EFFECTS OF BODY SIZE ON FOOD CONVERSION EFFICIENCY IN DAIRY COWS

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ABSTRACT

The present experiment was designed with the broad objective of examining the importance of differences in body size amongst high producing cows, on their efficiency (FE) of producing milk. For the purpose, a total of 30 multiparous cows (22 Friesians and 8 Jerseys) with similar milkfat (MF) yields were selected from the Dairy Cattle Research Unit at Massey University. Body weight (BW) of the cows ranged between 310 and 565 kg and they were 4-7 years old. Whilst no account of the calving dates was taken, most of the cows were in early to mid lactation. The experiment was divided into two parts- a 25 day grazing period and an 18 day indoor feeding period. During the grazing trial, cows were divided into three "size" groups- large, medium and small, 10 cows in each group (8 Jerseys in the "small" group), but during indoor feeding 11 Friesians and 5 Jerseys were used. The three groups of cows were offered a generous daily herbage allowance and grazed side by side in separate parts of a paddock. The herbage fed during the grazing and indoor feeding periods consisted of a mixture of high quality perennial ryegrass and white clover and representative samples were taken for in vitro digestibility determination. The daily faecal outputs, and then dry matter (DM) intakes, were estimated using gelatin pills and controlled release capsules (CRC) containing chromic oxide (Cr_2O_3). Milk yield and composition, BW and condition score change were measured during both experiments. The effects of body size (BW, wither height and chest depth) and breed (and Friesians and Jerseys combined) on intake, production and FE were studied. Energy in milk (NE milk) was estimated from milk composition and FE was then calculated as milk energy produced divided by total ME consumed. Finally using the General Linear Models procedure of the SAS statistical packet, analysis of variance, correlations, and multiple regression analyses were carried out. Intakes during the outdoor experiment were estimated from faecal outputs. Their accuracy, however, may have been reduced by insufficient sampling over the day in the case of the period during which gelatin capsules were administered, and because of the loss of

capsules from some cows or underestimation of intakes during the CRC feeding period. The difference in the mean BW between large- medium and medium-small size groups was 80 kg in both cases. The medium group (Friesians) ate 3.9% less DM, produced 2.8% less NE milk and were 2.6% more feed efficient than the large group (Friesians); the small group (mainly Jerseys) ate 13.4% less DM, produced 8.7% less NE milk than the medium ones and were 5.1% more efficient. Friesian cows were 114-127 kg heavier than Jerseys and ate 13.5-20.5% more DM, produced 5.7-8.4% more NE milk but were 5-15% less feed efficient than the Jerseys (outdoors and indoors). Cows which were taller or had greater chest depths had higher levels of intake, and only height was related to production (except MF-in combined data). Further details and the statistical significance of these relationships are summarized below.

1) Although all the cows produced relatively similar amounts of daily MF, NE milk was influenced by BW. This relationship was also affected by breed effects in that the larger cows were Friesians and they tended to produce more protein and lactose than the Jerseys.

2) During the outdoor period, DM intake was positively related to $LW^{0.75}$ in Friesians, and in the combined data all measures of size were significantly correlated with DM intake (and the highest correlation was obtained with $LW^{0.75}$). Similar significant relationships between DM intake and $LW^{0.75}$ were apparent in the multiple regression analyses. During indoor feeding, DM intake was again related significantly to $LW^{0.75}$ although the relationship was not apparent amongst the smaller number of Friesians used.

3) DM intake and NE milk production were strongly related during the indoor experiment but not during the outdoor experiment. DM intake was also significantly associated with liveweight gain (LWG) in the outdoor experiment (from the multiple regression analyses) but not in the indoor experiment.

4) FE was significantly higher for Jerseys than Friesians in the indoor experiment and during period 2 of the outdoor experiment. FE was highly correlated (positively) with NE milk within breeds and overall (0.2-0.4% MJ from regression coefficients), especially during the outdoor experiment (0.3-0.4%/MJ). Increasing $LW^{0.75}$ reduced FE significantly (0.2-0.3%/kg $LW^{0.75}$) in both outdoor and indoor experiments.

5) The grazing cows gained weight during the experiment and this significantly reduced the FE of the cows (6.1-7.3%/kg LWG from the regression analyses).

6) The multiple regression relationships between ME intake and $LW^{0.75}$ (maintenance), production and LWG provided partial regression coefficients as follows:

Maintenance : 0.89 (indoors)-1.40 (outdoors) MJME/$kg^{0.75}$

Production : 0.80 (outdoors)-1.76 (indoors) MJME/MJ NE milk

LWG : 33-40 (outdoors) MJME/kg LWG

These values showed variation when alternative analytical procedures were used. Estimated coefficients differed from published data mainly in respect to the higher values for maintenance requirements (ME_m).

The significance of these results are discussed and it was concluded that dairy cows in New Zealand should be chosen on the basis of an index which allows for differences in body weight as well as production.

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Admin = Administration

BW = Body weight

CP = Crude protein

CRC = Controlled release capsule

Cr_2O_3 = Chromic oxide

Cr = Chromium

d = Day

DE = Digestible energy

DM = Dry matter

DMD = Dry matter digestibility

DMI = Dry matter intake

FCM = Fat corrected milk

FE = Feed efficiency

FM = Fasting metabolism

g = Gram

GE = Gross energy

ha = Hectare

Ht = Height

k = Efficiency of metabolisable energy utilization

k_g = Efficiency of metabolisable energy utilization for LWG

k_l = Efficiency of metabolisable energy utilization for milk production

k_m = Efficiency of metabolisable energy utilization for maintenance

LW = Liveweight

$LW^{0.75}$ = Metabolic body weight

LWC = Liveweight change

LWG = Liveweight gain

MD = Energy density of feed

ME = Metabolisable energy

MEI = Metabolisable energy intake

ME_m = Metabolisable energy for maintenance

MF = Milk fat

MJ = Megajoules

NE = Net energy

NE milk = Energy content of milk (or milk energy)

OMD = Organic matter digestibility

Pr = Protein

Reg = Regression

SNF = Solid not fat

W = Weight

CHAPTER 1
INTRODUCTION

The dairy production system in New Zealand is based on the efficient utilization of grazed pasture by lactating cows. From managed grasslands, dairy cows can obtain adequate amounts of nutrients and energy at low cost to achieve a high level of productivity per hectare well within the limits fixed by cows' genotype. Three main factors are involved in determining the level of milk production from grasslands:

- the quality, quantity and seasonal distribution of grass grown;
- the proportion of the grass grown that is actuallly harvested by the cattle;
- the efficiency with which the cattle convert the harvested feed into milk.

(Mc Meekan, 1960)

Lack of extreme heat, cold and drought in New Zealand means that animal housing is not generally required; mild climates in dairying areas are favourable for ample pasture growth; due to adequate rainfall, irrigation is not necessary for pasture production. Compared with agriculture in the United States and Europe, the use of energy intensive fertilizer nitrogen is low in New Zealand pastoral farming (Daly, 1990). However, pasture containing white clover in addition to ryegrasses has the advantage of requiring less use of fertilizer nitrogen. In a mixed pasture of this kind containing 20 per cent white clover, an average of 200 kg N/ha is probably fixed each year (Walker, 1980).

The proportion of grass grown which is consumed by milking cattle is mainly altered by stocking rate and secondly the proportion of milkers to dry stock carried. In the New Zealand system, emphasis is placed on achieving a high utilization of pasture by using relatively high stocking rates which maximize farm profitability, but at the expense of production per animal (Holmes and Mc Millan, 1982; Holmes and Wilson, 1984).

The dairyfarming systems in New Zealand is thus considered "efficient" because input costs are very low in comparison with those in most other systems throughout the world. In general, the efficiency of use of ingested food depends on the maintenance requirement of the cow (i.e. efficiency decreases with increasing body size (or weight), the genetic potential of the cow (which may also be related to size) and the level of feeding. In the latter case a higher intake has the potential to increase efficiency by diluting the "overheads" of maintenance provided all the extra energy is not diverted to liveweight gain.

In the past within New Zealand, the smaller dairy breeds (Jersey and Jersey cross-breds) were farmed throughout the country, but with the recognition of larger breeds elsewhere and the increasing value of beef from dairy breeds, New Zealand farmers also started to replace the previous breeds with Friesian cows. Now this breed has gained widespread popularity throughout the country. However, food conversion efficiencies of dairy cows may vary between breeds, (or body size) and have yet to be precisely identified in New Zealand conditions. The present study was, therefore, commenced with the broad objective of providing information on the importance of body size in influencing the efficiency of milk production of cows in the New Zealand system.

CHAPTER 2
LITERATURE REVIEW

2.1 Estimation of Herbage Intake

Many alternative techniques have been developed to estimate the herbage intake of grazing animals. Leaver (1982)(cited by Holmes,1989) divided them into two main parts- direct and indirect.

2.1.1 Direct Measurement of Pasture Intake

Sward Cutting Technique

The mass of herbage per unit area is assessed by cutting to ground level before and after a grazing period and the intake of the grazed herbage is estimated by difference (Holmes,1989; Meijs, 1981). In other words, the amount (weight) of the herbage consumed = herbage offered-herbage left. This method is normally applicable to estimate the intake of groups of animals although it may be used in the case of individual animals by holding them separately in different paddocks. Also, herbage intake of confined animals can be measured by this technique by offering measured quantities and then taking account of the refusals. Minson (1990), however, pointed out that the accuracy of this method depends on three factors: the error in estimating the initial and the final yields of herbage; the proportion of the herbage that is actually consumed; and the growth of herbage that occurs during a trial, or loss of pasture through senescence, activity of insects or by trampling. When pastures are extensively grazed, errors in intake estimation may be high, but with strip grazing, this problem is reduced (Van der kley 1956, cited by Minson, 1990).

2.1.2 Indirect Measurement of Pasture Intake

Holmes (1989) described two distinct indirect methods. One depends on estimating the current level of feeding from the recorded animal performance (Baker, 1982, cited by Holmes,1989)(see Holmes, 1989). The other method in grazing steers was described by Garrigus (1934)(cited by Minson, 1990) and is called the faecal index method (Holmes, 1989). It involves the estimation of daily faecal production and dry matter digestibility of the herbage consumed.

A. Estimating Faecal Output

This can be achieved by two methods: total faecal collection and marker ratio technique.

i) Total Faecal Collection

Faecal production may be measured by the use of the harnesses and collecting bags but it is labourious and the determination of DMD with the cut pasture often underestimates the DMD of grazed pasture because animals usually select a diet higher in DMD (Minson,1990). Collection of faeces is difficult in cattle (Holmes, 1989).

ii) Marker Ratio Technique

Markers are non toxic and indigestible chemicals and are easily dispersible so that they are uniformly distributed through the digestive tract following some time after dosing. Since these chemicals do not occur naturally in feedstuffs, they are also called external markers.

Chromic oxide (Cr_2O_3) has been used extensively to estimate the faecal output of grazing ruminants and thus avoid the need to collect all the faeces. This can be administered in several forms but only four are in gereral use: gelatin capsule (or pill) in oil base, paper impregnated with Cr_2O_3, incorporating the marker into the feed (Le Du and Penning, 1982) and controlled release devices (Brandyberry et al.,1991; Parker et al.,1989; Pigden et al.,1964). Studies have also been carried out using polyethylene glycol (PEG), a water soluble marker, to determine the faecal output. However, results obtained from this marker were not reliable because the maximum variations in PEG concentration in the dry matter of separate faecal samples were $\pm$ 40 to 60% from the 24 hour weighed mean concentrations compared to 10% (on the similar basis) for Cr_2O_3 (Corbett et al.,1958). More recently, the reliability on the use of n-alkanes has been examined. When synthetic n-alkanes of even chain length (C_{28} and C_{32}) are administered and the naturally occurring forage n-alkanes of uneven chain length (C_{27}, C_{29}, C_{31}, C_{33} and C_{35}) are also measured, both are only partially recovered in the faeces, but if both n-alkanes of similar chain lengths are employed, any overestimation of faecal output is balanced by an underestimation of DMD, so intake can be estimated with minimal error (Mayes et al.,cited by Minson,1990).

By using indigestible markers, faecal output is calculated as follows:

$$F = \frac{R}{C}$$

where F=faecal DM output (kg/day)

R=expected daily release rate of Cr (g Cr/day)

C=concentration of Cr in faecal DM (g Cr/day)

Hodgson and Rodriguez (1970) applied weighed amounts of shredded paper containing Cr_2O_3 twice daily for 12 days and faecal samples were collected 7 days following the dosing. Two major sources of error detected were:

a) that the marker was not recovered quantitatively in the faeces, and

b) that the concentration of marker in the faeces was not estimated accurately.

Mir et al.(1989) conducted a study to determine the recovery of faecal Cr. In the faecal samples that were frozen fresh and later thawed, the recovery of Cr was greater than from samples either dried by use of a forced draft oven, or a microwave oven. Stevenson (1962)(cited by Jones et al.,1965) suggested that Cr_2O_3 losses during grinding processes can reach up to 2.6%; such losses would have exaggerated estimates of faecal output and feed intake by 3.1%. Carruthers and Bryant (1983), on the other hand, pointed out that when dairy cows were dosed with Cr_2O_3 (10g Cr_2O_3 in a gelatin capsule) and feed intake examined, there was consistent overestimation of feed intake by 14%.

It is generally agreed that when the animals are drenched with Cr_2O_3 pills every day, there is a diurnal variation in the recovery of Cr_2O_3 in the faeces. In one observation conducted by Hardison and Reid (1953), the variation in the recovery rate was 0.8 at 12.00 hours and 1.3 at 18.00 hours among the steers that were dosed once daily with 10g Cr_2O_3. With frequent administration, the diurnal variation was found to be minimal. For example, Pigden and Brisson (1956) and Brisson et al.(1957), cited by Pigden et al.(1963) showed that drenching the grazing wethers and steers with Cr_2O_3 every 4 hours eliminated the diurnal excretion cycle.

The concentration of Cr_2O_3 is not immediately equilibrated throughout the gut after administration. A preliminary dosing is, therefore, necessary for the constancy of concentration in the faeces. After completing 55 experimental results using Cr_2O_3 as a marker, Le Du and Penning (1982) suggested that faecal output can be estimated within $\pm$ 6% variation if the following procedures are followed:

- A 7 days' preliminary dosing period
- Animals dosed twice a day at approximately 8 and 16 hours intervals and faecal samples collected at the same time for at least 5 days
- A slow release form of Cr_2O_3 reduces the diurnal fluctuation in the recovery of the marker in the faeces.

Parker et al.(1989) observed " controlled release capsules (CRC) provide a continuous uniform release of Cr_2O_3 into the rumen and so offer an improved means of estimating faecal output in grazing animals." Of the two experiments conducted on rumen-fistulated and intact wethers housed indoors, there was no difference in the release rate (62±1 and 62±2mg (mean ± SE) Cr per day respectively). It was concluded that with low diurnal variation in faecal Cr concentration, almost complete recovery of Cr, together with reduced animal handling required to administer Cr_2O_3, there were many potential advantages of CRC for estimating herbage intake of grazing animals. Conversely, Pigden et al.(1964) used sustained- release pellets in cattle and observed a small but statistically significant diurnal variation in Cr_2O_3 concentration of faecal grab samples. It was, however, observed that variability within sampling times was lower for animals kept indoors than at pasture, with less variability during late afternoon and at night and least variability occurred at 7 pm sampling. Similarly, Brandyberry et al.(1991) could not get satisfactory results by using controlled-release bolus containing Cr_2O_3. In an experiment carried out on crossbred steers, they also used Co-EDTA and $YbCl_3$ intraruminally and collected all faeces to study the reliability of these markers. It was observed that results of faecal output obtained from Co (cobalt) and Yb (ytterbium) did not differ from total faecal collection, but Cr_2O_3 overestimated faecal output. Despite these findings which suggest that the reliability of CRC containing Cr_2O_3 is still questionable, the controlled release capsules were used in the present experiment (Chapter 3).

B. Measurement of Dry-Matter Digestibility

Several indirect methods have been devised to estimate in vivo DMD of grazed herbage. Minson (1990) divided them into two distinct groups : faecal index techniques and methods that use a sample of the selectively grazed forage.

i) Faecal-Index Technique

There are many naturally occurring chemical components (internal markers) in the feedstuffs including silica, iron, lignin, chromogen, potentially indigestible cellulose, acid-insoluble ash, and n-alkanes. However, chromogen, nitrogen and fibre are most commonly used to measure the digestibility of the grazed forage (Minson, 1990).

Regression analyses previously derived indoors are used to establish the relationships between the DMD and chemical composition of the faeces. But while deriving the faecal index regressions, the differences in DMD associated with animal species, level of feeding and endoparasites are not taken into account and thus can be the source of error (Minson, 1990).

ii) Using Selectively Grazed Forage

The grazed herbage can be sampled by hand plucking or by fitting animals with oesophageal fistulae (Van Dyne and Torrell, 1964, cited by Minson, 1990). In vitro techniques can be employed to estimate the DMD of these samples (see Minson, 1990). Regressions derived with sheep fed in pens are used in determining the DMD of the grazed herbage but it is likely that there can be an error while relating the regressions to grazing situations because of the sources of error mentioned above. Minson (1990), however, confirms that when DMD is estimated from the concentrations of internal markers, this source of error does not apply. The concentration of internal marker is greater in the faeces than in the feed because as the feed passes through the digestive tract, most of the nutrients are absorbed and digested. So the following equation is used to calculate the DMD of the grazed forage:

$$DMD = \frac{F-H}{F}$$

where H and F are the concentrations of the markers in the forage and faeces respectively.

When the faecal DM production (F) and DMD of the herbage (D) are measured, DM intake (I) is estimated from the following equation:

$$I = \frac{F}{1-D}$$

2.2 Energy Requirements for Grazing Dairy Cattle

There are many different published estimates for the energy requirements of dairy cows largely because the values are likely to be influenced greatly by factors such as climate, extent of activity associated with grazing, and type of feed (e.g.grazed pasture versus roughage, concentrate diets). In this section, energy requirements of cows (in ME terms) as recommended in three sets of standards (ARC, 1980; Australian Standards,1990; Holmes and Wilson,1984) are summarised so that comparisons can be made with values obtained in the current experiment (Chapter 4).

2.2.1 Maintenance Requirements

Energy requirements for maintenance (ME_m) have been related to measurements of fasting metabolism (FM) in cattle and sheep (ARC, 1965,1980). For cattle, including a lactating cow, the ARC (1980) have adopted FM (MJ/d)=0.53 $FW^{0.67}$ (fasted weight, kg); the FM is adjusted by adding an 'activity allowance' of 0.0043 MJME/kg liveweight (LW). In practice, however, the FM values have to be adjusted for the differences between the fasted weight of an animal and its LW when it is fed (CSIRO, 1990). According to ARC (1980), fasted weight=LW/1.053 in cattle (k=0.67).

Van ES and Nijkamp (1967) and Van Es (1970) pointed out that the requirement for FM in lactating cows is 0.346 MJ/$kg^{0.75}$ per day, and the ME_m (MJME/$kg^{0.75}$ /day) derived by the corresponding authors are 0.489 and 0.510 respectively with the metabolizability figures of 0.59 and 0.50 (ARC,1980). Thus ME_m for a fasted $LW^{0.75}$ is lower than for the normally fed one. No concrete figures for ME_m exclusively for the grazing dairy cows have been mentioned in the ARC (1980). But as the grazing animal has to spend a great deal more energy than the housed animal due to muscular activities associated with walking and grazing, the ME_m of such an animal is greater. Holmes and Wilson (1984) estimate the ME_m of grazing animals to be approximately 20-30% higher than that needed for housed animals. For a lactating cattle grazing on pasture (containing more than 11 MJME /kg DM), the ME_m is 0.60 MJME/kg per day (Holmes and Wilson, 1984).

For the prediction of ME_m and k_m, CSIRO (1990) considers various factors such as energy expenditure at pasture, body condition, effects of stressful climates, rain, wind, heat and cold nights with clear sky, acclimatization and drought feeding (see CSIRO Australia, 1990). But little information was available regarding the use of ME_m from LW loss.

Generalized equations used by CSIRO (1990) to calculate ME_m after Corbett et al.(1987) are as follows:

a) To calculate MEm (for use in ration formulation)

$$ME_m\ (MJ/d) = \frac{K.S.M.(0.28W^{0.75}\ exp(-0.03A)}{k_m} + 0.1ME_p + \frac{EGRAZE}{k_m} + ECOLD$$

b) To calcalculate MEm when ME intake is known and animal performance is to be predicted (note change from 0.28 -0.26 MJ/$W^{0.75}$ with change from ME_p to MEI)

$$ME_m\ (MJ/d) = \frac{K.S.M.(0.26W^{0.75}exp(-0.03A)}{k_m} + 0.09MEI + \frac{EGRAZE}{k_m} + ECOLD$$

where,

k= 1.0 for sheep and goats, 1.2 for *B.indicus*, or 1.4 for *B.taurus*, or a value intermediate between 1.2 and 1.4 for crosses between these breeds (e.g. 1.3 for first cross 1.25 for 3/4 *B.indicus*)

S= 1.0 for females and castrates or, following ARC (1980) and supported by evidence from Graham (1968), takes the value of 1.15 for entire males (rams, goats, bulls)

M= 1+(0.23*percent diet DE from milk)= 1+(0.26-Ba) with B=0.015 for suckled lambs and kid goats or = 0.01 for suckled calves, and a is week of life. Minimum value of M is 1.0.

W= liveweight (kg)

A= Age in years, with a maximum value of 6.0 when exp (-0.03A)=0.84.

k_m= net efficiency of use of ME for maintenance

ME_p= the amount of dietary ME being used directly for production

MEI= total ME intake

EGRAZE= additional energy expenditure of a grazing compared with a similar housed animal

ECOLD= additional energy expenditure in cold stress by animals in below lower critical temperature environments.

(CSIRO, 1990)

Table 2.1. Estimates of fasting metabolism (FM) of weaned *Bos taurus* female and castrate cattle at various liveweights (LW) and ages (years) calculated with generalized equation (a)[AB], and of their minimal metabolism predicted with an equation of ARC (1980)[AC] (MJ/d)

LW (kg)	Age (years) (CSIRO, 1990) 4.0	6.0	(ARC, 1980)
300	25.1	23.6	24.3
400	31.1	29.3	29.6
500	36.8	34.6	34.5

A. values increased by 15% for entire males (bulls).
B. values for unweaned calves increased by [1+(0.26-0.01a)], where a is week of life with a maximum value of 26.
C. Minimum metabolism (MJ/d)=0.53 $(W/1.08)^{0.67}$ + 0.0043W

Comparative values of FM in a thermoneutral environment (ECOLD=0) are shown in Table 2.1.

The following is the Energy Expenditure at Pasture (EGRAZE) estimated by CSIRO (1990):

Activity	Energy cost/kg LW
-Standing (compared with lying)	0.01MJ/d
-Changing body position (double movement of lying down and standing again)	0.00026 MJ
-Walking (horizontal component)	0.0026 MJ/km
-Walking (vertical component)	0.028 MJ/km
-Eating (i.e.prehension and chewing)	0.0025 MJ/hr
-Ruminating	0.002 MJ/hr

Suppose, a 500 kg grazing cow walks 1 km, EGRAZE of this cow using the above figures will be 24.33 MJME (excluding eating and ruminating) more than that of a cow housed indoors. CSIRO (1990) estimates a 10-20% increase in ME_m of grazing cattle under good grazing conditions, and up to about 50% for animals on extensive, hilly pastures.

It is thus clear that an accurate ME_m figures of a grazing cow is difficult to establish. The value for the efficiency of ME utilization for maintenance (k_m) estimated by Holmes and Wilson (1984) ranges between 0.65 and 0.75 with the ME of the diets ranging between 7 and 12 MJ/kg DM. CSIRO (1990) use the following equation for the estimation of k_m.

$$k_m = 0.02\ M/D + 0.5$$

Thus, if the M/D (energy density or energy content) value of pasture is 11, K_m= 0.72. These values are also preferred by ARC (1980).

2.2.2 ME for Liveweight Gain

When the M/D value of pasture is higher than 11 MJME/kg DM, a lactating cow will need 38.5 MJME/kg LWG, but in autumn, when the M/D value of pasture is 10 MJ, the same cow requires 58.1 MJME/kg gain (Holmes and Wilson, 1984).

According to ARC (1980), q (=ME/GE) is used to derive the prediction equations of ME requirement, k_m etc. The mean GE value of New Zealand pasture estimated by Hutton (1961) is 18.8 MJ/kg DM. Thus, if the ME content of the pasture is assumed to be 11.0-11.5 MJ/kg DM, q will be approximately 0.60 (because GE is found to range between 18.1-19.1 MJME /kg DM).

Using the q value of 0.60, estimated ME requirement for maintenance and growth by ARC is presented in Table 2.2.

It is apparent from the Table 2.2 that for the cattle weighing 300, 400, and 500 kg, the respective ME required /kg gain is 27, 32 and 38 MJ. The ME required for lactating cows producing different levels of production and LWG are given in Table 2.3.

ARC (1980) recommended as an interim measure " every kg of weight change consisting of 150 g protein and 550 g fat requires 26 MJNE."

Following ARC (1980), CSIRO (1990) used the following conversions for weaned animals:

LW (cattle)=1.09 (EBW + 14)

LWG (sheep and cattle) = 1.09 EBG

where, EBW = empty body weights

EBG = empty body gain

Maximum energy content of gain is 27 MJ/kg EBG (applicable to all breeds of cattle)

Thus, LWG = 1.09*27 = 29.4MJME/kg LWG.

It is suggested that the energy value of LWC for dairy cows is varied with their condition score (CS), which is assessed on a scale of 1 (emaciated) to 8 (very fat) (CSIRO, 1990). The equation is as follows:

$$MJ/kg\ LWC = 10.1 + 2.47\ CS$$

Table 2.2 ME requirements (MJ/d) of cattle for maintenance and growth-Bullocks of breeds of large mature size (ARC, 1980)-activity allowance included.

	LWG (kg/d)				
LW (kg)	00	0.25	0.50	0.75	1.00
300	34	39	45	52	61
400	42	48	55	64	74
500	48	56	64	74	86

Table 2.3 ME requirements of British Friesian and Jersey cows (MJ/d)(activity allowance of 0.0043 MJ/kg LW included)(ARC,1980)

			Milk yield (kg/d)		
Breed	LWC (kg/d)	ME/GE (q)	10	15	20
British Friesian	zero	0.6	104	129	155
weighing 600 kg	-0.5	0.6	86	111	136
(MF% 3.68)	+0.5	0.6	127	153	179
Jersey weighing	zero	0.6	99	129	160
400 kg	-0.5	0.6	81	110	141
(MF% 4.9)	+0.5	0.6	123	153	184

With increases in forage ME concentration from 8-12 MJ/kg DM, k_g (efficiency of ME utilization for synthesis of body tissue) increases from 0.4-0.6 (Holmes and Wilson,1984).

Equations used by ARC (1880) and cited by CSIRO (1990) to derive k_g values are as follows:

Forages (first growth) k_g=0.072 M/D-0.318

Forages (aftermath) k_g=0.063 M/D-0.308

But CSIRO (1990) assume a general value of 0.60 for efficiency of conversion of ME to gain in lactating cows.

2.2.3 ME for Milk Production

Recommended ME requirements for milk synthesis in dairy cattle are presented in Table 2.4 (from Holmes and Wilson, 1984).

According to CSIRO (1990), k_l of a Friesian cow grazing abundant pasture (DMD=0.75, M/D=10.75) will be 0.62, the value is the same for a housed cow consuming a diet that has 11 MJME/kg DM. ARC (1980) use the following equation:

$$k_l=0.35q+0.42$$

With zero LWC and producing 30 kg milk/day (MF% 3.6), a 600 kg Friesian cow (housed) given a feed with M/D=11 (q=0.60) will need 155.1 MJME for milk production and 87.5 MJME will be available as NE milk (CSIRO, 1990), total ME required (MJ/d) being 211.9. For a similar cow ARC (1980) estimates 207 MJME/d (including activity allowance). Thus, according to CSIRO (1990), ME required to produce 1kg milk is 5.2 MJ.

Daily ME required by Friesian and Jersey cows for different purposes including production is presented in Table 2.3.

Following formula can be used to estimate NE milk (ARC, 1980):

$$-0.2360+0.386\ fat\%+0.205\ SNF\%$$

Energy retention is reduced by 10.92 MJ/d to allow for weight loss of 0.5 kg/d or increased by 13.68 MJ/d to allow for weight gain of 0.5 kg/d (ARC,1980). k_g-$_1$ (i.e.the efficiency of utilization of energy mobilized from body tissues for milk synthesis) is 0.84 according to CSIRO (1990). It is claimed that 1 kg LWC=20 MJ of net energy (k_g=0.60). Thus, from the loss of 1 kg LW, NE used for milk production will be (20*0.84) or 16.8 MJ. With k_l=0.60, dietary ME=16.8/0.60=28 MJ (CSIRO, 1990).

Table 2.4 ME requirements for Milk Synthesis

Energy utilization	Efficiency of ME utilization			ME requirements for milk or MF synthesis (MJ/kg)					
	k_l*	k_g*	k_g-$_1$	Jersey		Friesian		FCM	
				Milk	MF	Milk	MF	Milk	MF
Directly from dietary energy	0.65	-	-	5.7	105	4.8	122	4.8	120
Indirectly from mobilization of body reserves deposited during lactation	-	0.65	0.83	6.9	127	5.7	147	5.8	145
Indirectly from mobilization of body reserves deposited during dry period	-	0.55	0.83	8.1	150	6.8	174	6.9	171

* Assuming pasture diet containing more than 11 MJME/kg DM

2.3 Partition of Energy

Ruminant body tissues use the ME of a diet for several physiological functions at the same time but over time the proportions allocated to different functions can vary; this is called "partitioning". The energy spent for various purposes are: maintenance (and activity), lactation, growth, pregnancy and the surplus will be stored principally as fat (Holmes and Wilson, 1984; Johnson,1986). Partition of energy is influenced by various factors such as level of feeding, stage of lactation, frequency of milking and composition of the diet (Thomas, 1980). As the level of feeding is increased, the incremental response to milk yield becomes progressively smaller and a greater proportion of the energy consumed is utilized for body tissue gain. When the lactation advances, the responsiveness of milk yield to additional energy becomes gradually smaller. But at the same time if frequency of milking is increased, milk yield becomes greater and this must be associated with the partitioning of ME. Sometimes ME supplied by the feed may not be sufficient for all the physiological functions and the cow then draws on her stored fat and protein to supplement the dietary supply. When this situation occurs, the cow is said to be in negative energy balance. When the energy supply exactly matches the cow's demand, she will have zero energy balance and when there is a surplus, the cow will be in positive energy balance.

From a series of experiments, a very close correlation between total energy balance (body tissues plus milk) and ME consumed has been revealed (Johnson, 1986). This kind of relationship indicates that, although it is difficult to say in which way and for what purpose the ME is partitioned, the total energy input and output is equal.

2.4 Liveweight Change

Korver (1982) observed "in lactating dairy cows, changes in LW may result from a combination of growth, change of alimentary tract fill, pregnancy and alternate deposition and subsequent catabolism of body reserve tissues." Although body reserves during early lactation may be catabolized to provide metabolites for milk secretion, this process is inherently less efficient compared to direct utilization of nutrients for milk production. However, the pattern of LW loss is by no means constant in early lactation nor its magnitude equal in all cows (Wilson and Wood, 1983). Thus in a herd, daily rate of mobilization of body reserves for milk synthesis varies markedly between cows.

Cows given the low energy diet lost weight during weeks 3 to 20 of lactation whereas cows given the high-energy diet gained weight during the same period (Poole, 1986). The efficient mechanism of a lactating dairy cow to gain and lose weight suggests that high levels of energy can be provided at peak lactation, partly from body reserves but mainly from the feed in order to allow high milk yield (Wilson and Brigstocke, 1981).

2.4.1 Milk Production and Liveweight Change under Different Feeding Systems

i) General Introduction

The ability of an animal to utilize energy determines intake (Bines, 1976). From a range of research work, it is now well-established that cows which give higher yields of milk can eat more feed than the low producing or the dry ones, and peak food intake during lactation is generally 30-40% higher than in the non-lactating animal. In other words, selecting dairy cows for greater production leads to an increased amount of nutrient demand (Korver, 1982) which must be supplied either from the higher intake of feed and /or mobilization of body reserves. It is, however, not established whether the lactating cows eat more because they give more milk, or whether they give more milk because they eat more (Wilson and Brigstocke, 1981). Nonetheless, in order to produce high milk yields, high levels of DM and associated nutrients should be introduced in the dairy cow's ration.

In grassland farming, dairy cows are subject to fluctuations in their daily energy intake because on paddock grazing, cows can experience abrupt changes in feed quality or quantity every few days as they change from paddock to paddock (Scrimgeour and Thompson, 1975). In such situations, it is difficult to establish and interpret the relationship between feed intake, milk production and LWC. Clearly, the evidence on milk yield and LWC as affected by diet composition is extensive and conflicting (Broster et al.,1978; Wilson and Wood, 1983). But Wallace (1961) examined the performance of dairy cows that were kept indoors and fed cut pastures during the years 1958-59 and 1959-60. Multiple regression technique was employed to estimate the relative importance of a number of factors which influenced the amount of feed eaten. It was found that the amount of food eaten was associated with LW, milk production and LW increase.

ii) Mathematical Relationships

Wallace (1961) obtained the following equation:

$$\text{D.O.M.} = 0.35\ \text{FCM} + 0.08\ \text{LW}^{0.73} + 3\ \text{LWI}$$

where, DOM = mean daily intake of DOM (lb)

FCM = mean daily fat corrected milk production (lb)

$\text{LW}^{0.73}$= mean liveweight (lb) raised to the power 0.73

LWI = mean daily liveweight increase (lb)

Other estimates of forage intake of lactating cattle were devised by different authors (cited by Minson, 1990):

Cox et al.(1956):

$$I=0.13FCM + 0.0053W + 0.96G$$

where, I=kg DM/day, FCM=4% fat-corrected milk (kg/day), W=liveweight (kg), G=growth (kg/day).

Bines et al.(1977):

$$I=0.16M + 0.0113W + 2.45G + 4.25$$

where, I=kg DM/day, M=milk yield (kg/day), W=liveweight (kg), and G=growth (kg/day)

Neal et al.(1984):

$$I=0.20M + 0.022W$$

where I=kg DM/day, M=milk yield (kg/day), W=liveweight (kg).

iii) Liveweight Change and Production

During early lactation, food intake (in terms of energy) increases slower than does the energy output in the milk. Thus, dairy cows commonly tend to lose considerable amounts of BW which is replaced later when milk production starts to decline and appetite remains high (Bines, 1976; Bryant and Trigg,1982; Swan, 1980). The response to a fixed allowance of extra food is larger during the early stages of lactation than the latter stages (Swan, 1980). It is, however, not clear why food intake does not increase faster in early lactation (Bines, 1976). Even when feeds containing concentrates : roughages at a ratio of 90:10 were fed to the cows or heifers, they still lost weight in early lactation but for a short period (Broster et al.,1978). The same phenomenon is applicable for cows dependent on pasture (Bryant and Trigg, 1982; Holmes and Wilson, 1984). Johnson (1977)(cited by Wilson and Wood, 1983) reported that different patterns of feeding fixed amounts of concentrates in a restricted feeding regime produce similar amounts of milk but different patterns and magnitudes of LWC.

In general, a lactating cow moves from negative to positive energy status during mid to late lactation. This is achieved by an increased DM intake capacity and also by a gradual change in the partition of nutrients away from milk production and towards body tissue deposition (Haresign, 1979). This phenomenon is applicable to all age groups. However, information is inadequate concerning the extent to which these relations may be influenced by such factors as previous level of milk production, body condition of the cows and genetic merit (Wilson and Davey, 1982).

For indoor fed cows after parturition, daily milk yield reaches its peak between 35 and 45 days of lactation; thereafter there is a steady decline of about 2.5% per week in yield until the cow is dried off (Haresign, 1979). It appears that the lag between peak milk yield and peak food intake is greater in the first than in the subsequent lactations (Bines, 1976). But if lactating cows are subjected to restricted levels of feeding, both milk production and LWG are affected. An example of such changes is given in Table 2.5.

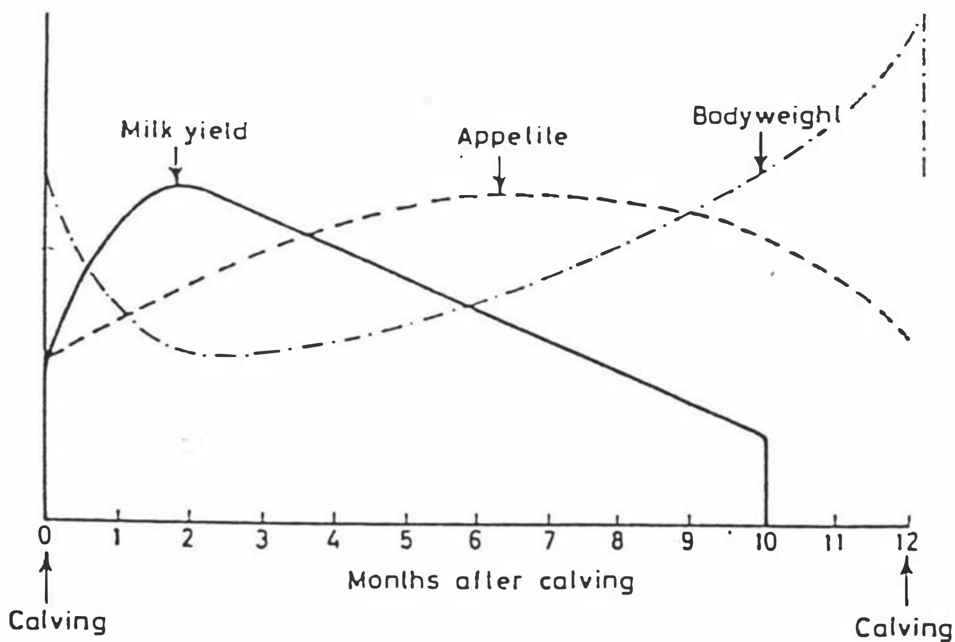
Table 2.5 Average (± SD) intake, FCM production and liveweight at *ad lib* (A) and restricted (R) feeding levels during balance periods (From Trigg et al.,1982)

Stage of lactation	Weeks 8-18 A	Weeks 8-18 R	Weeks 22-32 A	Weeks 22-32 R
Intake (kg DM/100 kg LW)	3.58 (±0.36)	2.67 (±0.31)	3.36 (±0.28)	2.30 (±0.23)
FCM (kg/day)	18.9 (±3.6)	16.2 (±3.1)	12.2 (±2.5)	8.8 (±2.5)
LW (kg)	373 (±43)	348 (±44)	376 (±38)	343 (±39)

The results in Table 2.5 were obtained from 15 sets of identical twin dairy cows of mixed breed in three years' experimental observations and feed consisted predominantly of perennial ryegrass, white clover and paspalum (Trigg et al.,1983).

There is a considerable variation between LWC and milk yield patterns among the cows of high and low genetic merit and the amount of milk produced by the individual cows is not similar in different lactations. Cows categorized as low in genetic merit lost less weight, gave less milk, and directed less energy to milk than the high producers (Belyea and Adams, 1990). Milk yield increased from first to second lactation for all measures of yield (Donker et al.,1983). A general trend in the relationships between DM inake capacity (appetite), BW changes and milk yield throughout the lactation cycle, however, has been established in lactating cows which is illustrated in Figure 2.1

Figure 2.1 Changes in milk yield, body weight and appetite of dairy cows throughout the lactation cycle (from Haresign, 1979).



2.5 Condition Score and Production

2.5.1 Measurement of Condition Score

The relationship between condition score and LW established by several workers is not similar. Grainger and Mc Gowan (1982) reviewed several trials and found a range of 17 to 45 kg LW /unit condition score (0-10 scale). Values of 20 and 35 kg liveweight /unit condition score respectively would appear appropriate for adult Jersey and Friesian cows (Holmes and Wilson, 1984).

Workers in different parts of the world use different condition score scales. The most common alternatives are 0-5 and 0-10.

On the scale 0-5, Webster (1987) classified the dairy cows as follows:

5. Grossly fat: tailhead buried in fatty tissues, pelvis impalpable even with firm pressure.
4. Fat: folds and patches of soft fatty tissue under the skin. Pelvis palpable with firm pressure but transverse processes of lumbar vertebrae impalpable.
3. Good: all bones palpable but are well covered with fatty tissue.
2. Moderate: all bones easily palpable, muscle concave around tailhead, some fatty tissue.
1. Poor: muscles and tailhead and lumbar vertebrae shrunken and concave. No fatty tissue palpable. Skin, however, is supple and movable.
0. Very poor: emaciated. Skin is thin, tight, there is no palpable tissue between skin and bone.

In New Zealand and Australia, workers have generally assessed condition score on 0-10 scale basis which is roughly equivalent to using 1/2 scores in Webster's classification.

The condition score of a lactating cow changes over the season and may also vary due to the system of measurement applied and the persons scoring it. Frood and Croxton (1978) reported that actual condition score at calving, measured on an eight-point scale, in Australia was more important than a progressive increase in score (or weight). A change of one condition score using an eight-point system was equivalent to approximately 30 kg (Buxton, 1982). But a change of one point in a nine-score system was equivalent to a change of about 24 kg (Nicholson and Sayers, 1987).

2.5.2 Importance of High Condition Score at Calving

Where cows were fed at 14 kg DM/day in the first five weeks of lactation, MF production over the first 20 weeks increased by 8.5 kg/cow for each unit increase in condition score, over the range from 3 to 6 (Grainger and Mc Gowan, 1982). Another advantage of one score higher at calving was that the cow had still 0.24 condition scores higher after 20 weeks of lactation. In the case of a lower level of feeding (8 kg DM/cow/day) for the same period, the response to condition score was 6.5 kg MF and an extra 0.35 condition score after 20 weeks (Grainger and Mc Gowan, 1982). In Victorian studies, Grainger (1980) and Grainger et al.(1981)(cited by Mac Millan et al.,1982) found that a one unit increase in condition at calving was associated with a 30 kg increase in LW and an 8 to 10 kg increase in MF production with fully fed cows in the ensuing lactation. These studies indicate the production advantages of higher condition scores of dairy cows at calving but subsequent reproductive performance may also be improved.

2.6 Influence of Body Size on Milk Production

2.6.1 Definition of Body Size

Research workers and authors have used various parameters to establish relationships between the size of the dairy cow and milk yield. Many workers have used three body measurements (or conformation) for body size-wither height, chest girth and

BW (e.g. Dickinson et al.,1969; Hickman and Bowden, 1971; Mason et al.,1957). Besides these three measurements, Dickinson et al.(1969) and Yerex et al.(1988) have also included body length. Sieber et al.(1988) used the following seven body measurements besides the BW:

1. heart girth: smallest circumferences just behind the forelegs with the cow standing square on her legs and holding her head up.
2. paunch girth: largest circumference about the barrel.
3. wither height: distance from ground to the highest point of the withers.
4. chest depth: vertical distance from the back to the floor of the chest at the shallowest part of the chest.
5. pelvic length: distance from in front of the hook bone to the back of the pin bone.
6. pelvic width: distance from outside of the left hook bone to the outside of the right hook bone.
7. body length: horizontal distance from the front point of the shoulder to the end of the pinbones.

All the measurements were taken when the animals remained standing on a level surface. Recently, Bonczek et al. (1992) used six body measurements for body size-BW, heart girth, chest depth, height at withers, length from withers to pins and length from withers to hooks. However, most workers and authors have used BW and the words 'large' or 'small' to compare the relative body size of dairy cattle (e.g. Andersen, 1978; Fredeen et al.,1982; Hutton, 1966; Mc Daniel and Legates, 1965; Stakelum and Connolly, 1987; Thonney et al.,1981).

2.6.2 Body Weight and Production

Much research work regarding the relationship between BW and production has been performed. Results, however, are not very consistent.

Bailey and Broster (1954) found a positive relationship between BW and milk production in Shorthorn cattle. While comparing the influence of age and BW on milk production, Clark and Touchberry (1962) observed approximately equal effects in the first lactation. During the second lactation, the influence of age was more important than BW, but in the later lactations, BW accounted for more of the variation in production than age. In a similar study, Mc Daniel and Legates (1965) found a minor effect of BW among first lactation and 5 to 10 year old cows, and the influence of BW was more important than age. In agreement with the observation of Clark and Touchberry (1962), the influence of age was greater in 3 and 4 year old cows than the BW. In more recent studies, Sieber et al.(1988) examined the first and second lactation cows and found significant BW relationships with FCM. Lee et al.(1989) studied the influence of BW on milk yield during different periods after calving. At the 8th week of lactation, weight was uncorrelated with production (r=0.002) and a negative correlation was observed between LWG and milk yields during the trial. Persuad and Simm (1991), on the other hand, discovered a moderate positive genetic correlation between BW and milk production traits. Cows that were heavier at calving produced higher amounts of milk, consumed more feed and gained more weight during the lactation (Hickman and Bowden, 1971). But while comparing the production levels of the cows with equal body size, Sieber et al (1988) discovered that cows that lose weight produce more milk and cows that gain weight produce less milk.

In agreement with Bailey and Broster (1954) and Sieber et al. (1988), Fredeen et al. (1982) found a large positive influence of BW both on daily and lactation yield. Also, milk yield was influenced by the intake capacity and the amount of food given. Although marginal response in yield was diminished at high levels of intake, high production, in general, was associated with shorter calving intervals, higher energy intake and larger cows.

Mc Daniel and Legates (1965) classified Holstein cows into four groups- first lactation, 3 and 4 years old cows and 5 to 10 year old cows. When compared to smaller herdmates, larger cows in all four age classes showed slight but significant linear increases in both 90- and 305- day milk yield. Therefore, from these studies, a general association between BW and milk yield was revealed. It was found that profitability could be increased by selecting larger cows if the true genetic correlation between milk yield and body size is equal to or larger than 0.3. They concluded that " selection indices computed for a range of economic situations and genetic relationships showed that little, if any, benefit can be expected by jointly considering body size when selecting for increased milk yield." But Bonczek et al(1992) selected Jersey cows on the basis of higher milk yield and found them to be heavier and larger in some measurements. Their monthly rate of LWG was greater and they could be bred earlier. It was concluded that when Jersey cows are selected on the basis of milk yield, there will not be an undesirable correlated response in any growth or body measurement. Ahlborn-Breier and Dempfle (1991) in a New Zealand context have, however, made the point that when selection of dairy cows is made on the basis of combined body size and production with their respective economic values, more accurate estimates of daughter profitability could be expected.

The extent to which BW is correlated with milk production is likely to be influenced by several factors such as stage of lactation, management practices, feeding standards, age, breed etc. Therefore, a variety of correction criteria are necessary for comparison from one situation to another. Morris and Wilton (1976) reviewed the observations of different authors and these are shown in Table 2.6. The average phenotypic value of 0.33 in Table 2.6 indicated a positive correlation between milk yield and body size.

2.6.3 Body Conformation and Production

Besides BW, other body measurements of a dairy cow are found to have varying relationships with milk production.

Table 2.6 Correlations between Milk Yield and Body Size

Authors	Phenotypic	Genetic	Details of measurement
Clark and Touchberry (1962)	Positive	-0.12	Pooled over first four lactations
Gaines et al. (1940)	Positive		Data derived from FCM/W with W; no age adjustments; all lactations
Harville and Henderson(1966)	0.12	0.45	NE milk; age adjusted weights for heifers
Hooven et al (1968)	0.44	0.30	FCM; age adjustment for genetic correlation only
Mason et al. (1957)	Positive	-0.07 0.26	FCM; BW at constant age FCM;height at constant age
Miller and Mc Gilliard (1959)	0.23	0.26	No correction for age
Ridler et at. (1965)	Regression of 530 kg/ 100 kg wt.	Positive	Constant lactation length
Syrstad (1966)	-0.03	-0.13	FCM for 4-year-olds; size measured as heart girth
Average	0.33	0.14	

Above authors used body weight as a measure of size unless otherwise stated.

(Data taken from Morris and Wilton, 1976)

Hickman and Bowden (1971) made an observation on the effect of heart girth on production among Holstein and Ayrshire cows at 60 days post-partum and found a negative association between FCM and increased heart girth. This suggested that less fleshy cows produced more milk. Similarly in Holstein cows, the coefficients for heart girth were negative (between -0.71 and -0.75) and highly significant ($p<0.001$) (Sieber et al.,1988); higher yield was also associated with larger paunch girth.

The influence of wither height on milk production has been studied by many authors (e.g. Dickinson et al.,1969; Hickman and Bowden, 1971; Mason et al.,1957; Sieber et al.,1988). In the studies of Dickinson et al.(1969) and Hickman and Bowden, a negative phenotypic relationship was found to exist between milk yield and wither height. Conversely, Mason et al.(1957) were able to establish a significant positive correlation ($r=0.31$) between these variables ($p<0.05$). Similarly, Sieber et al.(1988) observed that the amount of milk produced by taller cows was significantly greater ($r=0.44$ to 0.56) in all lactations ($p<0.05$-0.01).

Sieber et al.(1988) also studied the effect of chest depth on milk production. It was noticed that cows with deeper chest measurements tended to produce larger milk yields ($r=0.58$-0.92; $p<0.05$). They also carried out a stepwise regression analyses to establish the relationship between FCM and different body measurements (conformation). After making a comparison of the F-statistics, it was found that pelvic width, paunch girth and heart girth had greater correlations with FCM and ranked in the highest order followed by chest depth, BW and wither height.

2.6.4 Biological Effects of Body Size

Foley et al.(1972) pointed out that although large cows produce more milk than small ones, production does not vary in direct proportion to BW. It rather varies by the 0.7 power of weight which is also the approximate value for the body surface area. Thus, if a cow is twice as big as the another cow, it is likely that the bigger cow will produce about 70% more instead of 100%.

Dikerson (1978) showed an association between increased mature size of cattle, more rapid gains in growth rate and greater weights at puberty. It was also revealed that large mature animals have longer gestation and lactation lengths with possible calving difficulties, but less likelihood of genetic dwarfism. Taking account of the effects of potential climatic conditions, genetically smaller individuals were described to be likely better suited to hot, dry climates with sparse seasonal grazing. Conversely, in temperate areas of abundant food supply, larger body size may be advantageous because cows could tolerate cold stress and utilize food more efficiently.

2.7 Effect of Age on Milk Production

Milk yields increase with age, but at a decreasing rate until about the 8th year of age depending upon the breed; they then decrease with increasing age at an increasing rate (Foley et al.,1972). Foley et al. (1972) further pointed out that mature cows are generally capable of producing about 25% more milk than two-year-old heifers. Young cattle (although they eat less) are less efficient than mature animals mainly due to their additional growth requirements (Hutton, 1966).

MF and SNF concentrations decreased by about 0.2 and 0.4% units respectively between first and fifth lactation; thereafter there was little change (Foley et al.,1972). Gains (1942)(cited by Clark and Touchberry, 1962) reported " as a cow grows older from first calving to maturity, she gives more milk, not because she grows older but because she grows larger."

2.8 Efficiency of Dairy Farming and Dairy Cows

2.8.1 Measurement of Efficiency

There are different measures of efficiency. In the broadest sense, many authors have emphasized the economic efficiency of a farming enterprise (e.g. Buttazzoni and Mao, 1989; Custodio et al.,1983; Dempfle, 1986; Smothers et al.,1986; Webster, 1987; Yerex et al.,1988). In a dairy industry, the primary goal of breeding, feeding and management is to improve the economic efficiency of production (Lee et al.,1989). Apart from the efficiency of the individual animal, net return or economic efficiency of a dairy enterprise is dependent on a host of additional factors including size of operation, disease control and market considerations (Legates, 1990).

Mc Meekan in a grassland environment stated that efficient dairy farming depends on 3 main factors:

1. The amount and quality of feed grown
2. Grown feed that is actually harvested by the animal
3. The proportion of the feed consumed that is actually utilized by the animal.

In a narrower sense, biological efficiency or feed efficiency (product output:feed input) are the terms used to measure the performance of individual animals. The ratio of feed input to product output is termed feed conversion (Tess and Greer, 1990). Thus, the efficiency of a dairy cow to convert feed into milk or products is called biological efficiency. This is also expressed as:

$$\text{Efficiency} = \frac{\text{NE in milk}}{\text{ME intake}}$$

The term ' partial efficiency' refers to the efficiency of individual production processes in which ME for maintenance, gain and production are considered.

Although the definitions of efficiency differ among studies, they all attempt to

measure a ratio of energy output to energy input (Sieber et al.,1988). Distinction also must be made between gross and net efficiency because they are generally used in nutritional terms. Gross efficiency is expressed as the energy value of milk/total ME intake and net efficiency as the energy value of of milk/total ME minus ME_m. The following example distinguishes the difference between these two terms:
Suppose, the energy value of milk is 3.1 MJ/kg. Then, a cow giving 10 kg milk will produce 31 MJNE as milk. Let us suppose that the cow consumes 110 MJME (60 MJ for maintenance and 50 MJ for production) per day, then the gross efficiency is calculated as 31/110 or 0.28. The net efficiency of the cow in this case would be 31/110-60 or 0.62. Now if the same cow produces 20 kg of milk per day, then the gross and net efficiencies might be 62/160 or 0.39 and 62/160-60 or 0.62 respectively. It is, thus apparent that when milk production is increased, gross efficiency becomes greater but net efficiency remains unchanged (Johnson, 1986).

2.8.2 Interrelations between Feed Intake, Body Size and Efficiency

i) Feed Intake and Efficiency

Freeman (1967) stated that efficiency of a cow is dependent upon her production, but under normal conditions, the amount of milk produced by cows will vary much more than the amount of feed they consume. The proportion of feed attributable to maintenance requirements is decreased with increased level of production and feeding. Citing the work of Lamb and Anderson (1966), Freeman (1967) pointed out that when the dairy cows were fed with forage plus grain ration, average gross efficiency was slightly higher compared to the cows fed with all roughage. Interestingly, the opposite was true in the case of New Zealand dairy cows because they were least efficient on roughage plus grain diet.

Hutton (1966), in pastoral farming, used 17 sets of lactating identical twin cows and fed one member to appetite, while the other was exposed to a small degree of restricted feeding. The degree of restriction was that required to induce a marginal drop only in her milk production (relative to fully fed twin-mate) throughout the season. In spite of substantial intake differences within most twin sets throughout the 20 week experiment, milk production was not much affected. When within-set differences were analysed, there was a significant ($p<0.05$) average increase in gross efficiency of one percentage unit associated with the lower feeding level.

Lee et al.(1989) studied the feed efficiency of first lactation Holstein and Ayrshire cows. The animals were fed forage *ad libitum* and a balanced concentrate mixture according to milk yield. It was confirmed that variation in efficiency is more dependent on milk yield than on consumption. The correlation between intake and feed efficiency was 0.38. Phenotypic correlation with efficiency was very high (0.64). The authors also suspected that there were biological differences in the ability to convert feed to milk among different cows where weight, weight change and feed intake were similar.

By supplying 10% more than the estimated cow's energy requirements, Buttazzoni and Mao (1989) established the following relationships:

- Moderate phenotypic correlation between milk yield and net energy intake (.36)

- Phenotypic correlation between milk yield and net energy efficiency was nil
- No evidence of phenotypic correlation between net energy intake and net energy efficiency for milk yield was reported, but there was a strong positive genetic correlation (.72).
- The genetic correlation between milk yield and gross efficiency for milk yield was stated to be above .90.

Thus, there were different values of correlations between milk yield and net energy efficiency and milk yield and gross energy efficiency, and the authors recommended that for a more efficient dairy production system, cow's NE efficiency in producing milk be considered. In contrast, Persaud and Simm (1991) emphasized gross efficiency for the selection criterion.

ii) Effects of Stage of Lactation on Efficiency

Hutton (1963) observed a peak milk yield in the 6th week of lactation, but gross energy intake at this stage was only 75% of the maximum that was observed 15 weeks later. It was, however, shown that the highest gross efficiency indexes were achieved 2-3 weeks after calving. Both at the beginning and end of lactation, there was marked variation between animals, but in general, cows that achieved high food conversion efficiencies during early lactation maintained the advantage throughout the lactation. In the beginning, individual differences in efficiency ranged between 23% and 35%, the figures at the end of lactation were between 12.6% and 23.5%. In both seasons of 1960-61 and 1961-62, estimated food conversion efficiency was consistently higher during early lactation. The author pointed out that a combination of factors such as high milk yield, relatively low ME intake, LW loss (drawing the energy reserves) might be attributable to the consistently higher values of efficiency in early lactation. After 8-10 weeks of calving, efficiency suddenly dropped down probably because food intakes had risen to very high levels, milk yield commenced to fall and body repletion might have started to take place. It was suggested that in most circumstances, energy efficiency tends to decline after the first 4-5 months of lactation.

iii) Relation between Body Size and Efficiency

Stakelum and Conolly (1987) compared the gross efficiency of milk production between lighter and heavier cows having similar levels of milk yield. It was found that there was less variability in efficiencies at low BW compared with high. Substantial increases in efficiency occurred at high BW as yield increased. It was concluded that smaller cows were generally more efficient but less so at higher milk production levels. On a comparative basis, many other authors also found the smaller cows to be more efficient (e.g. Dickinson et al.,1969; Mason et al.,1957; Persuad and Simm, 1991; Yerex et al.,1988). After completing a trial on Ayrshire, Brown Swiss and Holstein cows, Dickinson et al.(1969) remarked "The negative relationships with body size do not necessarily indicate that the larger cows were, therefore, less efficient. It is possible that if fixed as well as variable costs were apportioned among production units (cows), the larger cows which produce more total milk and fat may still be more profitable (even though they do it less efficiently)". At 30 months age uniformly negative relations existed between efficiency and mean BW, LWG, and body conformation-chest girth, wither height and body length. Using a discrete-effects model, that included only the discrete effects of breed, year and season the least square means for net feed efficiency were 60.3% for Ayrshires, 54.3% for Brown Swiss, and 61.0% for Holsteins. It was apparent that at a given body weight (and chest girth and wither height) Holsteins were comparatively more efficient than the other two breeds. In contrast Mason et al.(1957) were able to establish a positive relationship between wither height and efficiency. In partial agreement with Dickinson et al. (1969), Sieber et al. (1988) established uniformly negative correlations between estimated feed efficiency and seven body mearurements-heart girth, paunch girth, wither height, chest depth, pelvic length, pelvic width, body length, and also with BW.

Like Dickinson et al. (1969), mentioned above, many other authors have made breed-wise comparisons. In New Zealand study, Hutton (1966) could not establish a significant relationship between feed conversion efficiency and LW in Jersey and crossbred cows.

Smothers et al.(1986) selected 232 Jersey cows directly on the basis of milk production to study the correlated response in feed efficiency. Hay and silage were provided *ad lib* plus grain at the rate of 1 kg grain/3 kg milk yield and gross feed efficiency was measured. It was confirmed that selection did not affect efficiency of direct conversion of nutrients into milk and also the genetic lines of Jersey did not

Table 2.7 Correlations between Dairy Efficiency and Body Size

Authors	Phenotypic	Genetic	Details of measurements
Dickinson et al. (1969)	-0.27		No age adjustments; heifers only
Gaines et al. (1940)	Negative		No age adjustments; all lactations
Hooven et al (1968)	-0.04	-0.12	FCM; age-adjusted
Mason et al. (1957)		-0.33	FCM; size measured as height at constant yield
Stone et al. (1960)	-0.08		FCM; no age adjustments; cows only
Syrstad (1960)	-0.34	-0.67	FCM for 4-yr-olds; size measured as heart girth
Average	-0.18	-0.37	

-All efficiencies recorded here as output/input
-Body size measured as body weight unless otherwise stated

(from Morris and Wilton, 1976)

differ in gross feed efficiency when fed according to yield. Oldenbroek (1986) made a comparative study between lactating heifers of Jersey, Holstein-Friesian, Dutch Friesian and Dutch Red and White breeds. The heifers were fed *ad lib* after calving which consisted of a complete diet of roughage or a complete diet of the same roughage with 50% concentrates on DM basis. Records of feed intake, milk production and BW were taken in the 39th week of lactation. On a complete diet of roughage and concentrates, the biological efficiency of milk production (net efficiency) was found to be 59% in the Jerseys; the value was 65% on roughage diet. The figures for Holstein Friesian, Dutch Friesian and Dutch Red and White on corresponding diets were 55% and 56% respectively. Comparing the performance of Jersey and Holstein cows during the first and second trimester of lactation, on the other hand, Blake et al.(1986) observed that despite the higher ratios of milk to BW and feed intake in Jerseys, cows of similar lean tissue balance and DM intake had similar feed efficiency. It was, therefore, pointed out that Jerseys had no comparative advangage over Holsteins.

A summary of data for genetic and phenotypic correlations between dairy efficiency and body size are presented in Table 2.7.

CHAPTER 3
MATERIALS AND METHODS

A total of 30 multiparous cows (Friesians and Jerseys) were selected from the Dairy Cattle Research Unit herd at Massey University for the experiments. The cows selected produced approximately similar amounts of MF (per day) but varied greatly in BW and conformation (height, chest girth). The age of the cows ranged between 4 and 7 years, and while no account of calving date was taken, most of the cows were in early to mid lactation.

The experiment was split up in 2 periods

1. Outdoor period (4-29 November 1991) with 30 cows grazing on pasture;
2. Indoor feeding period (2-20 December 1991), with 16 cows fed indoors on freshly cut pasture.

3.1 Outdoor Period

3.1.1 Animals and Management

Of the 30 cows selected, 22 were Friesians and 8 were Jerseys. The cows were divided into 3 groups according to BW with 10 cows in each group, as follows:

Group	Body weight
Large	458-565 kg (All Friesians)
Medium	412-459 kg (All Friesians)
Small	310-393 kg (2 Friesians and 8 Jerserys)

During the experimental period, all the cows were allocated a generous daily herbage allowance. The cows were 4-7 years old and 3-4 months into lactation. Little increase in body size, foetal growth or fat deposition was expected (ARC, 1980). Therefore, ME requirements for milk production and maintenance only were calculated in order to estimate the area of pasture required each day.

The generous daily herbage allowance provided was based on 2.5 times the cows' estimated daily requirement for maintenance and production. Although a pre-grazing herbage mass of about 2500 kg DM/ha was thought to be ideal, it was not similar in all paddocks and ranged approximately between 2200 kg and 3200 kg DM/ha. For grazing, an area of approximately 0.5 ha was divided into 3 parts every day for the 3 groups of cows. Thus, every 24 hours, they were given a fresh part of a paddock. The purpose of dividing the paddocks into 3 parts was to provide more appropriate levels of herbage allowance to the cows of different size-groups. The grazed herbage consisted of mixed perennial ryegrass/white clover pastures. The cows had access to ample clean water at all times. They were milked twice daily at 0530 and 1530 hours.

3.1.2 Measurements and Calculations

A general overview of the experimental plan and the sequence of events during the experiment is presented in Appendix 1.

3.1.3 Milk Yield and Composition

Milk yields and percentages of MF, protein and lactose were measured for individual cows on 3 days each week (Tuesday pm to Friday am).

3.1.4 Size and Weight (and Change in Weight)

During the 4 experimental weeks, the cows were weighed after the morning milking, every Monday and Friday. Measurements were made of the height of the cows (at the wither) and their chest depths (under the wither line) at the start of the experiment. The body condition score, which is a visual estimate of the body fatness of a cow, was recorded for each cow on two consecutive days at the beginnig and the end of the experiment on a scale from 1 to 10 as described by Holmes and Wilson (1984).

3.1.5 Herbage Sampling and Analysis

The experimental cows grazed a paddock of approximately 1 ha in two days. A rising plate meter was used to estimate the pasture DM/ ha before allocating the area for grazing. For one measurement of the herbage intake, 60 quadrants before and 60 quadrants after grazing were cut from two paddocks every week. These samples were used for DM determination. Fresh samples of pasture from every paddock were also collected. These samples were freeze-dried, ground through a 1 mm screen and analysed for ash, total nitrogen, ME and in vitro digestibility.

In vitro digestibility determinations of the fresh herbage were carried out according to the procedure described by Roughan and Holland (1977).

3.1.6 Feed Intake

Two alternative marker methods for determining faecal output were used. Each experimental cow was given Cr_2O_3 pills (containing 10 gm Cr), one in the morning and one in the afternoon during milking time. Administration started on day -4 and continued until day 13. Faecal samples from each cow were collected twice daily in the field, one before the morning milking and another in the afternoon before milking. The faecal samples were bulked over 2 consecutive periods of 5 days each, starting on day 3. On day 13, each cow was dosed with a CRC of Cr_2O_3. This leads to an improved means of estimating feed intake in grazing animals because CRC provide for the continuous uniform release of Cr_2O_3 into the rumen (Le Du and Penning, 1982; Parker et al., 1989). Faecal samples were collected once daily and bulked over 2 successive periods of 4 days each, starting on day 18. The concentration of Cr in the faeces was measured by means of atomic absorption spectroscopy according to the procedure described by Parker et al. (1989).

Herbage intakes were also estimated by two methods: rising plate meter and sward cutting techniques (see 3.1.5).

3.1.7 Liveweight Change

LWC for each cow was estimated by calculating a linear regression of LW on day number.

3.1.8 Condition Score Difference

The condition difference was calculated as the average condition score at the end of the experiment less the average score at the beginning.

3.1.9 Dry Matter Intake

DMI was calculated using the following equations:

$$1)\quad FDMO = \frac{RR}{Cdm}$$

where,

FDMO= faecal dry matter output (kg DM/day)

RR = expected average daily release rate of chromium (g Cr/ day); the release rate was 13.68 g Cr/day for 2 pills per day and 1.197 g Cr/day for the capsule.

Cdm= concentration of Cr in faecal dry matter (g Cr/kg);

$$2)\quad DMI = \frac{FDMO}{1-DMD}$$

where,

DMI= dry matter intake (kg per day)

DMD= dry matter digestibility (%)

Metabolisable Energy Intake

MEI was calculated as follows:

1) FOMO= FDMO * % OM;

where,

FOMO= faecal organic dry matter output (kg/day);

% OM= percentage organic matter in the faecal dry matter

2) $$OMI = \frac{FOMO}{1-OMD}$$

where,

OMD= organic matter digestibility (%)

3) DOMI= OMI * OMD

where,

DOMI= digestible organic matter intake (kg/day)

4) MEI= DOMI * 15.59[#] ;

or MEI (MJ/day)= DMI*DMD*14.9

[#] 1 kg digestible organic matter contains approximately 19 MJ DE and ME/DE = 0.82

(Geenty and Rattray, 1987)

where,

MEI = metabolizable energy intake (MJ/day)

3.1.10 Energy in Milk

NE milk was estimated from milk composition as follows:

NE milk =F*38.5+P*24.5+L*15.7;

where,

F= kg MF produced/day;

P= kg protein produced/day;

L= kg lactose produced/day;

The figures used for the energy content (MJ/kg) of the milk constituents were derived by McDonald and Greenhalgh (1981).

3.1.11 Feed Efficiency

Efficiency is generally calculated as energy output divided by energy input (see 2.8). In this experiment, feed efficiency was calculated as NE milk divided by ME intake, expressed as a percentage.

3.2 Indoor Period

3.2.1 Animals and Management

16 cows (11 Friesians and 5 Jerseys) were choosen at random from the cows used for the outdoor period. The cows were housed in the feeding barn and milked in the milking shed twice daily at the Dairy Cattle Research Unit of Massey University. The floor was metal grating covered with rubber mats. The cows were restrained in their stands by a chain attached to their collar.

3.2.2 Feeding and Feed Intake

Mixed pasture, consisting of perennial ryegrass/white clover, was cut fresh with a single-chop forage harvester twice a day for each feeding period (Stakelum and Connolly, 1987). Cows were let out for milking at 7 am and pasture not eaten by each cow was weighed, sampled for DM determination and discarded. The feeding bin was then refilled with a weighed quantity of fresh herbage. The DM% of the fresh herbage was determined on a bulked representative sample taken during weighing of the feed into the bin. The cows were allowed to remain on a saw dust area for about 1.5 hour and were then brought to the barn at 9 am. At 3 pm, the cows were let out for milking again. Additional pasture was weighed into each bin to ensure that each cow had about 10 kg DM available overnight and a refusal of at least 2 kg pasture DM next morning.

The amount of pasture required daily was harvested from about 0.25 ha area each day. Thus, 1 ha of pasture area was harvested every four days.

3.2.3 Liveweight, Milk Yield and Condition Scoring

These measurements were recorded in a similar way as for the grazing period.

3.2.4 Measurements and Calculations

The experimental plan and the sequence of events is presented in Appendix 2.

3.2.5 Dry Matter Intake

The DM intake of each cow was measured in two different ways:
Directly:- Pasture DM (in kg) offered - Pasture DM refused
Indirectly:- 8 cows received a controlled release Cr capsule on day 4. 8 cows received Cr_2O_3 pills, 1 pill twice daily, starting on day 4. The faecal samples were collected 3 times a day. These samples were subsampled into storage bottles and bulked over 2 successive periods of 4 days. So, for each period, there was a morning, an afternoon, and evening bulk sample, a total of 12 samples per cow. For in vitro digestibility, samples of fresh herbage were taken during each feeding and freeze dried.

3.2.6 Statistical Analyses (Outdoor and Indoor Experiments)

The intake and performance data of the large and small body size groups were subjected to analysis of variance (Stakelum and Connolly, 1987). The model used in the analysis of the data was:

$Y_{ijkl}= \mu+\beta_1 M_1+\beta_2 W_j+\beta_3 G_k+e_{ijkl}$;

where,

The observation for DMI (kg/day), MEI (MJ/day) or FE (%) of the lth cow, with liveweight gain k, metabolic liveweight j and NE milk i.

μ= intercept;

$\beta_1\beta_2\beta_3$= linear regression coefficients;

M_1= Net energy used for milk production (MJ/day);

W_j= average $LW^{0.75}$ during period ($kg^{0.75}$);

G_k= LWG (kg/day);

e_{ijkl}= random residual.

The model was also run separately for Friesian and Jersey cows, for the period when pills were used to estimate intake (period 1) and the period when capsules were used to estimate feed intake (period 2). This was done because the pills and capsules might otherwise give different estimates of the same actual intake. Also, level of intake might have been influenced by other factors such as the composition of the herbage and the stage of lactation. In addition, the model was run for the analyses of combined data of Jerseys and Friesians.

All the models were computed with the General Linear Models procedure of the SAS statistical packet. Least Square Means of different traits were compared by Duncan's Multiple Range Test at a significance level of $p \leq 0.05$. In Duncan grouping, Least Square Means with the same letter are assigned to indicate a non-significant difference.

Effects of body size (LW, wither height and chest depth) on production (e.g.NE milk, MF, protein and lactose) were observed during the outdoor experiment, but during the indoor period, only the effects of LW on production were measured. As described in the model used, the relationships between different variables were also observed. Asteriks are used to indicate the levels of significance of the correlation coefficients and the relationship between different variables in the model. Throughout this thesis, the asterisks and notation assigned to test the levels of significance are:

*** Significant difference at $p \leq 0.01$

** Significant difference at $p \leq 0.025$

* Significant difference at $p \leq 0.05$

ns Not significant difference

CHAPTER 4
RESULTS

4.1 Outdoor Period

4.1.1 Introduction

The main factors affecting the herbage intake of a grazing animal are the animal itself, the pasture and management (Holmes, 1989). In this chapter, the nature of the pasture used is described first. Then the many characteristics of the animals such as size (breed and age) and milk production (including stage of lactation) which affect intake are considered.

4.1.2 Pasture Herbage Description and Composition

The pastures used in the present trial consisted primarily of perennial ryegrass and white clover. Herbage allowance, or the daily allocation of pasture, was generous (approx. 2.5 times of the average daily requirement) since increases in milk production per cow are generally associated with increased herbage allowance and maximum intake values were sought. Cows within the three size groups were offered the same allowance relative to their predicted ME requirements.

The composition of pasture during the experimental period is shown in Table 4.1. Although crude protein % declined slightly from 20% in period 1 to 19.5% in period 2, other values such as DMD (%), OMD (%) and MJME/kg DM were a little higher in period 2. The ME contents of the pasture (estimated by using the equations described by Geenty and Rattray, 1987) were 11.5 and 11.8 for periods 1 and 2 respectively, which indicate that the quality of the pastures used was high.

Table 4.1 Composition of pasture herbage consumed by experimental cows **(Outdoor Period)**

	CP (%)	DMD (%)	OMD (%)	Calculated MJME/kg DM	Ash (%)
Period 1	20.0	77.0	80.6	11.5	10.30
Period 2	19.5	78.5	82.2	11.8	10.15

4.1.3 Intake Estimations

The means and standard deviations of herbage intakes estimated by three alternative procedures: marker ratio, rising plate meter and sward cutting techniques are presented in Tables 4.2 and 4.3. Since the rising plate meter and sward cutting techniques were employed to measure average values (and not values for individual breeds or groups) only the figures in Table 4.3 are comparable. The results showed that there was little difference between the mean values of herbage intake estimated using three different methods.

4.1.4 Breed Comparisons

The means and standard deviations of the body measurements, feed intake, production, LWG, differences in condition score and FE for the Friesian and Jersey cows are presented in Table 4.2. Similar measurements for the combined data (Friesians and Jerseys) are shown in Table 4.3. In period 2, 6 cows were omitted from the dataset because the Cr concentration in the faecal samples for two weeks was almost zero which led to impossibly high values for calculated DM intake. An absence of Cr concentration in faeces was seen for 6 bigger Friesian cows which suggested that they had regurgitated the CRC Cr capsules. Therefore the intake

Table 4.2 Means and standard deviations of the traits for Jerseys and Friesians **(Outdoor Period)**

Variables	Period 1				Period 2			
	22 Friesians		8 Jerseys		16 Friesians		8 Jerseys	
	Means	SD	Means	SD	Means	SD	Means	SD
Age	5.95	0.99	5.5	1.31	5.95	0.99	5.5	1.31
Wither Height (cm)	128.86^{A}	4.06	116.25^{B}	4.43	128.86^{A}	4.06	116.25^{B}	4.43
Chest Depth (cm)	75.45^{A}	3.75	70.00^{B}	3.78	75.45^{A}	3.75	70.00^{B}	3.78
LW (kg)	463.81^{A}	54.91	349.75^{B}	36.88	472.68^{A}	52.17	359.00^{B}	36.10
$LW^{0.75}$	99.94^{A}	8.88	80.80^{B}	6.39	101.26^{A}	8.39	82.40^{B}	6.21
DM Intake (kg/d) (Indirect Method)	17.99^{A}	1.81	15.85^{B}	1.23	19.22^{A}	1.73	16.31^{B}	1.70
ME Intake (MJ/d)	206.88^{A}	20.83	182.32^{B}	14.10	226.82^{A}	20.47	192.44^{B}	20.09
NE Milk (MJ/d)	79.75^{A}	10.06	73.59^{A}	7.34	79.54^{A}	7.03	74.09^{A}	8.44
MF yield (kg/d)	1.05^{A}	0.14	1.04^{A}	0.09	1.04^{A}	0.10	1.06^{A}	0.12
Protein yield (kg/d)	0.83^{A}	0.10	0.73^{B}	0.10	0.82^{A}	0.08	0.74^{B}	0.11
Lactose yield (kg/d)	1.17^{A}	0.15	0.98^{B}	0.18	1.22^{A}	0.15	1.02^{B}	0.21
LWG (kg/d)	0.57^{A}	0.30	0.60^{A}	0.21	0.57^{A}	0.30	0.60^{A}	0.21
Cond. score diff.	0.20^{A}	0.22	0.16^{A}	0.14	0.20^{A}	0.22	0.16^{A}	0.14
Feed Efficiency (%)	39.00^{A}	0.05	41.00^{A}	0.06	35.00^{B}	0.03	39.00^{A}	0.03

figures for period 2 are probably unreliable due to the absence of adequate data. Also, when the DM intake calculated for one week deviated by more than 25% from the average value for the other three weeks, that value was not used for calculating the average feed intake for that period. For this reason, 5 cows (nos. 18,142,182,196 and 206) in week one, three cows in week three (nos. 5, 132 and 224) and two cows in week four (nos. 134 and 180) were excluded.

It is apparent from Table 4.2 that Friesian cows, compared with Jerseys, were of larger body size (LW, height, chest depth)($p \leq 0.05$), had a higher DM intake ($p \leq 0.05$) and produced more, although the production (NE milk and MF) was not significantly different between the two breeds. However, FE was greater in Jerseys and in period 2, the difference reached a 5% level of significance (Table 4.2). LWG and condition score were not significantly different (5% level) between the breeds.

Table 4.3 Means and standard deviations of the traits for Jerseys and Friesians (combined -30 cows) **(Outdoor Period)**

Variables	Means	SD
Age	5.83	1.09
Wither Height (cm)	125.50	6.99
Chest Depth (cm)	74.00	4.43
LW (kg)	433.40	71.72
Metabolic LW ($kg^{0.75}$)	94.75	11.84
DM Intake (kg/d)	17.42	1.91
ME Intake (MJ/d)	199.86	21.95
NE Milk (MJ/d)	78.11	9.70
MF yield (kg/d)	1.04	0.13
Protein yield (kg/d)	0.81	0.11
Lactose yield (kg/d)	1.12	0.18
LWG (kg/d)	0.57	0.27
Cond. score diff.	0.20	0.20
Feed Efficiency (%)	39.00	0.05
Intake Estimation from other methods (kg DM/d)		
Using Rising Plate Meter	17.50	2.4
Sward Cutting Technique	18.20	2.7

The main factors (maintenance, milk production and LWG) affecting the feed intake of lactating Jersey and Friesian cows (and Jerseys and Friesians combined) were examined using multiple regression analyses and two alternative techniques : a regression with a constant, and a regression line forced through zero (or with no regression constant). The results are presented in Tables 4.6, 4.7 and 4.8. Since a regression constant (intercept) should be included in normal multiple regression analyses, these data are probably the more acceptable. However, the ones estimated with zero regression constant also provide considerable additional information (Tables 4.7 and 4.8). The important results relating to breed are summarized in Section 4.1.8 along with the combined breed results.

4.1.5 Group Comparisons

The means and standard deviations for different traits within the three size groups of cows were also calculated and are shown in Appendix 3. The three groups differed significantly (5% level) in height and BW, but other traits did not differ in similar order. Multiple regression analyses were carried out to examine the factors affecting feed intake and efficiency within each of the three group of cows by two ways i.e. a regression with a constant, and a regression line forced through zero. The results are given in the Appendices 4 and 5 but are not described in detail because R^2 values were often very low, especially within the "small" groups. The estimated ME_m in the case of the " large" group during period 1 was surprisingly high (4.02 MJME/kg $LW^{0.75}$/d) and significant (Appendix 4). In spite of the high statistical level of significance, such isolated values are difficult to explain in biological terms. Other corresponding results across all animals seem more accurate and informative.

4.1.6 Coefficients of Correlation between Different Traits

The correlation coefficients between body size (liveweight or $LW^{0.75}$, wither height, chest depth), production and feed efficiency (FE) in Friesian and Jersey cows and for the combined data are shown in Tables 4.4 and 4.5. For Friesian cows, DM intake was positively related to $LW^{0.75}$ ($p \leq 0.05$). Level of milk production also had no significant association with DM intake. None of the above relationships were significant in Jerseys. When the data for breeds were combined (Table 4.5), all measures of size were significantly related to DM intake but $LW^{0.75}$ showed the highest correlation coefficient.

Table 4.4 Correlation Coefficients between body size, production and feed efficiency for Friesian and Jersey cows **(Outdoor Period)**

Variables	Ht	Chest Depth	$LW^{0.75}$	DMI	NE Milk	MF yield	Pr yield	Lactose yield
Friesians								
DMI	0.34 ns	0.31 ns	0.45 *					
NE Milk	0.27 ns	-0.12 ns	0.10 ns	0.28 ns				
MF yield	0.20 ns	-0.21 ns	-0.05 ns	0.12 ns	0.92 ***			
Protein yield	0.38 ns	-0.16 ns	0.15 ns	0.28 ns	0.86 ***	0.78 ***		
Lactose yield	0.22 ns	-0.19 ns	0.04 ns	0.07 ns	0.72 ***	0.61 ***	0.87 ***	
FE	-0.007 ns	-0.35 ns	-0.25 ns	-0.49 **	0.70 ***	0.75 ***	0.58 ***	0.61 ***
Jerseys								
DMI	-0.47 ns	-0.14 ns	-0.40 ns					
NE Milk	0.63 ns	0.57 ns	0.86 ***	-0.35 ns				
MF yield	0.38 ns	0.29 ns	0.46 ns	-0.22 ns	0.77 **			
Protein yield	0.69 ns	0.58 ns	0.90 ***	-0.44 ns	0.94 ***	0.51 ns		
Lactose yield	0.60 ns	0.67 ns	0.92 ***	-0.33 ns	0.86 ***	0.33 ns	0.96 ***	
FE	0.66 ns	0.47 ns	0.79 **	-0.79 **	0.85 ***	0.65 ns	0.85 ***	0.73 *

There were strong positive relationships between the alternative measures of production (NE milk, MF, protein and lactose yields) for both breeds and for the combined data. Production was closely (and positively) associated with $LW^{0.75}$ in Jerseys (Fig. 4.2) and for protein and lactose yields in the combined data but was not important within Friesians. FE was positively related to most production traits (including NE milk-Figs 4.1, 4.3) in Friesians and Jerseys and in the combined data. The relation between $LW^{0.75}$ and FE was not significant for Friesians or in the combined data (and surprisingly, positive for Jerseys)

Table 4.5 Correlation coefficients beteween body size, production and feed efficiency for Jerseys and Friesians (combined) **(Outdoor Period)**

Variables	Ht	Chest Depth	$LW^{0.75}$	DMI	NE Milk	MF yield	Pr yield	Lactose yield
DMI	0.50 ***	0.44 **	0.56 ***					
NE Milk	0.42 **	0.17 ns	0.35 ns	0.30 ns				
MF yield	0.15 ns	0.09 ns	0.02 ns	0.07 ns	0.87 ***			
Protein yield	0.58 ***	0.24 ns	0.48 ***	0.33 ns	0.88 ***	0.67 ***		
Lactose yield	0.56 ***	0.30 ns	0.48 ***	0.23 ns	0.76 ***	0.48 ***	0.91 ***	
FE	-0.02 ns	-0.19 ns	-0.13 ns	-0.54 ***	0.64 ***	0.70 ***	0.52 ***	0.49 ***

4.1.7 Body Conformation, Intake and Production

Independent of breeds and groups, the overall effects of wither height and chest depth on intake and production were also studied. It was observed that there was a significant association of wither height with both DM intake and production (although relationship with MF yield ns) (Table 4.5). However, chest depth had significant correlation only with intake, but not with production.

Figure 4.1 Relationship between milk energy (NE MILK) and feed efficiency (FE) within Jersey cows (**Outdoor Period**)

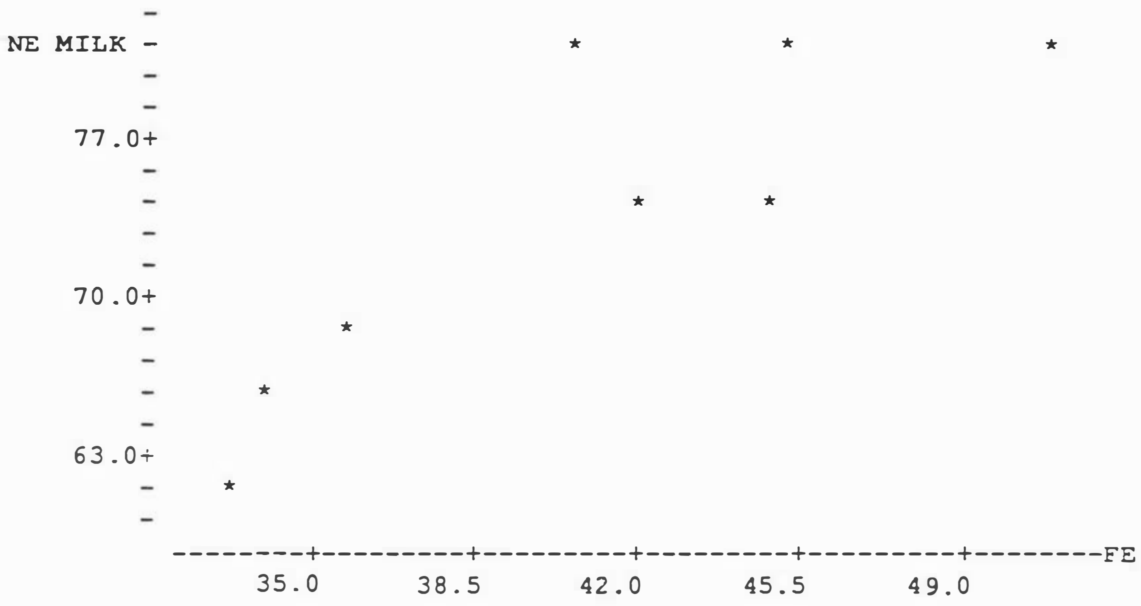


Figure 4.2 Relationship between milk energy (NE MILK) and metabolic bodyweight (MET.BW) within Jersey cows **(Outdoor Period)**

```
                   -
           NE MILK -                                                 *    2
                   -
                   -
               77.0+
                   -                                      *
                   -          *
                   -
                   -
               70.0+
                   -         *
                   -
                   -      *
                   -
               63.0+
                   -             *
                   -
                     --------+---------+---------+---------+---------+--------MET.BW
                           75.0      78.0      81.0      84.0      87.0
```

Figure 4.3 Relationship between milk energy (NE MILK) and feed efficiency (FE) within Friesian cows (**Outdoor Period**)

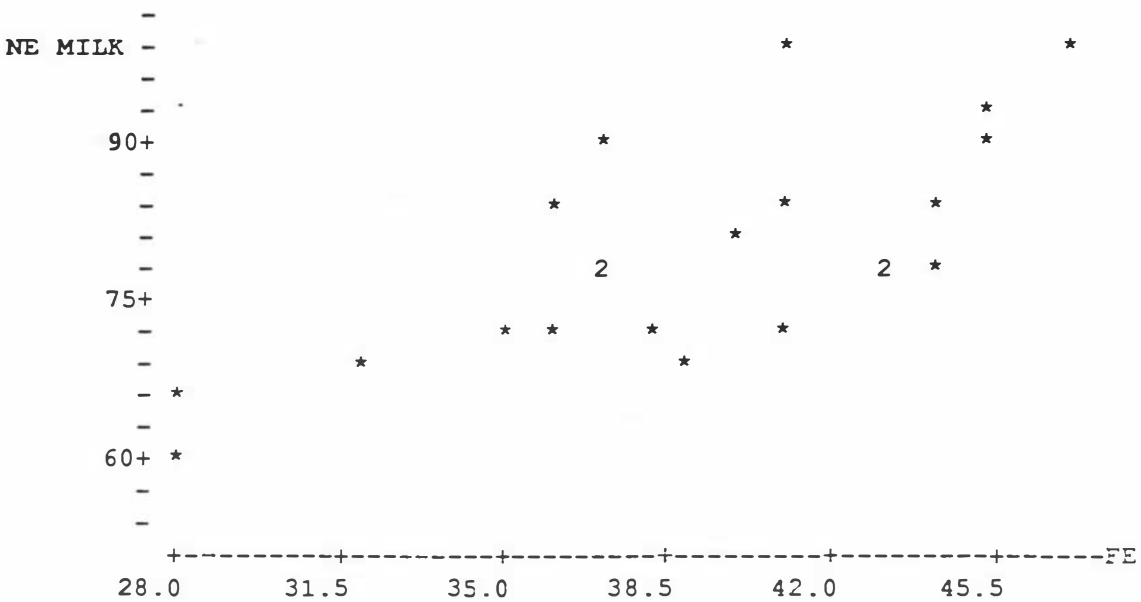


Table 4.6 Factors afffecting feed intake and efficiency within Friesian and Jersey cows : Partial regression coefficients **(Outdoor Period)**

Breed	Dependent variables	Period	Reg. constant (μ)	β_1 NE milk/MJ	β_2 $LW^{0.75}$/kg	β_3 LWG/kg	R^2	N
Friesians	DMI	1	-1.9 NS	0.07 *	0.122 ***	3.48 ***	0.51	22
	MEI	1	-21.8 ns	0.80 *	1.40 ***	40.00 ***	0.51	22
	DMI	2	7.74 ns	0.10 ns	0.04 ns	-1.44	0.45	16
	MEI	2	90.53 ns	1.17 ns	0.47 ns	-16.84 ns	0.45	16
	FE	1	0.44 ***	0.3 ***	-0.3 ***	7.3 ***	0.74	22
	FE	2	0.22 ns	0.3 **	-0.08 ns	3.0 ns	0.41	16
Jerseys	DMI	1	16.96 *	-0.14 ns	0.09 ns	4.18 ns	0.50	8
	MEI	1	194.58 *	-1.61 ns	1.03 ns	48.00 ns	0.50	8
	DMI	2	6.36 ns	0.18 ns	-0.05 ns	0.99 ns	0.55	8
	MEI	2	74.38 ns	2.11 ns	-0.58 ns	11.57 ns	0.55	8
	FE	1	-0.04 ns	0.9 ns	-0.2 ns	-11.0 ns	0.83	8
	FE	2	0.25 ns	0.07 ns	0.1 ns	-2.4 ns	0.23	8

Table 4.7 Factors affecting feed intake and efficiency within Friesian and Jersey cows : Partial regression coefficients (with zero regression constant) **(Outdoor Period)**

Breed	Dependent variables	Period	Reg. constant(μ)	$ß_1$(NE Milk)	$ß_2$($LW^{0.75}$)	$ß_3$(LWG)	R^2	N
Friesians	DMI	1	-	0.063 **	0.111 ***	3.23 ***	0.99	22
	MEI	1	-	0.72 **	1.27 ***	37.05 ***	0.99	22
	DMI	2	-	0.142 ***	0.083 *	-0.779 ns	0.99	16
	MEI	2	-	1.66 ***	0.97 *	-9.35 ns	0.99	16
	FE	1	-	0.5 ***	0.007 ns	-1.5 ns	0.99	22
	FE	2	-	0.4 ***	0.03 ns	-4.9 *	0.99	16
Jerseys	DMI	1	-	-0.28 ns	0.4 ns	7.4 ns	0.99	8
	MEI	1	-	-3.26 ns	4.61 ns	85.14 ns	0.99	8
	DMI	2	-	0.118 ns	0.082 ns	1.277 ns	0.99	8
	MEI	2	-	1.38 ns	0.96 ns	14.94 ns	0.99	8
	FE	1	-	0.9 *	-0.3 ns	-1.1 ns	0.99	8
	FE	2	-	-0.2 ns	0.6 ns	-1.4 ns	0.99	8

Table 4.8 Factors affecting feed intake and efficiency for Friesian and Jersey cows (combined) : Partial regression coefficients **(Outdoor Period)**

Dependent variables	Period	Reg. constant (μ)	ß1 NE milk/MJ	ß2 $LW^{0.75}$/kg	ß3 LWG/kg	R^2	N
DMI	1	3.99 ns	0.04 ns	0.093 ***	2.897 ***	0.48	30
MEI	1	45.777 ns	0.46 ns	1.07 ***	33.24 ***	0.48	30
DMI	2	1.728 ns	0.105 **	0.094 ***	-0.79 ns	0.63	24
MEI	2	20.211 ns	1.23 **	1.10 ***	-9.24 ns	0.63	24
FE	1	0.305 ***	0.4 ***	-0.2 ***	-6.1 **	0.63	30
FE	2	0.344 ***	0.3 ***	-0.2 ***	1.7 ns	0.37	24
DMI	1	-	0.061 **	0.112 ***	3.513 ***	0.99	30
MEI	1	-	0.7 **	1.28 ***	40.30 ***	0.99	30
DMI	2	-	0.118 ***	0.099 ***	-0.593 ns	0.99	24
MEI	2	-	1.38 ***	1.16 ***	-6.94 ns	0.99	24
FE	1	-	0.6 ***	-0.06 ns	-1.41 ns	0.99	30
FE	2	-	0.5 ***	-0.08 ns	5.7 ns	0.99	24

4.1.8 Factors affecting Feed Intake and Efficiency

The main factors affecting the ME intake of lactating dairy cows were examined in multiple regression analyses and they are presented in Tables 4.6, 4.7 and 4.8.

a) Production

The estimates and significance of the different parameters used in the model are indicated separately for Friesian and Jersey cows in Table 4.6. When observations of 22 cows were used in period 1, the effect of milk production (NE milk) on pasture DM intake reached a 5% level of significance (although the partial efficiency of milk production was greater than 100%) and on feed efficiency a 1% level. The corresponding values were non-significant for period 2. An increase on 1 MJ NE milk among Friesian cows led to a significant increase in efficiency by 0.3%. This means that the highest producing Friesian cow in period 1 (98 MJ NE milk/d) would be expected to partition (98-60) * 0.3 or 11.3% more of her ME intake to milk production than the lowest producing cow (60 MJ NE milk/d). With zero regression constant, efficiency increased by 0.4-0.5% (Table 4.7). The corresponding relationships were non- significant in Jerseys. In the combined analysis, milk production exerted a significant influence ($p \leq 0.025$) on pasture DM intake in period 2 but not in period 1 (Table 4.8). In period 2, with every MJ increase of milk energy, efficiency increased by 0.3% ($p \leq 0.01$). With zero regression constant, the partial efficiency of milk production was greater than 100% in period 1 and significant ($p \leq 0.025$)(which is impossible). The corresponding value in period 2 was more significant ($p \leq 0.01$). Efficiency decreased from 0.6% in period 1 to 0.5% in period 2 for every MJ increase of milk energy ($p \leq 0.01$).

b) Liveweight

In Friesian cows, the ME_m was estimated to be 1.40 MJME/kg$^{0.75}$ and efficiency decreased by 0.3% per kg increase in $LW^{0.75}$ ($p \leq 0.01$)(Table 4.6). This indicated that the Friesian cow with the lowest $LW^{0.75}$ (83 $kg^{0.75}$) in this experiment would be expected to produce (116-83)*0.3 or 9.9% more milk energy out of the same amount of ME consumed than the cow with the highest $LW^{0.75}$ (116 $kg^{0.75}$). When the regression constant was excluded, the estimated value of ME_m ranged between 0.97 and 1.27 MJ/$kg^{0.75}$ (Table 4.7). In Jerseys, none of these effects reached statistical significance. With the combined analyses of the data, the ME_m was found to be 1.07-1.10 MJ/$kg^{0.75}$ (Table 4.8). According to this calculation, FE decreased significantly by 0.2%/kg increase in $LW^{0.75}$ ($p \leq 0.01$). With zero intercept, the estimated ME_m was 1.16 to 1.28 MJ/kg $LW^{0.75}$ ($p \leq 0.01$) (see Table 4.8)

c) Intake and Liveweight Gain

The ME requirement per kg LWG was estimated to be 40 MJ ($p \leq 0.01$) (37.0 MJME/kg gain with zero regression constant)(see Table 4.6 and 4.7). With the energy being utilized for body tissue gain, FE of these cows declined at the rate of 7.3%/kg increase in LW ($p \leq 0.01$). In the combined analysis, the estimated ME requirement/kg LWG was 33.2 MJ ($p \leq 0.01$)(Table 4.8); the corresponding value with zero regression constant was 40.3 MJME. With the gain of 1 kg LW, the cows' efficiency decreased by 6.1% ($p \leq 0.025$).

4.2 Indoor Period

4.2.1 Herbage Measurements

During indoor feeding freshy harvested pasture consisting mainly of perennial ryegrass and white clover was offered to the cows in weighed amounts twice daily. Generous feeding indoors meant that each cow had a refusal of at least 10% of the offered pasture every day.Two methods, direct and indirect, were used to estimate the herbage intake.

Intake from the direct method was measured from a difference of the herbage offered and refused. For indirect estimation, in vitro digestibility of the herbage and daily faecal output (using Cr_2O_3 as a marker) were first determined to estimate herbage intake.

Composition of the harvested pasture offered to the cows is presented in Table 4.9. For most of the attributes measured, the feed was of poorer value than that used for the outdoor feeding period.

Table 4.9 Composition of pasture consumed by experimental cows (**Indoor Period**)

CP (%)	DMD (%)	OMD (%)	Calculated MJME/kg DM	Ash (%)
15.6	72.6	76.2	10.8	9.4

4.2.2 Release of Chromic Oxide in the Faeces

The differences in mean Cr concentration of the faecal samples that were collected three times a day i.e. am, pm and at night are shown in Table 4.10. With the pill administration, the amount released in the day time was lower, but with the dosing of capsules, there was little variation between the am, pm and night samples.

Table 4.10 Mean chromium concentration in the faeces (g Cr/kg faecal DM) taken at three different times of the day **(Indoor Period)**

	Pills		Capsules	
	Means	SD	Means	SD
AM	3.18	0.77	0.276	0.045
PM	2.63	0.39	0.285	0.059
Night	2.99	0.50	0.279	0.031

Table 4.11 Means and standard deviations of the traits for Jerseys and Friesians **(Indoor Period)**

Variables	11 Friesians		5 Jerseys	
	Means	SD	Means	SD
Age (years)	6.18	1.17	5.00	1.41
LW (kg)	498.00^{A}	56.49	371.00^{B}	37.10
Metabolic LW ($kg^{0.75}$)	105.00^{A}	8.98	84.53^{B}	6.30
DM Intake (kg/d)	18.00^{A}	1.44	14.94^{B}	1.28
ME Intake (MJ/d)	194.93^{A}	15.59	161.57^{B}	13.80
NE Milk (MJ/d)	64.91^{A}	7.99	61.42^{A}	9.30
MF yield (kg/d)	0.88^{A}	0.12	0.87^{A}	0.12
Protein yield (kg/d)	0.67^{A}	0.08	0.62^{A}	0.10
Lactose yield (kg/d)	0.90^{A}	0.15	0.79^{A}	0.19
LWG (kg/d)	0.79^{A}	0.75	0.40^{A}	0.19
Cond. score diff.	-0.30^{A}	0.21	-0.50^{A}	0.22
Feed Efficiency (%)	33.00^{B}	0.02	38.00^{A}	0.03

4.2.3 Breed Comparison

The means and standard deviations of the BW, feed intake, production, LWG, condition score difference in the Friesian and Jersey cows are presented in Table 4.11. LW and DM intake of Friesian cows were significantly greater than those of Jerseys ($p \leq 0.05$), but differences in the production of NE milk, MF, protein and lactose yields did not reach the statistical level of significance. LWG in Friesian cows was higher than in the Jerseys, but the gains were not significantly different. The differences in condition score between the beginning and end of the experiment were -0.3 and -0.5 for the Friesian and Jersey cows respectively. The FE of Jersey cows, however, was greater than that of the Friesians and the difference reached a 5% level of significance. The mean values for all traits (Friesians and Jerseys combined) and their standard deviations are shown in Table 4.12.

Table 4.12 Means and standard deviations of the traits for Friesians and Jerseys (combined) **(Indoor Period)**

Variables	Means	SD
Age (years)	5.81	1.33
LW (kg)	458.00	78.46
Metabolic LW ($kg^{0.75}$)	98.78	12.76
DM Intake (kg/d)		
(Indirect Method)	17.06	2.00
ME Intake (MJ/d)	184.50	21.63
NE Milk (MJ/d)	63.82	8.28
MF yield (kg/d)	0.88	0.12
Protein yield (kg/d)	0.66	0.09
Lactose yield (kg/d)	0.87	0.16
LWG (kg/d)	0.66	0.65
Cond. score diff.	-0.36	0.23
Feed Efficiency (%)	35.00	0.03

Comparison of Actual and Estimated DM Intake (kg/d)

	Pills	**Capsules**
Direct Method (Actual)	16.8	17.2
Indirect Method (Estimated)	17.2	15.6

4.2.4 Coefficients of Correlation between Different Traits

Correlation coefficients between important traits of Friesian and Jersey cows are shown in Table 4.13. For Friesian cows, DM intake was positively related to all measures of production (NE milk, MF, protein and lactose yields) (DM intake-NE milk relationship shown in Fig. 4.4) but there was no significant relationship with $LW^{0.75}$. On the other hand, DM intake of Jersey cows was closely related to all production traits and $LW^{0.75}$ (although MF relationship ns).

There were also strong relationships between the alternative measures of production (NE milk, MF, protein and lactose yields) for both breeds, in spite of the fact that cows were selected on the basis of having similar MF yields. Milk production traits were not associated with $LW^{0.75}$ in Friesians but there was a strong association between them within Jersey cows ($p \leq 0.01$-0.25).

FE was positively associated with most level of production parameters for both breeds but the relationships with $LW^{0.75}$ were not significant. When the data were combined (Table 4.14) the DM intake was positively related to production traits (see Fig.4.5)($p \leq 0.01$-0.05) and $LW^{0.75}$ ($p \leq 0.01$). As for the individual breeds, there were highly significant ($p \leq 0.01$-0.05) positive relationships between all the alternative measures of production. Milk production levels (NE milk, MF, protein and lactose) were not closely associated with $LW^{0.75}$. FE was positively associated with level of milk production (but only relation with MF significant) and negatively ($p \leq 0.025$) related to $LW^{0.75}$. That is, heavier cows were less efficient.

Table 4.13 Correlation coefficients between different traits for Jersey and Friesian cows **(Indoor Period)**

Variables	$LW^{0.75}$	DMI	NE Milk	MF yield	Pr yield	Lactose yield
Friesians						
DMI	0.07 ns					
NE Milk	-0.14 ns	0.87 ***				
MF yield	-0.13 ns	0.71 **	0.92 ***			
Protein yield	-0.13 ns	0.92 ***	0.97 ***	0.83 **		
Lactose yield	0.01 ns	0.83 ***	0.77 ***	0.52 ns	0.80 ***	
FE	-0.37 ns	0.42 ns	0.81 ***	0.87 ***	0.70 ***	0.42 ns
Jerseys						
DMI	0.90 *					
NE Milk	0.93 **	0.93 **				
MF yield	0.66 ns	0.79 ns	0.89 *			
Protein yield	0.99 ***	0.90 *	0.95 **	0.72 ns		
Lactose yield	0.99 ***	0.88 *	0.88 *	0.58 ns	0.97 ***	
FE	0.81 ns	0.72 ns	0.93 **	0.88 *	0.86 *	0.75 ns

Table 4.14 Correlation coefficients between different traits for Jersey and Friesian cows (combined) **(Indoor Period)**

Variables	$LW^{0.75}$	DMI	NE Milk	MF yield	Pr yield	Lactose yield
DMI	0.67 ***					
NE Milk	0.23 ns	0.73 ***				
MF yield	0.07 ns	0.52 *	0.90 ***			
Protein yield	0.30 ns	0.78 ***	0.96 ***	0.77 ***		
Lactose yield	0.39 ns	0.76 ***	0.82 ***	0.53 *	0.88 ***	
FE	-0.56 **	-0.26 ns	0.46 ns	0.60 **	0.35 ns	0.17 ns

4.2.5 Factors affecting Feed Intake and Efficiency

a) Production

The effects of $LW^{0.75}$, milk production and LWC on intake of DM (or ME intake) and FE from multiple regression analyses are indicated for Friesians and Jerseys separately in Table 4.15. Regression equations are shown for two forms of analysis as for outdoor period (see 4.1.4). In the Friesians, the effect of milk production on DM intake (or ME intake) was highly significant ($p \leq 0.01$). The cows consumed 1.76 MJME to produce 1 MJ of milk energy indicating the k_l value to be 1/1.76 or 0.57. With every MJ increase in milk production, efficiency increased by 0.2%($p<0.01$). The corresponding relationship for Jerseys was not significant. With the analyses of combined data (Table 4.16), estimated k_l was 0.62. In this analysis also, efficiency increased by 0.2% per MJ increase of milk energy ($p \leq 0.01$). The ME intake for milk production estimated with the exclusion of regression constant in the Friesian cows was relatively higher but significant ($p \leq 0.01$) (Table 4.15). In the combined analyses,

Table 15 Factors affecting feed intake and efficiency within the Friesian and Jersey cows : Partial regression coefficients (**Indoor Period**) -a) with regression constant b) with zero regression constant

Breed	Dependent variables	Reg. constant (μ)	β_1 NE milk/MJ	β_2 $LW^{0.75}$/kg	β_3 LWG/kg	R^2	N
Friesians	DMI	3.91	0.163	0.033	0.036	0.80	11
		ns	***	ns	ns		
	MEI	42.28	1.76	0.357	0.39	0.80	11
		ns	***	ns	ns		
	FE	0.26	0.2	-0.06	0.03	0.72	11
		***	***	ns	ns		
	DMI	-	0.183	0.056	0.165	0.99	11
			***	***	ns		
	MEI	-	1.99	0.611	1.783	0.99	11
			***	***	ns		
	FE	-	0.4	0.09	0.9	0.99	11
			***	*	ns		
Jerseys	DMI	4.76	0.098	0.049	-0.198	0.87	5
		ns	ns	ns	ns		
	MEI	51.53	1.068	0.536	-2.141	0.87	5
		ns	ns	ns	ns		
	FE	0.27	0.4	-0.1	-0.5	0.87	5
		ns	ns	ns	ns		
	DMI	-	0.041	0.146	0.194	0.99	5
			ns	ns	ns		
	MEI	-	0.443	1.578	2.101	0.99	5
			ns	ns	ns		
	FE	-	0.05	0.04	1.7	0.99	5
			ns	ns	ns		

Table 4.16 Factors affecting feed intake and efficiency for Friesian and Jersey cows (combined) : Partial regression coefficients **(Indoor Period)**- a) with regression constant b) with zero regression constant

Dependent variables	Reg. constant (μ)	ß1 NE milk/MJ	ß2 $LW^{0.75}$/kg	ß3 LWG/kg	R^2	N
DMI	-0.713 ns	0.149 ***	0.082 ***	0.264 ns	0.81	16
MEI	-7.71 ns	1.61 ***	0.89 ***	2.857 ns	0.81	16
FE	0.369 ***	0.2 ***	-0.2 ***	-0.5 ns	0.70	16
DMI	-	0.143 ***	0.078 ***	0.258 ns	0.99	16
MEI	-	1.550 ***	0.85 ***	2.788 ns	0.99	16
FE	-	0.5 ***	0.008 ns	-0.2 ns	0.99	16

Table 4.17 Comparative results of multiple regression analyses between Outdoor and Indoor experiments for determination of MEI

Source of data	Reg. constant (μ)	Partial regression coefficients for NE Milk (/MJ/d)	LW (/$kg^{0.75}$/d)	LWG (/kg)
Friesians				
a) Grazing (22 cows)	-22.0 ns	0.80 *	1.40 ***	40.0 ***
b) Grazing (16 cows)	90.5 ns	1.70 ns	0.47 ns	-16.8 ns
c) Indoors (11 cows)	42.3 ns	1.76 ***	0.36 ns	0.39 ns
Friesians and Jerseys				
a) Grazing (30 cows)	46.0 ns	0.46 ns	1.07 ***	33.3 ***
b) Grazing (24 cows)	19.8 ns	1.23 **	1.10 ***	-9.24 ns
c) Indoors (16 cows)	-7.71 ns	1.61 ***	0.89 ***	2.86 ns
Friesians				
a) Grazing (22 cows)		0.72 **	1.27 ***	37.0 ***
b) Grazing (16 cows)	-	1.66 ***	0.97 *	-9.11 ns
c) Indoors (11 cows)	-	1.99 ***	0.61 ***	1.78 ns
Friesians and Jerseys				
a) Grazing (30 cows)	-	0.70 **	1.28 **	40.3 ***
b) Grazing (24 cows)	-	1.38 ***	1.16 ***	-6.94 ns
c) Indoors (16 cows)	-	1.55 ***	0.85 ***	2.79 ns

however, the ME intake figures were close to the conventionally accepted values reaching a 1% level of significance (Table 4.16). In this case, efficiency increased by 0.2 (0.5% with zero regression constant) per MJ increase in NE milk ($p \leq 0.01$).

b) Liveweight

For the Friesians, the intake of ME had a highly significant relationship with $LW^{0.75}$ ($p \leq 0.01$), but only when the regression was forced through zero (Table 4.15) and the estimated ME_M was 0.61 MJ/kg $LW^{0.75}$. In the combined analyses, the estimated ME_m ranged between 0.85 and 0.89 MJ/kg $LW^{0.75}$ under alternative regression procedures showing high levels of significance ($p \leq 0.01$) (see Table 4.16). FE decreased by 0.2% due to the increase of maintenance requirement for every kg $LW^{0.75}$ ($p \leq 0.01$).

c) Intake and Liveweight Gain

In both combined and breedwise analyses, the effects of LWG on DM or ME intake was non-significant (Tables 4.15 and 4.16).

4.2.6 Comparative Results of Outdoor and Indoor Experiments for the Determination of MEI

Most of the estimated ME_m , milk production and LWG have already been described. For comparative purposes, they are presented in Table 4.17. Although there were little differences between estimated ME intake using two alternative analytical procedures in most cases, the estimated ME_m with zero regression constant was very similar to the published values. It was, however, to be noted that when the values of ME_m for maintenance were higher, there was a general trend of the ME for milk production to be lower and vice versa.

Figure 4.4 Relationship between dry matter intake (DMI) and production (NE MILK) within Friesian cows **(Indoor Period)**

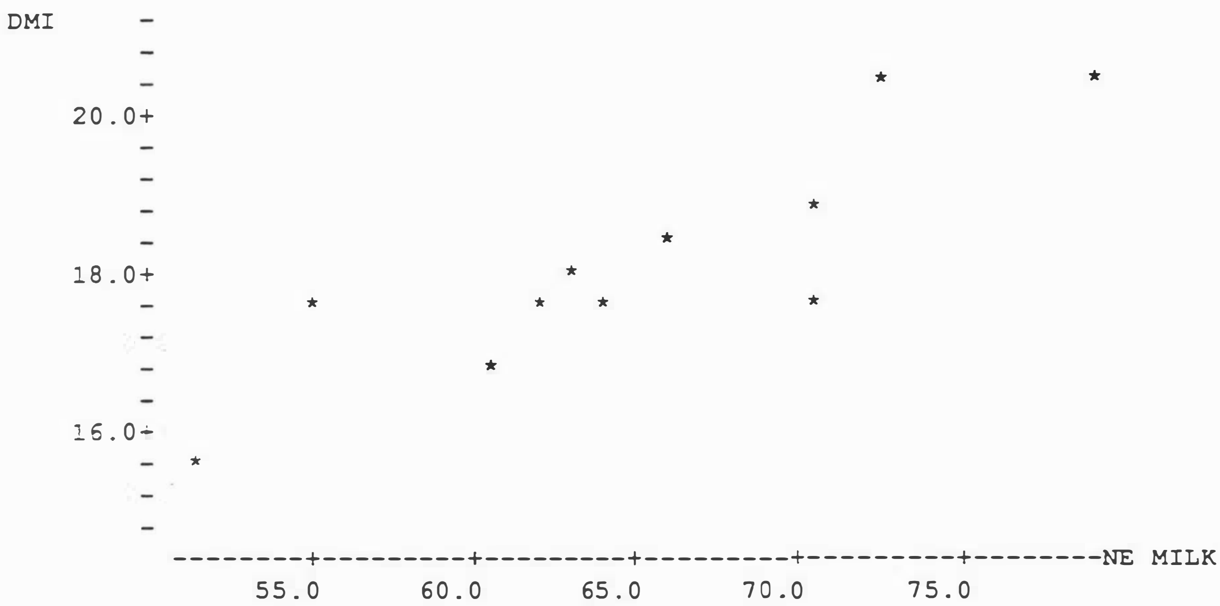
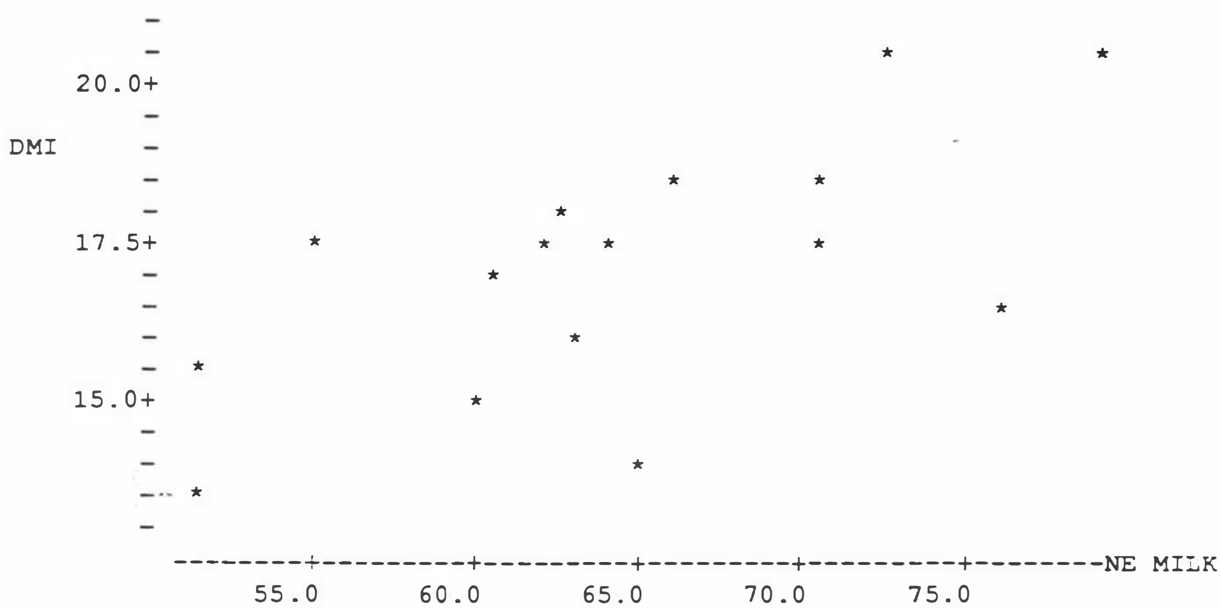


Figure 4.5 Relationship between dry matter intake (DMI) and production (NE MILK) for Friesian and Jersey cows (combined) **(Indoor Period)**



CHAPTR 5
DISCUSSION

5.1 Reliability of Intake Estimates using Chromic Oxide

Herbage intake may be estimated if total faecal output can be measured and an estimate of digestibility is available. Faecal collection is possible by fitting the animals with harnesses and collection bags but it is labourious and often unreliable (Hodgson and Rodriguez, 1970). So we preferred to use an indigestible marker, chromic oxide (Cr_2O_3), to measure the faecal production.

The purpose of dosing the experimental cows separately with pills and controlled release capsules (CRC) containing Cr_2O_3 was to compare the level of faecal output obtained from the two methods and to guarentee some results in the event that some capsules were regurgitated, although many authors are not satisfied with the results of pills due to a diurnal variation in the recovery of Cr_2O_3 (e.g. Brandyberry et al.,1991; Parker et al.,1989). We intended to seek a better understanding of this diurnal variation and therefore collected faecal samples three times a day- in the morning, in the afternoon and at night during the indoor experiment. In agreement with the above mentioned authors, a diurnal variation in the recovery of Cr_2O_3 from animals dosed with the pills was apparent- the Cr concentration was lowest in the afternoon and highest in the morning faecal samples. With the animals dosed with pills, the estimated mean DM intakes using the am, pm and night faecal samples were 15.8, 19.0 and 16.7 kg (mean 17.2 kg). The corresponding values with capsules were 15.7, 15.3 and 15.7 (mean 15.6 kg) kg DM respectively. Thus, when DM intakes were estimated from the afternoon and night samples, they were higher by 20.2% and 5.7% respectively than the one estimated from the morning samples. With capsules, Cr recovery in the am, pm and night samples were relatively uniform. In this case, intake from the afternoon samples was underestimated by 2.6% compared with those obtained from the morning and night samples. However, in spite of almost uniform release rate of Cr in the faecal samples from the animals dosed with capsules, the mean DM intake (15.6 kg DM/d) in this case was underestimated by 10.2% compared to the actual intake (17.2 kg DM/d). With pills this was overestimated by only 2.4% (estimated intake-17.2 kg DM/d; actual intake-16.8 kg DM/d)(Table 4.12). This implied that, when faecal samples were collected three times a day, pills containing Cr_2O_3 were more reliable than capsules. It is possible that the value of estimated DM intake using the CRC was in error because of errors in Cr determination, assumed Cr release rate or in vitro digestibility figures. Due to such unidentified causes, the estimated figures of DM intake during the outdoor period could also have been underestimated.

5.2 Factors affecting ME Intake of Lactating Cows

The energy requirements of the lactating cows are influenced by a number of factors such as LW or $LW^{0.75}$ (for maintenance), energy content of the milk produced, rate of LWC, activities etc (see Chapter 2.2).

Owen (1979) (cited by Poole, 1986) claimed that the feed intake of lactating cows over the full lactation would be proportional to their milk yields. However, while feed consumption is influenced heavily by milk yield, it has a smaller correlation with efficiency (Lee et al.,1989). The present results also agreed with this observation. The regression coefficients indicated that significant variability in ME intake among the experimental cows could be accounted for by differences in $LW^{0.75}$, NE milk and LWG.

5.2.1 ME for Maintenance

For the Friesian cows, the estimated ME_m under alternative regression procedures during the grazing period ranged between 0.97 and 1.40, and between 1.07 and 1.28

MJME/kg $LW^{0.75}$/d when the data were combined (see Table 4.17). The corresponding values during the indoor experiment were lower : 0.61 for Friesians (excluding regression constant) and 0.85-0.89 for the combined analyses.

Mc Donald et al.(1981) pointed out that " an increase in production, which is obtained by higher intakes, is usually associated with an increase in overall efficiency of the production process, since maintenance costs are decreased proportionately as productivity rises." In the present experiment, production was higher outdoors than indoors but the estimated ME_m were much higher than those recommended by ARC (1980), Holmes and Wilson (1984), CSIRO (1990) and Dempfle (1986)(who used 0.55 MJME/kg $LW^{0.75}$ to allow for the higher activity of grazing). Not surprisingly, the ME_m values for the indoor period were lower than for the outdoor period due to reduced activities (grazing, walking etc.) (although still higher than the conventionally accepted values). It has been pointed out by CSIRO, Australia (1990) that the maintenance costs of grazing cows can be increased due to a number of reasons such as activities, stressful conditions, rain, wind etc. Although the present grazing trial was conducted during the late spring, it was generally cold, wet and windy throughout the experimental period. It could, therefore, be claimed that the grazing cows without shelter were likely to have been subjected to various conditions that increased the maintenance demands. For the relatively higher ME_m of the indoor fed cows, the following causes were probably responsible:

a) cows may not have been fully acclimatized to indoors and were subject to strange and stressful conditions. These causes led to increased metabolic rate and maintenance need.

b) ME_m increased proportionately as the milk yield decreased.

5.2.2 ME for Milk Production

If the k_l value ranges between 0.62 (CSIRO, 1990) and 0.65 (Holmes and Wilson, 1984) for the cows grazing abundant pasture, ME required to produce each MJ of milk energy should range between 1.54 and 1.61 MJ/day. So if the calculated feed energy requirement to produce 1 unit of NE milk is less than 1, k_l will be higher than 1, and thus will not have any practical significance. From the intake data of Friesian cows grazing outdoors, a lower value of 0.8 (Table 4.6) MJ feed energy requirement (and as low as 0.70 with zero regression constant in combined analysis-Table 4.17) was estimated but had low levels of significance ($p \leq 0.025$-0.05). The figures obtained from the indoor data ranging between 1.61 and 1.76 MJME of feed energy for the production of each MJ of NE milk reached a higher level of significance ($p \leq 0.01$), indicating that k_l value ranged between 0.57 and 0.62, although the results showed variation when the regression constant was omitted (see Table 4.17).

It was notable that relatively high values for the regression coefficient for $LW^{0.75}$ were associated with relatively low values for the regression coefficient for NE milk and vice versa during both grazing and indoor experiments, e.g. 0.80 v 1.40, 1.61 v 0.89, 1.99 v 0.61 (Table 4.17).

5.2.3 ME for Liveweight Change

For heifers in early and mid lactation and for cows in early lactation, Alderman et al.(1982) estimated MJME /kg LWG as 40; and for cows in mid lactation the value was 89 MJME/kg gain. However, the relationship in the latter case was not strong and was difficult to explain in physiological terms. From the present study, it was found that there was a strong relationship between ME intake and LWG and a grazing cow required 33-40 MJME/kg LWG ($p \leq 0.01$) (Table 4.17). Our finding is in general agreement with the recommendations of ARC (1980), Holmes and Wilson (1984) and CSIRO (1990).

5.3 Intake and Production Differences between Breeds

5.3.1 Intake

Friesian cows consumed higher amounts of herbage DM than Jersey cows. The differences during grazing and indoor experiments were 2.14 and 3.06 kg DM/cow/day respectively, both reaching a 5% level of significance. Thus, during the grazing period, the difference in herbage intake was only 13.5%, but during indoor feeding, it reached 20.5%. The differences in protein, lactose (and energy) yields together with the differences in body size within the breeds would have contributed to the coefficients of variation in intake between the cows during the indoor and outdoor experiments which were 4.26-7.42 % and 6.03-10.83 % in the Friesians and Jerseys respectively.

L'Huillier et al.(1988) reported that when the herbage allowance was generous (approx. 2.5 times of the DMI), intake differed between the lactating Friesian and Jersey cows by 9.5%. Similarly, when the feed intakes of Holstein and Jersey (mean LW: Holsteins-546 kg, Jerseys-384 kg) cows given complete rations of corn silage and concentrates were compared during the second trimester of lactation, Holstein cows were found to consume higher amounts of feed and the difference in intake between the two breeds was 20.4% (Blake et al.,1986).

5.3.2 Production

In a comparative study of average New Zealand Friesian and Jersey cows, L'Huillier et al.(1988) observed the former to produce 26% more milk, 6% more MF, 13% more protein and 24% more lactose. Oldenbroek (1986) compared the production performance of a group of Jersey heifers with those of Dutch Friesian, Holstein Friesian and Dutch Red and White given two types of ration *ad libitum*- a complete diet of roughage or a complete diet of the same roughage with 50% concentrates in the first 39 weeks of lactation. Average milk, MF and protein production of Jerseys on a mixed diet (roughage + concentrates) was lower by 36%, 2.4% and 23% respectively than those of the other breeds. On the roughage diet, milk and protein production of Jerseys were lower by 26% and 13% respectively, but MF yield was higher by 4%. When cows were fed complete rations of corn silage and concentrates, the amount of FCM produced by Holsteins during the second trimester of lactation was 35% higher than the amount produced by the Jerseys (Blake et al.,1986). For the present experiments, as the cows were selected on the basis of similar daily MF yield, the amount of MF produced by the Friesian cows was greater by only about 1%. The amounts of NE Milk, protein and lactose produced by Friesian cows during the grazing and indoor experiments were higher by 5-8%, 8-14% and 14-19% respectively than the amounts produced by the Jerseys.

Oldenbroek (1986) observed a more favourable ratio between milk production and BW in Jersey cows compared with bigger dairy breeds. The present report also indicated closer associations between NE milk and $LW^{0.75}$ within Jersey cows (Tables 4.4 and 4.13). Besides, these cows showed greater correlation coefficients between $LW^{0.75}$ and DM intake, and DM intake and NE milk compared to the Friesians during the indoor experiment.

Generally there is not consistency in the variation of production between different parities and stages of lactation for the different breeds. For example, in the comparative observation of Holsteins and Jerseys, the former produced 35% more of milk in the second trimester of lactation than the Jerseys, but when the performance of the same cows were compared during the first trimester of lactation, the amount of daily milk produced by Holsteins was greater by only 23% (Blake et al.,1986). It is, however, clear from those observations and the present ones, that the big body size and/or the dairy breed (Friesian or Holstein) has enabled them to produce greater daily and total lactational yields.

5.4 Effects of Body Size on Overall Efficiency

5.4.1 Significance of Gross and Net Efficiency

Level of production and food intake are important components of overall efficiency and profitability and have important effects on breeding programmes (Persaud and Simm, 1991). But when gross efficiency is used, cows consuming small amounts of food and mobilizing body reserves due to high production, appear more efficient (Legates, 1989). Hutton (1966) evaluated grazing dairy cows in terms of gross efficiency. Due to uncertainty and controversies regarding the ME_m of grazing dairy cows, we also preferred to use gross efficiency, although some authors have estimated net efficiency (e.g.Buttazzoni and Mao, 1989; Dickinson et al.,1969; Oldenbroek, 1986).

5.4.2 Breed Comparisons

Bryant et al.(1985) found a superior gross food conversion efficiency of Friesian cows compared to Jerseys (45 v 40 g MF/kg DM eaten for Friesians and Jerseys). The opposite was true in the present experiment i.e. food conversion efficiency of Jerseys was higher (62 v 53g MF/kg DM eaten for Jerseys and Friesians) and agreed with the finding of L'Huillier et al.(1988)(67 v 61g MF/kg DM eaten for Jerseys and Friesians).

When the biological efficiency for milk production between Jerseys and three other breeds, Holstein Friesian, Dutch Friesian and Dutch Red and White, was compared by offering two types of ration- roughage, and roughage + concentrates, Jerseys were 14% and 7% more (net) feed efficient than the other breeds (Oldenbroek, 1986). From a New Zealand study, L'Huillier et al.(1988) reported that Jerseys had 17% higher net feed efficiency than the Friesians. From the present observations, Jerseys were found to have 5% and 15% greater gross feed efficiency than the Friesians during the grazing and indoor periods respectively.

Hutton (1966) observed an association between higher BW and gross FE in Jersey crossbreds that were stall-fed on fresh cut pasture during 36 weeks of lactation in 1960-61 and 1961-62 seasons. Conversely, for Holsteins, FCM decreased by 7.8 kg for each kg increase in BW for cows with equal body measurements (Sieber et al., 1988) indicating that feed efficiency probably decreased with increasing BW.

5.4.3 Group comparisons

a) Effects of Body Weight

Hooven et al.(1968) (cited by Morris and Wilton, 1976) plotted efficiency against BW and found a maximal efficiency at an intermediate BW (about 540 kg). Stakelum and Connolly (1987) compared the performance of large (LW-554 kg) and small (LW-500 kg) cows and found relatively lower food conversion efficiencies of large cows especially at low yields, but it was concluded that at differences of 50 kg LW the gross efficiencies are unlikely to be very large. In the present study, the differences in BW between large and medium, and medium and small cows were 80 kg and that between large and small cows was 160 kg. Medium-sized cows in period 1 were 2.6% more feed efficient (gross) than large ones, and 5.1% less efficient than small cows. Thus, the large cows appeared to be least efficient (gross)(Appendix 3).

b) Effects of Height and Chest depth

According to Mason et al.(1957), the taller animal is usually less efficient than the shorter one for a given amount of milk production. Similarly, Sieber et al.(1988) observed that taller, longer, deeper, and especially heavier cows tended to be less efficient than smaller ones in spite of the fact that taller cows consistently produced more milk than the shorter ones over first to fifth lactation.

Mason et al.(1957), however, made the remark that taller animals were economically more efficient because the value of milk produced was much higher than the extra energy they needed for maintenance, and that yield/height would be the best selection index. In agreement with this finding, significant associations between height and most production parameters (although ns relationship with MF yield) were revealed from the present study.

Lactating cows with deeper chests had higher milk yields (Sieber et al.,1988). Hagger and Hofer (1991) concluded that the phenotypic associations between milk yield, and height and heart girth were not strong but might be slightly positive. Although the tallest animals within breeds in our experiment tended to produce the highest amounts of NE milk and milk solids (protein and lactose), the relationships with NE milk, protein and lactose yield only reached significance when the data of two breeds were combined. Regarding the effects of chest depth, our findings did not agree with those of Sieber et al.(1988) because chest depth was not significantly associated with any of the production parameters (Tables 4.4 and 4.5).

As in the present experiment, Ahlborn-Breier and Dempfle (1991) observed a slightly stronger correlation between body size traits and protein than with MF yield both in Jersey and Friesian cows. Mason et al.(1957) noted a decreased correlation of BW with milk yield as lactation advanced and Sieber et al.(1988) found a significant positive association ($p<0.001$) in the range from .18 to .29 between milk yield, fat yield and FCM and all body measurements (e.g.heart girth, paunch girth, wither height, chest depth, pelvic length, pelvic width, body length) and BW.

5.5 Relationships between Intake, Yield and Efficiency

Johnson et al.(1966) found a significant correlation between forage DM intake and 4% FCM yield. Correlations with efficiency were .61 for milk yield,.62 for fat yield and .63 for FCM (Sieber et al.,1988). Efficiency was highly correlated phenotypically

(0.64) with milk yield between 8-16 weeks of lactation, but strong correlations between milk yield and consumption arose in part from feeding concentrates according to milk yield (Lee et al.,1989). In common with the report of Johnson et al.(1966) and Lee et al.(1989), we were able to show a strong association between feed intake and production during indoor feeding. Significant correlations were noted between FE and NE milk (or the protein) yield both in Friesians and the Jerseys; the results with MF and lactose yields were not consistent (see Tables 4.4 and 4.13;). In general, this finding also agrees with those found by Sieber et al.(1988) and Custodio et al.(1983). The latter authors found that in Holstein cows, that were fed complete rations of corn silage and concentrate, the correlation of energy-corrected milk yield (FCM) with energy efficiency was high.

In first lactation Ayrshire and Holstein cows, phenotypic correlations between milk and fat, milk and protein, and fat and protein for different stages of lactation ranged between .76 and .92 and were similar for both breeds (Moore et al.,1990). We measured the milk yield in terms of NE milk (i.e. milk energy) and the corresponding figures ranged between .67 and .97, the lowest association being between MF and protein yields.

During the grazing experiment, production of every MJ of ME within Friesian cows was associated with the increase of FE by 0.3%-0.4% (see Tables 4.6 and 4.8) and by 0.2% during the indoor period (see Tables 4.15 and 4.16).

5.6 Efficiency, Metabolic Liveweight and Liveweight Change

The present result suggested that smaller cows are better gross converters of food to NE milk which agreed with those of others (e.g.Dickinson et al.,1969; Donker et al.,1983; Oldenbroek, 1986; Stakelum and Connolly, 1987). In the study of Donker et al.(1983) small cows ate 4% less DM (mostly forage) than large cows (.7 kg/day), but when intake was related to unit BW, they ate about 4% more than large cows, the difference of mean BW being 47 kg. The present report indicated that small Friesian cows ate 3.9% less DM than large cows, but at a difference of 80 kg mean BW the amount consumed in terms of unit $LW^{0.75}$($kg^{0.75}$) was higher by 9.2% in smaller cows (see Appendix 3). The higher amount of feed consumed per unit BW was efficiently utilized for production. It was found that with the increase of every unit of $LW^{0.75}$($kg^{0.75}$), gross efficiency generally decreased by 0.2-0.3% (average .25%). Thus, if the gross efficiency of a cow weighing 350 kg is assumed to be .40 (or 40%), the gross efficiencies of heavier cows producing similar amount of NE milk can easily be estimated (see Table 4.1).

When a lactating cow gains weight, feed energy is partitioned and diverted to meet the requirement of daily LWG. Friesian cows in our experiment needed 40 MJME/kg gain, but when the data of Friesians and Jerseys were combined, the figure dropped to 33 MJME/kg gain probably indicating that Jersey cows required a lower amount of ME for LWG than the Friesians. With the diversion of 40 MJME/kg gain in Friesians, gross efficiency was decreased by 7.3% ($p \leq 0.01$), but in the combined analysis, the value dropped to 6.1% ($p \leq 0.025$) because ME required per kg LWG was comparatively lower than that required for Friesian cows.

Table 5.1. Estimation of gross efficiency

Liveweight (kg)	Metabolic LW ($kg^{0.75}$)	Gross Efficiency
350	80.9	40.0
400	89.4	37.9
450	97.7	35.8
500	105.7	33.8
550	113.6	31.8
600	121.2	29.9

CHAPTER 6
FINAL DISCUSSION AND CONCLUSIONS

Feed involves one of the major costs in a pastoral dairy farming, and profitability could be enhanced if more efficient cows were used. To measure the individual efficiency of grazing cows herbage intake as well as production must be accurately determined. For estimating herbage intake, animal scientists and research workers have developed various techniques. This study has shown that CRC containing Cr_2O_3 (marker) can be used to estimate intake provided that accurate release rates are available, but when pills containing the same marker are used, faecal samples must be collected at least three times a day. Other outstanding problems which remained were that some grazing cows with larger body size regurgitated the capsules, and possible differences in the forage digestibility between individuals could not be measured.

Feed intake of lactating dairy cattle is affected by three main factors- body size or LW (for maintenance), level of production and LWC. In addition, milk production is also related to body size. The relationships between all these variables and their effects on the efficiency of the cows (which differed in size and breed) were the main subject of the present study.

Cows with similar MF yields were chosen so as to minimize this as a source of variation in affecting efficiency. However, production measured in energy terms did vary considerably due to higher yields of lactose and protein from the larger animals. Differences in the amounts of lactose and protein produced between breeds were more pronounced than between cows within breeds; Friesian cows consistently produced higher amounts. It should, therefore, be emphasized that relationships were examined within Friesians, within Jerseys as well as "overall" (including Friesians and Jerseys) and that in the case of the "overall" relations, body size effects were confounded by breed effects.

The relative extent of the differences in intake and production which are associated with size are important in determining differences in efficiency. The larger animals in this study (outdoors and indoors) consumed more forage DM (in kg) per day (large- 18.6, medium- 17.9, small- 15.8; Friesians- 18.0, Jerseys- 14.9-15.9). All the measures of body size had positive relationships with intake, but consumption per unit $LW^{0.75}$ size of the smaller cows was higher.

Of the three body size traits measured, only BW and height (although ns with MF yield) had a significant positive association with production . Thus, the cows with higher BW (height) produced more energy in milk (MJ/d) (large- 81.7, medium- 79.5, small- 73.1 - outdoors; Friesians 64.9-79.7, Jerseys 61.4-73.6 - outdoors and indoors).

However, the efficiency of smaller (v larger) and Jersey cows (v Friesians)(outdoors and indoors) was higher (large- 38%, medium- 39%, small- 41%; Friesians- 33-39%, Jerseys- 38-41%).

In general, there were strong relationships between FE and alternative measures of production within both breeds and in the combined data. The association of DM intake with efficiency was either weak or negative. Similarly, correlations between LW and FE were also weak or negative in most instances (except for grazing Jersey cows).

In theory, the gross efficiency of lactating cows would be affected by variation in the maintenance requirement. For example, if a value of 0.6 MJME/kg $LW^{0.75}$ daily is assumed, then a 400 kg cow neither gaining nor losing weight is 9.3% more efficient than a 500 kg cow if both produced 150 kg MF per year (assumption : 115 MJME/kg MF production). If a maintenance requirement of 1.20 MJME/kg $LW^{0.75}$ is assumed, the corresponding difference in gross efficiency would be 14.8%. In the present experiment, all the estimates of ME_m were higher than the published values; so the differences in FE between cows of different sizes may have been exaggerated.

The effects of body size ($LW^{0.75}$), production and LWC on efficiency were examined by multiple regression analyses. These indicated that for every kg increase of $LW^{0.75}$, efficiency decreased by 0.2-0.3%. On the other hand, 1 MJ increase of NE milk produced was associated with a 0.2-0.4% increase in efficiency. When 33-40 MJME was diverted for the gain of every kg LW, efficiency decreased by 6.1-7.3%.

The present evidence has shown that bigger Friesian and Jersey cows within and across breeds produce greater amounts of NE milk than their smaller herdmates, although they do so less efficiently. However, it is not certain how the efficiency would have been affected if the cows had been randomly selected from each of the breeds. Therefore, the above figures need to be treated with caution as the differences in efficiencies with size are mainly due to the large differences in efficiencies between Friesian and Jersey cows. Whilst the associations between higher BW (wither height), intakes and production have been established, confounding effects of body size (or BW) and/or breed were a problem. For more precise results, it would be useful if the effects of body size within and across breeds are dealt with separately using larger sample sizes. Also, since uncertainty still exists regarding the true value of ME_m of the grazing dairy cattle in temperate grasslands as a result of this work, further experiments seem to be justified.

In the New Zealand context, there are large differences in BW amongst individual cows associated with the use of Jerseys, Friesians and cross-breds, so there would seem to be a need to select animals on efficiency (or indirectly by use of an index related to size) rather than just production. The smaller cows were not only shown to be more efficient but more cows can be fed per unit area and this should result in higher per hectare production and greater economic efficiency. Equally, if production is measured only in terms of MF yield, Jersey cows would bring greater economic returns compared to the Friesians. However, economic efficiency was not considered in the present experiment, as in addition to the parameters measured, it would vary with stocking rate, method and level of payout (milk yield v milk solids) and relative returns from the sale of culls and calves from animals of different sizes (or breeds).

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APPENDICES

Appendix 1 Experimental Plan (**Outdoor Period**)

Day	Capsule admin.	Pill admin.		Faecal collection		Milk testing		Weigh cows	Condition scoring
		am	pm	am	pm	am	pm	am	pm
-4 Thu		*							
-3		*	*						
-2 Sat		*	*						
-1 Sun		*	*						
0		*	*					*	*
1		*	*				*	*	*
2		*	*			*	*		
3		*	*		p1	*	*		
4		*	*	p1	*	*		*	
5 Sat		*	*	*	*				
6 Sun		*	*	*	*				
7		*	*	*	p1			*	
8		*	*	p1	p2		*		
9		*	*	p2	*	*	*		
10		*	*	*	*	*	*		
11		*	*	*	*	*		*	
12 Sat		*	*	*	p2				
13 Sun	*	*		p2					
14								*	
15							*		
16						*	*		
17						*	*		
18				p3		*		*	
19 Sat				*					
20 Sun				*					
21				p3				*	
22				p4			*		
23				*		*	*		
24				*		*	*		*
25				p4		*		*	*

p=Period

Appendix 2 Experimental Plan (**Indoor Period**)

Day	Capsule admin	Pill admin		Faecal sample		Milk testing		Weigh cows	Condition scoring
	pm	am	pm	am	pm	am	pm	am	pm
0 Mon								*	*
1							*		*
2						*	*		
3	*		*			*	*		
4		*	*			*		*	
5 Sat		*	*						
6 Sun		*	*						
7		*	*					*	
8		*	*				*		
9		*	*		p1	*	*		
10		*	*	p1	*	*	*		
11		*	*	*	*	*		*	
12 Sat		*	*	*	p1				
13 Sun		*	*	p1	p2				
14		*	*	p2	*			*	
15		*	*	*	*		*		
16		*	*	*	p2	*	*		
17		*		p2		*	*		*
18						*		*	*

p=Period

Appendix 3 Means and standard deviations of the traits for three size groups of cows **(Outdoor Period)**

Period 1

Variables	Large		Medium		Small	
	Means	SD	Means	SD	Means	SD
Age (years)	6.3	0.8	6	0.8	5.2	1.3
Height (cm)	132^{A}	2.6	127^{B}	2.6	117.5^{C}	4.9
Chest Depth (cm)	77^{A}	4.2	74.5^{A}	2.8	70.5^{B}	3.7
LW (kg)	513.3^{A}	31.7	433.5^{B}	15.7	353.4^{C}	33.5
$LW^{0.75}(kg^{0.75})$	107.8^{A}	5.0	95.0^{B}	2.6	81.4^{C}	5.8
DMI (kg/d)	18.6^{A}	2.0	17.9^{A}	1.4	15.8^{B}	1.09
MEI (MJ/d)	213.8^{A}	22.6	205.7^{A}	16.2	181.5^{B}	12.6
NE Milk (MJ/d)	81.7^{A}	12.1	79.5^{A}	8.3	73.1^{A}	6.6
MF yield (kg/d)	1.05^{A}	0.15	1.06^{A}	0.14	1.03^{A}	0.09
Protein yield (kg/d)	0.86^{A}	0.12	0.83^{A}	0.08	0.73^{B}	0.09
Lactose yield (kg/d)	1.20^{A}	0.19	1.16^{A}	0.11	0.99^{B}	0.16
LWG (kg/d)	0.5^{A}	0.35	0.61^{A}	0.24	0.60^{A}	0.2
Cond. score diff.	0.25^{A}	0.30	0.19^{A}	0.15	0.15^{A}	0.13
FE (%)	38^{A}	0.06	39^{A}	0.06	41^{A}	0.5

Period 2

Variables	Large		Medium		Small	
	Means	SD	Means	SD	Means	SD
Age (years)	6.3	0.8	6	0.8	5.2	1.3
Height (cm)	132[A]	2.6	127[B]	2.6	117.5[C]	4.9
Chest Depth (cm)	77[A]	4.22	74.5[A]	2.8	70.5[B]	3.69
LW (kg)	519.5[A]	30.64	443.5[B]	17.41	364.1[C]	33.77
$LW^{0.75}$	108.8[A]	4.82	96.6[B]	2.85	83.3[C]	5.8
DMI kg/d)	19.7[A]	1.42	19.6[A]	1.57	16.3[B]	1.5
MEI (MJ/d)	232.3[A]	16.7	230.9[A]	18.6	192.7[B]	17.7
NE Milk (MJ/d)	82.3[A]	7.9	77.7[AB]	5.9	74.2[B]	7.5
MF yield (kg/d)	1.07[A]	0.09	1.02[A]	0.10	1.05[A]	0.11
Protein yield (kg/d)	0.86[A]	0.09	0.8[AB]	0.05	0.74[B]	0.1
Lactose yield (kg/d)	1.27[A]	0.17	1.18[AB]	0.11	1.05[B]	0.19
LWG (kg/d)	0.5[A]	0.35	0.61[A]	0.24	0.6[A]	0.2
Cond. score diff.	0.25[A]	0.30	0.19[A]	0.15	0.15[A]	0.13
FE (%)	36[AB]	0.04	34[B]	0.02	39[A]	0.03

Appendix 4 Factors affecting feed intake and efficiency within the large, medium and small groups of cows : Partial regression coefficients **(Outdoor Period)**

Group	Dependent variables	Period	Reg. constant(μ)	ß₁(NEMilk)	$ß_2(LW^{0.75})$	$ß_3$(LWG)	R_2	N
Large	DMI	1	-34.09 **	0.16 ***	0.35 ***	3.76 ***	0.81	10
	MEI	1	-391.11 **	1.83 ***	4.02 ***	43.14 ***	0.81	10
	DMI	2	-28.69 ns	0.16 ns	0.33 ns	-1.64 ns	0.66	6
	MEI	2	-335.57 ns	1.87 ns	3.86 ns	-19.18 ns	0.66	6
	FE	1	1.14 ***	0.1 ns	-0.7 ***	8.2 **	0.88	10
	FE	2	0.89 ns	0.15 ns	-0.6 ns	3.4 ns	0.83	6
Medium	DMI	1	20.46 ns	-0.01 ns	-0.05 ns	4.87 ***	0.74	10
	MEI	1	234.73 ns	-0.11 ns	-0.57 ns	55.87 ***	0.74	10
	DMI	2	10.44 ns	0.16 ns	-0.03 ns	-0.69 ns	0.45	8
	MEI	2	122.11 ns	1.87 ns	-0.35 ns	-8.07 ns	0.45	8
	FE	1	-0.008 ns	0.5 ***	0.07 ns	-9.5 **	0.93	10
	FE	2	0.15 ns	0.2 ns	0.06 ns	1.8 ns	0.18 ns	8

Small	DMI	1	20.55 ***	-0.02 ns	-0.06 ns	2.14 ns	0.33	10
	MEI	1	235.77 ***	-0.23 ns	-0.69 ns	24.55 ns	0.33	10
	DMI	2	6.47 ns	0.18 ns	-0.05 ns	0.96 ns	0.53	10
	MEI	2	75.67 ns	2.10 ns	-0.58 ns	11.23 ns	0.53	10
	FE	1	-0.122 ns	0.6 *	0.1 ns	-6.0 ns	0.79	10
	FE	2	0.25 ns	0.09 ns	0.1 ns	-2.3 ns	0.23	10

Appendix 5 Factors affecting Feed Intake and Efficiency within the large, medium and small groups of cows : Partial regression coefficients (with zero regression constant) **(Outdoor Period)**

Group	Dependent variables	Period	Reg. constant(μ)	$ß_1$(NE Milk)	$ß_2$($LW^{0.75}$)	$ß_3$(LWG)	R^2	N
Large	DMI	1	-	0.083 *	0.10 ***	2.18 ns	0.99	10
	MEI	1	-	0.95 *	1.15 ***	25.01 ns	0.99	10
	DMI	2	-	0.094 ns	0.11 *	-1.43 ns	0.99	6
	MEI	2	-	0.98 ns	1.29 *	-16.72 ns	0.99	6
	FE	1	-	0.4 ***	0.08 ns	-3.0 ns	0.99	10
	FE	2	-	0.4 *	0.05 ns	3.0 ns	0.99	6
Medium	DMI	1		0.008 ns	0.15 ***	5.32 ***	0.99	10
	MEI	1	-	0.09 ns	1.72 ***	61.04 ***	0.99	10
	DMI	2	-	0.18 ns	0.06 ns	-0.54 ns	0.99	8
	MEI	2	-	2.10 ns	0.70 ns	-6.32 ns	0.99	8
	FE	1	-	0.5 ***	0.06 ns	-9.0 ***	0.99	10
	FE	2	-	0.2 ns	0.2 ns	2.0 ns	0.99	8

Small	DMI	1	-	0.03	0.09	3.80	0.99	10
				ns	ns	ns		
	MEI	1	-	0.34	1.03	43.60	0.99	10
				ns	ns	ns		
	DMI	2	-	0.13	0.07	0.89	0.99	10
				ns	ns	ns		
	MEI	2	-	1.52	0.82	10.41	0.99	10
				ns	ns	ns		
	FE	1	-	0.6	-0.009	-7.0	0.99	10
				*	ns	ns		
	FE	2	-	-0.9	0.6	-3.0	0.99	10
				ns	ns	ns		