricultural Research Centre (Bryant and Trigg, 1981; Bryant, 1981). During mid lactation, gains in LW and CS were 13 kg and 0.3 CS, respectively, for the HBI cows and 33 kg and 0.5 CS, respectively, for the LBI cows.

There were no differences between HBI and LBI cows in LCFA% in the milkfat during weeks 8 or 11 of lactation. This suggests that there was no effect of cow BI on the mobilization of bodyfat to support milkfat production in early lactation which is in keeping with the lack of difference between HBI and LBI cows in CS change over weeks 5-8 and 8-10 of lactation.

The difference in milkfat yield between HBI and LBI cows did not increase with time for any of the periods of analysis ($P > 0.05$). This was in agreement with Ngarmsak (1984) and Grainger et al (1985a). Bryant and Trigg (1981) reported the relative difference in milkfat yield between HBI and LBI cows to increase as lactation progressed although the level of significance of this interaction was not stated.

Table 4.3 The Milkfat Yields (kg/cow/day) of High (H) Versus Low (L) Breeding Index (BI) Cows (least square means and their standard errors averaged across the restricted and ad libitum feeding levels).

Week of Lactation	HBI	LBI	
	$\bar{x}$	$\bar{x}$	$SE_{\bar{x}}$
Pre-Experimental			
4	1.03	0.83	0.05
Experimental			
5	1.06	0.84	0.05
6	0.94	0.78	0.05
7	0.81	0.72	0.05
8	0.75	0.65	0.04
Post-Experimental			
9	0.75	0.65	0.04
10	0.81	0.66	0.05
13	0.81	0.68	0.05
16	0.80	0.65	0.05
19	0.78	0.65	0.04
38	0.52	0.45	0.03

4.3.2 Milk Protein Yield

High BI cows produced more milk protein (kg/cow/day) than LBI cows except for weeks 14-16 and 17-19 of lactation (although there was a positive effect of cow BI for weeks 14-16 at $P < 0.10$). Grainger et al (1985a) reported that the protein yield (g/unit $LW^{0.75}$/day) of HBI cows was consistently higher than that at low BI cows. Ngarmsak's (1984) results also suggested an increase in milk protein yield due to cow BI although the level of significance was not stated.

4.3.3 Milk Yield and Composition

High BI cows produced more milk (kg/cow/day) than LBI cows ($P < 0.05$) for the pre-experimental period only. Thereafter, differences between HBI and LBI cows were not significant (although there was a positive effect of cow BI at $P < 0.10$ for experimental weeks 5-8 and post-experimental weeks 9-10 of lactation). There were no differences ($P > 0.05$ and $P > 0.10$) in milkfat % and milk protein % due to cow BI for any of the periods of analysis. However, as discussed above, there were significant differences due to cow BI for milkfat and milk protein yield (derived from the milk yield and composition data).

Grainger et al (1985a) found that the milk yield (g/unit $LW^{0.75}$/day), and in some cases the milkfat % of HBI cows, were higher than that of LBI cows but that there were no differences in milk protein %. Ngarmsak (1984) found that HBI cows had a higher milk yield (kg/cow/day), milkfat % and milk protein % than LBI cows. However, Ngarmsak gave no indication of the statistical significance of his findings. Bryant and Trigg (1981) in agreement with the present experiment found no differences ($P > 0.05$) in milkfat % or milk protein % due to cow BI; milk yield data were not reported. Davis et al (1985) found the milk yield of high BI cows to exceed that of low BI cows for both Jerseys (throughout lactation) and Friesians (early and late lactation).

Other researchers have adjusted their milk production data for differences in cow size between cow BI groups. Bryant (1981) adjusted milkfat data for differences in LW and, since the HBI cows were heavier than the low BI cows, obtained a reduction in milkfat yield differences due to cow BI. The statistical significance of this effect, however, was not indicated. Grainger et al (1985a and b) expressed performance variables per unit of metabolic LW ($LW^{0.75}$) before carrying out any statistical analyses because of a higher mean LW of LBI versus HBI cows.

In the present experiment HBI cows were lighter than LBI cows (see appendix 5). Therefore the effect of LW on milk yield within each BI group was examined by univariate analyses of variance to see if differences in milk yield due to BI would be increased by removing differences in milk yield due to LW. Milk yield and LW data were first converted to logarithmic values in order to identify the power of LW that milk yield was proportional to. There was found to be no effect of LW on milk yield prior to the experiment for either BI group ($P > 0.05$). Furthermore, the effect of LW and the interactive effects of LW with cow BI (LW X BI) on milk yield were examined across both groups.

Again there was no effect of LW or LW X BI on milk yield prior to the experiment ($P > 0.05$). The details of these analyses are presented in appendix 6 (it should be noted that the interactive effects of cow age with LW on milk yield was also examined). Since analysis of the preliminary data revealed no confounding effects of LW, no further analysis were carried out.

It would appear that the increased milkfat and milk protein yields of HBI cows are not necessarily associated with increases in milkfat % and milk protein %, respectively. Therefore, differences in fat and protein yields between HBI and LBI cows are probably mainly due to increased milk yields in the former although evidence for this is questionable in the present experiment.

4.3.4 Level of Voluntary Intake

No effect of cow BI on DOM intake was found either during the experiment (using the HCT and COT) or the following two weeks (using the COT). This is not surprising considering the lack of precision associated with current methods for measuring intake of grazing animals (see 4.v1.1). Other grazing trials have found no difference in intake due to cow BI (Grainger et al 1985a; Ngarmsak, 1984).

The lack of difference in SCFA% in the milkfat between cows of high or LBI further suggests that there were no differences in energy intake per animal (see 4.1.2). Some stall feeding trails (in which intake was measured directly) found no differences in ME intake per animal due to BI but found ME intake of high BI cows to exceed that of LBI cows when expressed per unit of LW (Bryant, 1981) or $LW^{0.75}$ (Grainger, et al, 1985 a and b; Trigg and Parr, 1981). It is likely that differences in LW between HBI and LBI cows in the present experiment confounded any differences in intake due to BI. The HBI cows weighed less than the LBI cows at the begining ($P < 0.05$), end ($P < 0.01$) and two weeks following ($P < 0.01$) the experiment (see appendix 5). When DOM intake was expressed per kg $LW^{0.75}$, the intake of HBI cows exceeded that of LBI cows (see table 4.4) but it must be noted that such differences were not necessarily statistically significant. There were no differences in CS between cows of HBI and LBI ($P > 0.05$, see appendix 5) and hence cow fatness should not have been a confounding factor.

Table 4.4 The DOM Intakes of High (H) Versus Low (L) Breeding Index (BI) Cows (least square means averaged across feeding levels) Expressed Per Unit of Metabolic Liveweight* ($g/kg^{0.75}$) during weeks 5-8 and 9-10 of Lactation.

Weeks of Lactation	Cow BI	$LW^{0.75}$ (kg)	HCT	COT (1)	COT (2)
5-8	High	95	134	117	85
	Low	104	123	108	76
9-10	High	94		102	113
	Low	106		92	101

* $LW^{0.75}$ was taken as the average of the measurements taken at the beginning and end of each period.

4.4 THE INTERACTIVE EFFECTS OF COW BREEDING INDEX AND UNDERFEEDING IN EARLY LACTATION

4.4.1 Immediate Effects on Milk Production

During the experiment HBI and LBI cows were affected to the same extent by underfeeding with respect to yields of milk, milkfat and milk protein (kg/cow/day). The reduction in DOM intake due to restricted DOM allowance was the same for each BI group. Furthermore, there were no differences between HBI and LBI cows in the effects of underfeeding on changes in LW and CS. Cow BI had no effect on the size of reduction in SCFA% or increase in LCFA% in the milkfat due to underfeeding. In keeping with the foregoing there were no differences in the calculated marginal efficiency (kg milkfat produced per kg increase in DOM intake) between cows of HBI or LBI. This agrees with stall feeding (Bryant, 1981; Grainger,1985a and b) and grazing (Ngarmsak, 1984) trials.

4.4.2 Residual Effects on Milk Production

1) Recovery from Underfeeding

The residual effect of underfeeding on milk and milk protein yields (kg/cow/day) of LBI cows was no different to that of HBI cows.

However, the milkfat yield (kg/cow/day) of LBI cows took longer to recover from previous underfeeding than that of HBI cows. This effect is shown in table 4.5. By weeks 14-16 of lactation it can be seen that there were no longer any effects of previous underfeeding on the milkfat yield of HBI cows ($P > 0.05$) whereas the milkfat yields of previously underfed LBI cows were still depressed ($P < 0.05$).

In total, previously restricted HBI and LBI cows produced 5.2 and 11.7 kg less milkfat over weeks 9-13 and 9-16 of lactation respectively, compared to their ad libitum fed counterparts (see appendix 7). The calculated residual effects were 0.8 and 2.0 times the immediate effect of underfeeding on milkfat production for HBI and LBI cows, respectively (see appendix 7). In keeping with this, previously restricted LBI cows gained more condition than their ad libitum fed counterparts over the two weeks immediately following the experiment whereas there was no apparent effect of previous underfeeding on the CS change of HBI cows.

It is possible that an interaction between cow BI and underfeeding in early lactation as found by the present experiment might explain in part the conflict between researchers in the reported values of residual effects on milkfat and milk production (see 1.1.3). Furthermore, such an interaction agrees with the suggestion made by Bryant (1984) that HBI cows show a greater ability to recover from

Table 4.5 The Milkfat Yields (kg/cow/day) of High (H) Versus Low (L) Breeding Index (BI) Cows Following Underfeeding in Early Lactation (least square means and their standard errors).

Week of	HBI		LBI		$S.E._{\bar{x}}$
Lactation	R	AL	R	AL	
9	0.56	0.94	0.46	0.83	0.06
10	0.78	0.85	0.54	0.77	0.07
11	0.76	0.89	0.58	0.80	0.06
12	0.83	0.95	0.63	0.81	0.06
13	0.83	0.80	0.60	0.77	0.06
14	0.83	0.77	0.66	0.81	0.05
15	0.81	0.80	0.58	0.72	0.05
16	0.81	0.80	0.54	0.76	0.06

Note: R = previously restricted AL = previously fed ad libitum

periods of underfeeding than LBI cows.

In contrast with the present experiment, Ngarmsak (1984) found no interaction between cow BI and the residual effects of underfeeding in early lactation. More recently at Massey University a trial was carried out over the 1984/1985 dairy season in which 20 HBI/LBI cows were underfed in weeks 4-7 of lactation (C.W. Holmes, unpublished). Underfed cows lost 22 kg LW and 0.2 CS compared to generously fed cows which gained 4 kg LW and 0.2 CS (averaged across cow BI groups) resulting in differences of 26 kg LW and 0.4 CS by the end of the experiment. When the raw data are examined it appears that the residual effect of underfeeding in early lactation on milkfat production was slightly greater for HBI versus LBI cows. However it must be stressed that these data were not statistically analysed. Furthermore, fewer cows were used and underfeeding was less severe as evidenced by the smaller effects on LW and CS than in the present experiment.

2) Compensatory Response from Previously Underfed Cows

Previously restricted HBI and LBI cows consumed similar amounts of DOM relative to their previously *ad libitum* fed counterparts following underfeeding. Furthermore during the third week subsequent to the experiment there was no interaction between cow BI and previous feeding level on SCFA% in the milkfat suggesting no interactive effect on the level of energy intake. Therefore it appears that the more rapid recovery of HBI versus LBI previously restricted cows in milkfat yield was not due to a greater compensatory response in voluntary intake.

4.4.3 Effects on Milk Composition

During the experiment HBI cows were no more affected by underfeeding than LBI cows in milkfat % but there was a greater reduction in milk protein %. Underfeeding reduced protein % of HBI cows by 13%, 7%, 15% and 13% and of LBI cows by only 1%, 4%, -3% and 7% for weeks one to four of the experiment, respectively. It is possible that cow BI varied between the experiments discussed in 1) in 4.2.3 thus partly explaining why some workers found a reduction in protein % due to underfeeding whereas others found no effect.

Ngarmsak (1984) found no interactive effects of cow BI and underfeeding during the experimental period on milkfat % ($P > 0.05$) which agrees with the present experiment.In contrast Ngarmsak(1984) found no interactive effect of cow BI and underfeeding during the experimental period on milk protein % ($P > 0.05$).

Following the experiment there were no differential effects of previous underfeeding on milkfat % or milk protein % due to cow BI ($P > 0.05$) as is also apparent from Ngarmsak's (1984) results.

CHAPTER FIVE

CONCLUSION

As in other studies the effect of underfeeding in early lactation was to immediately reduce milk production of HBI and LBI cows. In HBI cows the residual effect on milk production was small and transient in agreement with most other recent experiments which used high producing cows relative to New Zealand standards. It would appear that the rapid recovery in milk production was not due to any rapid compensatory increase in voluntary intake following the return to more generous feeding levels.

According to the N.Z.D.B. Annual Farm Production Report 1983/84 average cow BI is currently 121 for cows sired by proven bulls used in the artificial breeding service and 113 for all other cows. The former is close to the HBI average of 127 used in the present experiment. In practical terms this means that lower herbage allowances can be offered per cow in early lactation. Thus a higher efficiency of pasture utilization is achieved in addition to higher subsequent levels of pasture growth rate and quality without unduely jeopardizing production per cow over the whole lactation.

Low BI cows in the present experiment showed a residual effect of 2.0 times the immediate effect on milkfat production. This was quite substantial and likely to be significant over the whole lactation. The cow BI of 113 for cows not sired by proven bulls is closer to the LBI average of 103 used in the present experiment. The implication is that less flexibility is afforded in terms of feed management. However cow BI may only be important when underfeeding is severe since the less severe underfeeding in Ngarmsak's (1984) trial showed only a very small residual effect on milkfat yield with no differential effect of cow BI.

There was poor agreement between techniques used to estimate DOM intake and the variation around each estimate was high. Clearly improvements are required in the techniques currently employed to measure intake of the grazing ruminant. This would allow more effective comparison between experiments with respect to severity of underfeeding imposed and in calculated milk responses to changing levels of energy intake. Furthermore, there would be greater likelihood of finding small but real differences in intake e.g. between animals due to BI or within animals due to previous underfeeding.

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APPENDICES

APPENDIX 1 The Method of Calculating One Day's Area of Pasture (an example at the generous feeding level for a paddock of width 60 m during period B).

Estimated herbage mass:

average meter reading (X) = 27.1

herbage mass = 158 X - 800 (regression equation)

= 3482 kgDM/ha

Herbage allowance to be offered:

per cow = 45 kgDM (at the generous feeding level)

∴ per day = 45 x 8 (since there were 8 cows per break)

= 360 kgDM per day

Area of pasture required:

$$= \frac{\text{herbage allowance to be offered (kg DM)}}{\text{herbage mass (kg DM/ha)}}$$

$$= \frac{360 \text{ kgDM}}{3482 \text{ kgDM/ha}} = 0.1034 \text{ ha or } 1034 \text{ m}^2 \text{ per day}$$

APPENDIX 2 Differences Between Treatment Groups (Days in Lactation, Milk Production, Cow LW and CS) at the Beginning of the Experiment (12/9/83).

(1) Days in Lactation on 12/9/83

Treatment Group	Cow BI	Feeding Level	Days in Lactation $\bar{x}$	σ_{n-1}
1	LBI	Restricted	24.1	9.5
2	LBI	Ad libitum	31.6	10.7
3	HBI	Restricted	21.6	11.3
4	HBI	Ad libitum	27.0	10.9

Treatment Groups	t_{14}	L.O.S.
1 vs 2	1.48	NS
1 vs 3	0.48	NS
1 vs 4	0.57	NS
2 vs 3	1.82	NS
2 vs 4	0.85	NS
3 vs 4	0.97	NS

L.O.S. = Level of Significance NS = Not Significant($P > 0.05$)

(2) Milk Production Regressed on Days in Lactation on 12/9/83

Milk Production Characteristic	Cow BI	b	$F_{1,14}$	L.O.S.
Milk Yield	LBI	+0.00367	0.23	NS
	HBI	+0.04345	0.54	NS
Milkfat Yield	LBI	-0.00534	1.08	NS
	HBI	+0.00063	0.06	NS
Protein Yield	LBI	-0.00237	0.32	NS
	HBI	-0.00313	3.77	NS
Milkfat %	LBI	-0.04445	0.07	NS
	HBI	-0.02438	4.31	NS
Protein %	LBI	-0.02476	16.65	**
	HBI	+0.75263	9.30	**

L.O.S. = Level of Significance NS = Not Significant($P > 0.05$)
** = $P < 0.01$

(3) Cow LW and CS on 12/9/83

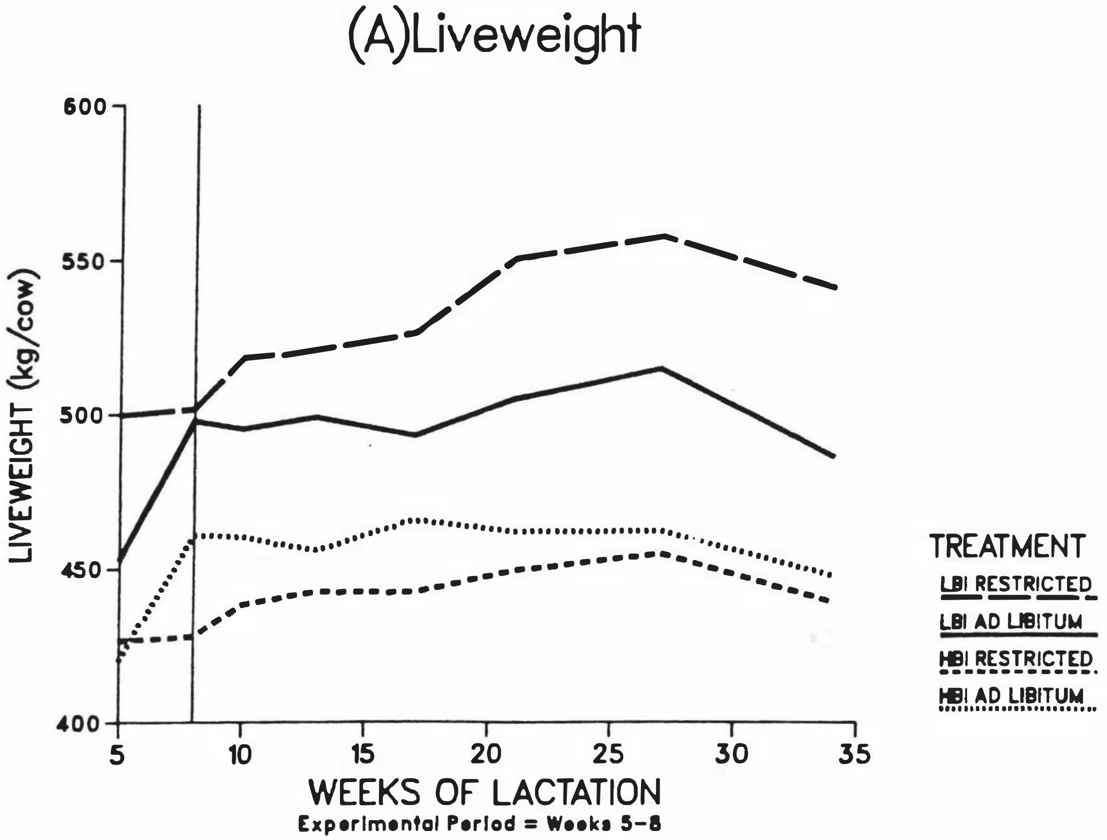
Treatment Group	Cow BI	Feeding Level	LW (kg) $\bar{x}$	LW (kg) σ_{n-1}	CS $\bar{x}$	CS σ_{n-1}
1	LBI	Restricted	500	63	5.0	0.6
2	LBI	*Ad libitum*	453	50	4.3	0.4
3	HBI	Restricted	427	57	4.4	0.6
4	HBI	*Ad libitum*	420	49	4.3	0.7

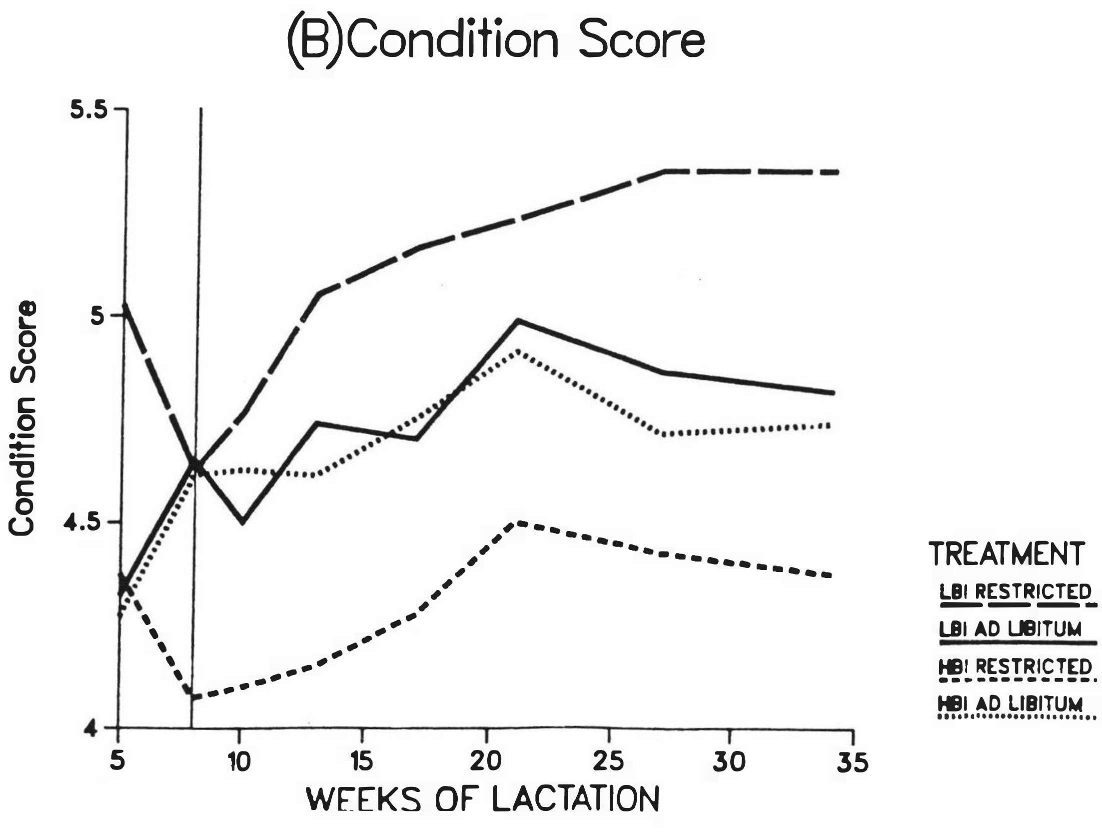
Treatment Groups	LW t_{14}	LW L.O.S.	CS t_{14}	CS L.O.S.
1 vs 2	1.65	NS	2.75	**
1 vs 3	2.43	*	2.00	NS
1 vs 4	2.84	**	2.15	*
2 vs 3	0.97	NS	0.39	NS
2 vs 4	1.33	NS	0.00	NS
3 vs 4	0.26	NS	0.31	NS

L.O.S. = Level of significance NS = Not Significant($P > 0.05$)

* = $P < 0.05$ ** = $P < 0.02$

APPENDIX 3 The liveweights and condition scores of high (H) versus low (L) breeding index (BI) cows grazed at restricted or *ad libitum* feeding levels during early lactation (raw data means).





APPENDIX 4 Nitrogen Concentrations (NC), *In Vivo* (Predicted) Organic Matter Digestibilities (OMD) and Organic Matter Concentrations (OMC) of the Herbage Quadrat Samples Before Grazing (BG) and After Grazing (AG) (raw data means).

Period (weeks of lactation)		Paddock Type	NC(%DM) $\bar{x}$	σ_{n-1}	DMD(%) $\bar{x}$	σ_{n-1}	OMC(%DM) $\bar{x}$	σ_{n-1}
5-8	BG	*Ad libitum*	3.1	0.3	75.3	4.4	86.5	1.2
		Restricted	3.0	0.2	77.7	3.3	86.5	1.4
	AG	*Ad libitum*	2.4	0.3	56.4	6.1	82.3	4.2
		Restricted	2.1	0.2	36.9	6.8	77.5	5.2
9-10	BG	Generous	2.8	0.4	75.9	0.9	86.3	1.8
	AG	Generous	2.1	0.4	77.3	0.0	85.6	2.1

APPENDIX 5 Differences Between Cow BI Groups in LW and CS at the Beginning (12/9/83), End (10/10/83) and Two Weeks Following the Experiment (24/10/83).

	HBI		LBI		HBI vs LBI	
	$\bar{x}$	σ_{n-1}	$\bar{x}$	σ_{n-1}	t_{30}	L.O.S.
LW (kg/cow)						
12/9/83	424	51	477	60	2.69	*
10/10/83	445	55	500	51	2.92	**
24/10/83	449	51	507	57	3.03	**
CS (per cow)						
12/9/83	4.3	0.6	4.7	0.6	1.89	NS
10/10/83	4.3	0.5	4.6	0.5	1.70	NS
24/10/83	4.4	0.5	4.6	0.5	1.13	NS

L.O.S. = Level of Significance NS = Not Significant($P > 0.05$)

* = $P < 0.05$ ** = $P < 0.01$

APPENDIX 6 The Effect of Cow LW on Milk Yield (kg/cow/day) for Week Four of Lactation.

Statistical Models

(1) Within Each BI Group (n=16)

Analysis of variance was based on the following model:-

$$y_{ij} = \mu + a_i + w_j + (a.w)_{ij} + e_{ijk}$$

where y_{ij} is log (milk yield) for a cow of ith age and jth log (LW)

μ is the general mean

a_i is the effect of cow age

w_j is the effect of log (LW) of the cow

$(a.w)_{ij}$ is the interactive effect of cow age and log (LW) of the cow

e_{ijk} is the random residual unique to y_{ij} which is assumed to be normally distributed with mean 0 and variance σ^2

(2) Across both BI Groups (n=32)

Analysis of variance was based on the following model:-

$$y_{ijk} = \mu + a_i + w_j + b_k + (a.w)_{ij} + (w.b)_{jk} + e_{ijkl}$$

where y_{ijk} is log (milk yield) for a cow of ith age jth log (LW) and kth BI.

μ is the general mean

a_i is the effect of cow age

w_j is the effect of log (LW) of the cow

b_k is the effect of cow BI

$(a.w)_{ij}$ is the interactive effect of cow age and log (LW) of the cow

$(w.b)_{jk}$ is the interactive effect of log (LW) and cow BI

e_{ijkl} is the random residual unique to y_{ijk} which is assumed to be normally distributed with mean 0 and variance σ^2

Results

	LBI	HBI	LBI/HBI
Power of LW to which milk yield was proportional (L.O.S.)	0.07(NS)	0.42(NS)	0.11(NS)
L.O.S. of following effects :			
age	NS	NS	NS
BI	-	-	*
LW	NS	NS	NS
age X LW	NS	NS	NS
BI X LW	-	-	NS

NS = Not Significant * = $P < 0.05$

APPENDIX 7 The Calculation of Total Immediate and Residual Effects of Underfeeding in Early Lactation on Milkfat Yield.

Total milkfat production (kg/cow) was calculated at *ad libitum* and then restricted feeding levels for the appropriate time periods and cow BI groups (see table below). The difference in milkfat yield (MFY) between the two feeding levels was taken as the total reduction in MFY due to underfeeding.

To calculate total MFY in keeping with the repeated measurements analysis of variance carried out on the milk production data (see 2.8.1), the area under the graph of least square MFY means was calculated in each case. This involved dividing the areas into trapezia and using the formula $((a+b)/2)h$. The sides of each trapezium, a and b, were the appropriate least square mean M.F.Ys (kg/cow/day) and the height, h, was equal to seven days (one week). The results obtained are presented as follows :

	HBI	LBI	HBI/LBI
Milkfat Yield (MFY) (kg/cow)			
(1) Immediate			
Weeks of Lactation	5-8	5-8	5-8
Feeding Level: *Ad Libitum* (AL)	28.3	23.8	26.1
Restricted (R)	21.4	17.8	19.5
Immediate Reduction in MFY due to Underfeeding (AL-R)	6.9	6.0	6.6
(2) Residual			
Weeks of Lactation	9-13	9-16	9-13
Previous Feeding Level: *Ad Libitum* (AL)	31.0	43.9	23.1
: Restricted (R)	25.8	32.2	29.4
Residual Reduction in MFY due to Underfeeding (AL-R)	5.2	11.7	6.3
(3) Residual/Immediate	0.8	2.0	1.0